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*Editors*

# Handbook of Space Security

## Policies, Applications and Programs

SpringerReference

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With 178 Figures and 36 Tables

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# Foreword

Space security is a subject of crucial importance to the United Nations, where references are made to it in the First Committee (Disarmament and International Security Committee) and the Fourth Committee (Special Political and Decolonization Committee) of the General Assembly. The issue pervades discussions at the Committee on the Peaceful Uses of Outer Space (COPUOS), most particularly at its subsidiary bodies, the Scientific and Technical Subcommittee and the Legal Subcommittee. In one way or another, the agenda items are underscored by space security: COPUOS discusses ways and means of maintaining outer space for peaceful purposes, space and sustainable development, and space and climate change; the discussions at the Scientific and Technical Subcommittee include space debris, disaster risk reduction, use of nuclear power sources, the threat from near-Earth objects, space weather and long-term sustainability of outer space activities; and the Legal Subcommittee addresses the issue of definition and delimitation of outer space, space debris mitigation measures, and national legislation related to outer space.

There is no doubt that a publication that comprehensively covers the issues of space security would augment the work of the General Assembly Committees and COPUOS and its subsidiary bodies.

The Office for Outer Space Affairs, with a mandate to support the work of the Committee and its subsidiary bodies, is often called upon to provide substantive inputs to be used as the basis for discussions and documentation, and frequently these relate to space security. But, the Office also concerns itself with issues pertaining to space security in the context of its capacity-building program which it rolls out for Member States. Under its Committee, Policy and Legal Affairs Section, the Office conducts capacity-building activities related to space law and policy, and under the Space Applications Section, the Office deals with the science that underlies space applications and space technology, which is the enabler for the applications and services, as well as data/information generation.

A book that encompasses the multidisciplinary aspects of space security could reinforce the role and work of the Office by explaining why space applications and services are important components of the foundation needed for the world's security and defense.

It is, therefore, gratifying to come across a book that addresses issues of space security in such a multi-facetted manner. In this handbook, Kai-Uwe Schrogl and the section editors have gathered over 60 authors who bring their experience and deep insight to bear: every chapter in this book has been the result of many years of research and analysis. While the pages contain much of what will be of great interest to those in the field of space security and students of space law, policy, science, and technology, the ideas expounded should be relevant to those generally associated with safety and security concerns.

The authors can be confident that amongst these pages, readers will find a gold mine of information and those not in the space security business will gain a much broader understanding of space security matters, both in the United Nations and outside.

Mazlan Othman
Deputy Director-General, United Nations Office at Vienna
Director, Office for Outer Space Affairs

# Foreword

Space and security have been inseparable since the beginning of space activities. The United States and the Soviet Union/Russia have launched, until now, some 2,000 military satellites. Since the Cold War, the effective functioning of these space-based assets for observation, early warning, navigation, and communications has played an essential role for the preservation of international stability and peace. That said, today's security environment is far more complex. Security threats and challenges are both civilian and military, local and global. Space-based assets are indispensible to enable global access, monitoring, and communications for addressing a whole range of security-related concerns. Approximately 20–30 % of some 1,000 satellites that are currently in orbit are directly related to such security functions and are usually operated by military institutions.

In short, space permeates foreign policy, national security, and global economic interests. As space systems are vital to many terrestrial endeavors, space security is rapidly emerging as a crucial dimension of national and international space policies. Naturally, the topic of space security is of growing significance also to Europe. It has gained momentum through such developments as the first European space policy formalized in May 2007 and adopted in a resolution at the fourth EU-European Space Agency "Space Council"; a subsequent Space Council Resolution of September 2008 that defined "space and security" as one of four new priority areas; and the Lisbon Treaty of 2009, which reinforced the legal basis for EU's involvement in space matters, as a competence shared with EU Member States.

As space systems are of dual-use nature, the EU's Common Foreign and Security Policy (CFSP) and the Common Security and Defence Policy (CSDP) are fundamental to the overarching framework for Europe's future space activities. As the CFSP is within the purview of the EU Member States and the High Representative of the Union for Foreign Affairs and Security Policy (assisted by the European External Action Service), it has important implications for the strategic nature of space assets and their contribution to Europe's independence, security, prosperity, and global influence.

Space has now been clearly recognized as a key element in the EU's security and defence-related activities. The EU's High Representative recognized in her Final Report of October 2013, entitled "Preparing the December 2013 European Council on Security and Defence", that the role of networks (including space) in today's globalized world “cannot be overestimated” and that “security of space is crucial for modern societies” (Ashton, 2013) (Preparing the December 2013 European Council on Security and Defence—Final Report by the High Representative/Head of the EDA on the Common Security and Defence Policy, Brussels, 15 October 2013). The report also acknowledges that Europe is increasingly dependent on space assets and the need for the EU and its Member States to protect them.

Europe clearly recognizes the immense added value and benefits of space for the security and prosperity of European citizens. Accordingly, it is engaged in various space activities, including Earth observation, global satellite navigation, satellite communications, and space diplomacy. In this connection, Europe attaches great importance to the international cooperative dimension of space policy, including in the area of space security. This is evident, for example, in the EU’s major diplomatic initiative on an International Code of Conduct for Outer Space Activities that aims at enhancing the safety, security, and sustainability of space by reinforcing existing space-related treaties, principles, and guidelines, as well as introducing other innovative space transparency and confidence-building measures.

To conclude, this publication is filling an important informational gap that exists on this topic and will most certainly help elevate understanding of the major issues related to space security, including the variety of challenges that decision-makers worldwide must grapple with in today’s changed outer space environment.

Frank Asbeck
Principal Adviser for Space and Security Policy
European External Action Service

# Introduction

The *Handbook of Space Security* (HbSS) is published at a time when the use of space and space-based assets and services has become so common that the global society – and we as citizens – simply cannot do without them anymore. This is true for telecommunications and navigation, environmental monitoring and resource management, as well as numerous aspects of our safety and security. At the same time, more and more countries are operating, or even launching, satellites autonomously. The space race that comprised of two superpowers some 50 years ago has turned into a plethora of space actors, totaling nearly 50 countries. These two trends demonstrate the attractiveness and importance of space utilization. They also, however, create pressing issues concerning policy and governance.

This handbook is investigating one of the most basic, urgent issues in this context: space security. For the purpose of the HbSS, we understand space security as having two dimensions, security in space and security from space. This means that all aspects which are related to the questions of how to make space operations more safe and secure as well as protect the usage of outer space (satellites in particular) to enhance terrestrial security are within the scope of this publication. To provide a better understanding of the coverage of space security, we have encouraged contributors to analyze a variety of definitions of space security, which have emerged from governments, international organizations, as well as from academic debates.

The HbSS does not seek to promote only one specific definition of space security. It rather intends to emphasize the two *dimensions* of space security – security in space and security on Earth from space – from a number of *constituent perspectives* (e.g., technical, political, legal, and economic). These are the guiding and structuring beacons underpinning this handbook. In this context, the linkages among civil, military, and dual use/purpose of outer space are addressed to advance a clearer understanding of the stark differences between legitimate military uses of space and the militarization and/or weaponization of outer space which have been imbued with negative connotations, whether deserved or not. From this analysis, the HbSS seeks to highlight the vulnerability of space itself as well as satellites being used as infrastructure and as means of security and defense. It will likewise address issues related to international governance of this policy area. Finally, the HbSS will underscore the need to advocate sustainable development of space and to take the preemptive measures required to avoid space becoming a new and perilous battleground.

It is readily apparent that space security encompasses a large number of disciplines. The multidisciplinary aspects of space security are highlighted in the HoSS, as space security is a vital policy portfolio that is heavily influenced by technological advances. At the same time, its value as a subject of international relations theory is stressed. While some of the specific technologies and/or applications related to space security have been publicized, as have many of the policy and governance aspects, the HbSS, for the first time, combines these in a holistic and integrated way. Accordingly, the handbook is comprised of four sections: International Space Security Setting, Space Applications for Security and Defense, Space Security Programs Worldwide, and Space Security Policies and Strategies of States and International Organizations.

The handbook can thus be viewed as a reference publication, providing a comprehensive and authoritative overview of the contemporary global space security environment and situation. It is a work of tertiary literature containing digested knowledge in an easily accessible format. It provides a sophisticated, cutting-edge resource on the space security–related policy portfolio and associated assets to assist fellow members of the global space community, academic audiences, and other interested parties in keeping abreast of the current and future directions of this vital dimension of international space policy. Concerning methodology, the handbook progressively examines both dimensions of space security, from its broader policy aspects to its narrower operational capabilities. It begins by investigating the general space security framework, including the security policy objectives of the principal space-faring nations. It then details the specific operational capabilities that are currently applied or developed to meet security needs from and for space. Finally, it examines how addressing these needs has led to space programs and the development of specific security space assets. In short, it examines the reciprocal relations among space policy objectives on one hand and operational capabilities on the other, allowing readers to understand the theoretical and practical interaction and limitations between them. It also features a number of recommendations concerning how best to improve the space security environment, given the often-competing objectives of the world's major space-faring nations.

Work on the HbSS was under way for nearly three years. 56 articles have been prepared for this first edition by around 100 contributors, from almost 25 countries. An Editorial Advisory Board of 23 distinguished experts from governments and academia from some 20 countries and almost every continent (i.e., Africa, Asia, Europe, North America, and South America) assisted the editors in identifying and evaluating contributions to ensure a high-quality, coherent final product. The major editorial work was performed by the four section editors Peter L. Hays, Jana Robinson, Denis Moura and Christina Giannopapa. These individuals are not only renowned experts in their respective fields but have exercised their broad competences, experience, commitment, and teamwork to guarantee that this handbook proves a valuable resource with a logical, researchable structure.

The handbook is available in both printed and electronic forms. It is intended to assist and promote both academic research and professional activities in this rapidly evolving field encompassing security from and for space. It aspires to be a go-to reference manual for space policy practitioners and decision-makers, scholars, students, researchers, and experts as well as the media. The Springer Publishing House has been an exemplary partner in this major undertaking. We would like to gratefully acknowledge the cooperation of Maury Solomon and Megan Ernst (New York) and Lydia Müller, Daniela Graf, Jutta Jäger, and Andreas Maisch (Heidelberg). Spyros Pagkratis acted as the main liaison between our editorial team and the publisher in the early phase of the project and, through that, was a very important driver of the whole endeavor. It is the hope of all of us who joined together to prepare this *Handbook of Space Security* that it will inspire those seeking to be active in shaping a secure, sustainable future for space activities, on which we all rely.

Kai-Uwe Schrogl

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# About the Editor

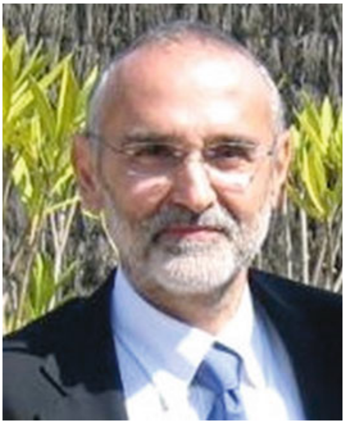
**Kai-Uwe Schrogl** is the Head of the ESA Policies Department in the European Space Agency (ESA, Headquarters in Paris, France). From 2007 to 2011 he was the Director of the European Space Policy Institute (ESPI) in Vienna, Austria, the European think tank for space policy. Prior to this, he was the Head of the Corporate Development and External Relations Department in the German Aerospace Center (DLR) in Cologne, Germany. Previously he also worked with the German Space Agency (DARA) in Bonn, Germany and the German Ministry for Post and Telecommunications.

He has been a delegate to numerous international forums and from 2014 to 2016 is the chairman of the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, the highest body for space law making, comprising 73 Member States. He recently served as the chairman of various European and global committees (ESA International Relations Committee and two plenary working groups of the UNCOPUOS Legal Subcommittee, the one on the launching State and the other on the registration practice, both leading to UN General Assembly Resolutions). He presented, respectively testified, at hearings of the European Parliament and the U.S. House of Representatives. Kai-Uwe Schrogl has written or co-edited 15 books and more than 130 articles, reports and papers in the fields of space policy and law as well as telecommunications policy. He launched and edited until 2011 the “Yearbook on Space Policy” and the book series “Studies in Space Policy” both published by ESPI at Springer Wien NewYork. He sits on editorial boards of various international journals in the field of space policy and law (Space Policy, Zeitschrift für Luft- und Weltraumrecht, Studies in Space Law/Nijhoff; previously also Acta Astronautica). Kai-Uwe Schrogl is Vice President of the International Institute of Space Law, Member of the International Academy of Astronautics (recently chairing its Commission on policy, economics and regulations) and the Russian Academy for Cosmonautics as well as Corresponding Member of the French Air and Space Academy. He holds a doctorate degree in political science and lectures international relations at Tübingen University, Germany, as an Honorary Professor.

# Section Editors

**Peter L. Hays** works for SAIC supporting the Intelligence Community, Department of Defense, and the Eisenhower Center. He helps lead development of space and security policy initiatives. Dr Hays holds a PhD from the Fletcher School and was an honor graduate of the USAF Academy. He served internships at the White House Office of Science and Technology Policy and National Space Council and taught space and security policy courses at the USAF Academy, School of Advanced Airpower Studies, National Defense University, and George Washington University. His major publications include the following: *Toward a Theory of Spacepower*, *Space and Security*, *United States Military Space*, *Spacepower for a New Millennium*, *Countering the Proliferation and Use of Weapons of Mass Destruction*, and *American Defense Policy*.

**Jana Robinson** has been Space Policy officer at the European External Action Service (EEAS), seconded from the Ministry of Foreign Affairs of the Czech Republic, since July 2013. From December 2009 to June 2013, Ms. Robinson worked as resident fellow at the European Space Policy Institute (ESPI), seconded from the European Space Agency (ESA), leading the Institute's Space Security Research Programme. She has published a number of articles on space security and space policy in various journals. Prior to joining ESPI, she served as development director for the Prague Security Studies Institute (PSSI) from 2005 to 2009, a leading Prague-based, nonprofit public policy organization focused on security policy and studies. She likewise provided key support in the corporate establishment of PSSI Washington, a nonprofit organization in Washington D.C., closely affiliated with PSSI Prague. Previously, she held positions consistent with her academic background in Asian Studies. She holds an MA in Asian Studies from George Washington University's Elliott School of International Affairs, in Washington D.C., specializing in Asia-Pacific security issues and space policy, and an MA in Chinese Studies from Palacky University, Olomouc, Czech Republic. She received scholarships to attend the International Space University (ISU) 2009 Space Studies Program (SSP09), the 2008 Summer Mandarin Training Course at the Mandarin Training Center of the National Taiwan Normal University in Taipei and Shanghai University during 1999–2000.



**Denis Moura** is adviser for science and technology in the French embassy in Italy.

He was previously adviser in the French Space Agency (CNES), in charge of strategic dossiers.

From 2010 to 2012, he was officer for space programs at the European Defence Agency in Brussels. This agency is in charge to support the Member States and the Council in their effort to sustain and improve the European defense capabilities needed for the Common Security and Defence Policy. He was and still is also providing expertise and support on space issues to other European institutions (Commission, European Economic and Social Committee, Secretariat General of the Council, European External Action Service, European Satellite Center, ESA, etc.) as well as to national ones.

Before these responsibilities, his career has been done within the French Space Agency (CNES) where he was in charge of the Space Science and Earth Observation pre-projects and programs, before being the CNES representative in Italy.

D. Moura is the chairman of the “Dual Use” Committee of the International Astronautical Federation and is also organizing conferences, workshops, and courses on space and the security and defense issues in Austria, Belgium, France, and Italy.

D. Moura holds a graduate engineering degree for aerospace from the Ecole Centrale Paris and the diploma from the French Defence Academy.

**Dr. Christina Giannopapa** is a senior advisor in the Department for Relations with Member States in the Cabinet of the Director General of the European Space Agency (ESA) in Paris. She is responsible i.a. for Parliamentary affairs and for liaising with Member States. From 2010 to 2012 she has been seconded from the Agency as Resident Fellow at the European Space Policy Institute (ESPI) in Vienna, where she has been supporting the European Interparliamentary Space Conference (EISC) and lead studies on innovation, Galileo, Copernicus, and Africa. In the policy area she also worked briefly in DG Research, European Commission. From 2007 to 2010, she has been working in the Mechanical Engineering Department of the Technical and Quality Management Directorate of ESA in the Netherlands. Prior to joining ESA she has worked as a Consultant to high-tech industries in research and technology development. She held positions in academia in Eindhoven University of Technology, the Netherlands and in the University of London, UK. She has received 14 academic scholarships and awards and has 40 publications in peer-reviewed journals and conferences. She holds a PhD in Engineering and Applied Mathematics; an MEng in Manufacturing Systems Engineering and Mechatronics; and an MBA in International Management from the University of London, UK. Additionally, she holds an assistant professor position in multiphysics at Eindhoven University of Technology. She is the chair of the Fluid Structure Integration (FSI) Committee of the American Society of Mechanical Engineers (ASME) and is the Secretary of the Committee for Liaison with International Organisations and Developing Nations (CLIODN) of the International Astronautical Federation (IAF).

# List of Abbreviations

| **Acronyms** | **Description** |
|---|---|
| ABM | Anti-Ballistic Missile |
| ACO | Allied Command Operations |
| ACS | Alcantara Cyclone Space |
| ACT | Allied Command Transformation |
| ADC | Analog to Digital Conversion |
| ADR | Active Debris Removal |
| AEB | Brazilian Space Agency |
| AEHF | Advanced Extremely High Frequency |
| AI&T | Assembly, Integration, and Test |
| AIS | Automatic Identification System |
| ALOS | Advanced Land Observation Satellite |
| APAS | Androgynous Peripheral Attach System |
| APEC | Asia-Pacific Economic Cooperation |
| APRSAF | Asia-Pacific Regional Space Agency Forum |
| APSCO | Asia-Pacific Space Cooperation Organization |
| AR | Acceptance Review |
| ARES | Affordable Responsive Spacelift |
| ARF | ASEAN Regional Forum |
| AS | Authorized Service |
| ASAT | Anti-Satellite |
| ASEAN | Association of Southeast Asian Nations |
| ASI | Agenzia Spaziale Italiana |
| ASLV | Augmented Satellite Launch Vehicle |
| ASV | Astrium Services |
| ATB | Agency Technology and Product Transfer Board |
| ATV | Automated Transfer Vehicle |
| BAMS | Broad Area Maritime Surveillance |
| BBM | BluemassMed |
| BLOS | Beyond Line Of Sight |
| BMD | Ballistic Missile Defense |
| BMEWS | Ballistic Missile Early Warning System |
| BOC | Besoin Opérationnel Commun |
| BPD | Boundary Protection Device |

| | |
|---|---|
| BTI | Build-To-Inventory |
| BWC | Biological Weapons Convention |
| C/A | Course Acquisition Code |
| C3 | Command, Control and Communications |
| C4IS | Command, Control, Communications, Computers and Information Systems |
| CAA | Contracting Administrative Authorities |
| CAIB | Columbia Accident Investigation Board |
| CAPP | Control Access Protection Profile |
| CAS | Chinese Academy of Sciences |
| CASIC | China Aerospace Science and Industry Corporation |
| CASTC | China Aerospace Science and Technology Corporation |
| CBERS | China-Brazil Earth Resources |
| CC | Common Criteria |
| CCDS | Consultative Committee for Space Data Systems |
| CCL | Commerce Control List |
| CCP | Commercial Crew Program |
| CCRP | Command and Control Research Program |
| CD | Conference on Disarmament |
| CEOS | Committee on Earth Observation Satellites |
| CF | Canadian Forces |
| CFSP | Common Foreign and Security Policy |
| CGS | Control Ground System |
| CGS | EU Council General Secretariat |
| CHIRP | Commercially Hosted Infrared Payload |
| CI | Critical infrastructure |
| CIA | Confidentiality, integrity, and availability |
| CIA | Central Intelligence Agency |
| CIL | Common Interoperability Layer |
| CIP | Critical infrastructure protection |
| CIS | Community of Independent States |
| CLBI | Centro de Lançamento da Barreira do Inferno |
| CMA | China Meteorological Administration |
| CNAE | Comissão Nacional de Atividades Espaciais |
| CNES | Centre National d'Etudes Spatiales |
| CNPQ | Conselho Nacional de Desenvolvimento Cientifico e Tecnológico |
| CNSA | China National Space Administration |
| COBAE | Brazilian Commission for Space Activities |
| COBAE | Comissão Brasileira de Atividades Espaciais |
| CoC | Code of Conduct for Outer Space Activities |
| COIN | Counter-insurgency |
| COLA | Collision Avoidance Analysis |

| | |
|---|---|
| COMINT | COMmunications INTelligence |
| COMPUSEC | Computer Security |
| COMSEC | Communications Security |
| COPUOS | Committee on Peaceful Uses of Outer Space |
| C-ORS | Coalition Operationally Responsive Space |
| COSAC | Conférence des Organes Parlementaires Spécialisés dans les Affaires de l'Union des Parlements de l'Union Européenne |
| COSMO-SkyMed | Constellation of Small Satellites for Mediterranean basin Observation |
| COSTIND | Commission for Science and Technology and Industry for National Defense |
| COTS | Commercial off the shelf |
| CRADAs | Cooperative Research and Development Agreements |
| CRPA | Controlled Reception Pattern Antennas |
| CRYPTOSEC | Cryptographic Security |
| CSA | Canadian Space Agency |
| CSDP | Common Security and Defence Policy |
| CSG | COSMO Second Generation |
| CSIC | Cabinet Satellite Intelligence Center |
| CSIP | Critical Space Infrastructure Protection |
| CSLLA | Commercial Space Launch Amendments Act |
| CSM | Conjunction Summary Message |
| CSO | Composante Spatiale Optique |
| CTA | Centro Técnico Aeroespacial |
| CTA | Centro Tecnológico da Aeronáutica |
| CTBT | Comprehensive Nuclear-Test-Ban Treaty |
| CWC | Chemical Weapons Convention |
| DAC | Discretionary Access Control |
| DAGR | Defense Advanced GPS Receiver |
| DARPA | Defense Advanced Research Projects Agency |
| DCTA | Departamento de Ciência e Tecnologia Aeroespacial |
| DEW | Directed Energy Weapons |
| DGA | Direction Générale de l'Armement |
| DHS | Department of Homeland Security |
| DISA | Defense Information Systems Agency |
| DJP | Democratic Party of Japan |
| DLR | German Aerospace Center |
| DLR | German Space Center |
| DMC | Disaster Management Constellation |
| DMSP | Defense Meteorological Satellite Programme |
| DND | Department of National Defense |
| DoD | Department of Defense |
| DOS | Department of Space |

| | |
|---|---|
| DOTMLFPI | Doctrine and concepts, Organization, Training, Material and equipment, including logistics, Leadership, Facilities like infrastructures, Personnel, Interoperability |
| DR | Debris Removal |
| DRC | Federal Special Program for the Development of Russia's Cosmodromes |
| DRDC | Defence Research & Development Canada |
| DSCS-III | Defense Satellite Communications System III |
| DSP | Defense Support Program |
| DWSS | Defense Weather Satellite System |
| EALs | Evaluation Assurance Levels |
| EAR | Export Administration Regulations |
| EC | European Commission |
| ECSC | European Coal and Steel Community |
| EDA | European Defence Agency |
| EDC | European Defence Community |
| EDRS | European Data Relay System |
| EEAS | European External Action Service |
| EELV | Evolved Expendable Launch Vehicle Program |
| EFC | European Framework Cooperation for defence, civilian security and space-related research |
| EGNOS | European Geostationary Navigation Overlay Service |
| EHF | Extremely High Frequency |
| ELINT | ELectronic INTelligence |
| ELINT | Electronic Intelligence satellites |
| EM | Electromagnetic |
| EMP | High altitude Nuclear Weapons |
| EMSA | European Maritime Safety Agency |
| EMSEC Or TEMPEST | Emission Security |
| END | National Strategy of Defense |
| ENMOD | Environmental Modification Techniques |
| EO | Earth Observation |
| EPAA | European Phased Adaptive Approach |
| EPCIP | European Programme for CI Protection |
| EPS | Enhanced Polar System |
| ERG-1 2002 | European Research Grouping Arrangement No 1 concerning Co-Operative Defence Research and Technology Projects |
| ERS | European Remote Sensing Satellite |
| ES | Kingdom of Spain |
| ESA | European Space Agency |
| ESCPC | European Satellite Communication Procurement Cell |
| ESDA | European Security and Defence Assembly |

| | |
|---|---|
| ESDP | European Security and Defence Policy |
| ESP | European Space Policy |
| ESPI | European Space Policy Institute |
| ESRAB | European Security Research Advisory Board |
| ESRIF | European Security and Research Innovation Forum |
| ESS | European Security Strategy |
| EU | European Union |
| EUISS | European Union Institute for Security Studies |
| EUISS | EU Institute for Security Studies |
| EUROPA MoU 2001 | European Understandings for Research Organisation Programmes and Activities |
| EUSC | European Union Satellite Centre |
| EUSC | EU Satellite Centre |
| EW | Electronic Warfare Weapons |
| EXAMETNET | Experimental InterAmercian Meteorological Rocket Network |
| FAA | Federal Aviation Administration |
| FAA-AST | Federal Aviation Administration's Commercial Space Transportation |
| FALCON | Force Application and Launch from CONUS |
| FAT | Frequency Allocation Tables |
| FCC | Federal Communications Commission |
| FDA | Food and Drug Administration |
| FFRDCs | Federally Funded Research and Development Centers |
| FIA | Fédération Internationale de l'Automobile |
| FOC | Full Operational Capability |
| FOCI | Foreign Ownership Control and Influence |
| FP | Framework Programme for Research and Technological Development |
| FR | French Republic |
| FRD | Functional Requirements Document |
| FRR | Flight Readiness Review |
| FSP | Federal Space Program |
| GAGAN | GPS-Aided Geo Augmented Navigation |
| GAO | Government Accountability Office |
| GBS | Global Broadcast Service |
| GCHQ | General Communications Headquarters |
| GCM | GMES Contributing Mission |
| GEO | Geosynchronous Earth Orbit |
| GEO | Group on Earth Observation |
| GEOs | Geosynchronous equatorial orbits |
| GETEPE | Grupo Executivo e de Trabalhos e Estudos de Projetos Especiais |
| GGE | Group of Governmental Experts |

| | |
|---|---|
| GIANUS | Global Integrated Architecture for iNnovative Utilization of space for Security |
| GIG | Global Information Grid |
| GIS | Geographic Information System |
| GIST | Globalize and Internationalize ORS Standards and Technology |
| GITsIU KS | Glavnii Ispitatelnii Tsentr Ispitanii i Upravleniya Kosmicheskimi Sredstvami |
| GLONASS | Russian Federal Program on Global Navigation Systems |
| GMES | Global Monitoring for Environment and Security |
| G-MOSAIC | GMES services for Management of Operations, Situation Awareness and Intelligence for regional Crises |
| GNSS | Global Navigation Satellite System |
| GoP | Group of Personalities |
| GP | General Perturbations |
| GPS | Global Positioning Systems |
| GSE | GMES Service Element |
| GSLV | Geosynchronous Satellite Launch Vehicle |
| GSSC | Global (or Regional) Satcom Support Center |
| HALE | High Altitude Long Endurance |
| HCOC | International Code of Conduct against Ballistic Missile Proliferation (Hague Code of Conduct) |
| HEMP | High Altitude Electromagnetic Pulse |
| HEO | Highly Elliptical Orbit |
| HMI | Hazardously Misleading Information |
| HQ | Headquarters |
| HR | High Resolution |
| HTS | High Throughput Satellites |
| HTV | H-2 Transfer Vehicle |
| HW | Hardware |
| I&A | Identification and Authentication Mechanisms |
| IA | Information Assurance |
| IADC | Inter-Agency Space Debris Coordination Committee |
| IAE | Instituto de Aeronáutica e Espaço |
| IASE | Information Assurance Systems Engineering |
| ICADS | Integrated Correlation and Display System |
| ICAO | International Civil Aviation Organization |
| ICBM | Intercontinental Ballistic Missiles |
| ICDs | Interface Control Documents |
| ICG | International Committee on GNSS |
| ICoC | International Code of Conduct for Outer Space Activities |
| IDCSP | Initial Defense Communication Satellite Program |
| IDSA | Institute for Defense Studies and Analyses |
| IDSS | International Docking System Standard |

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|---|---|
| IEM | Industrial Equipment Manufacturing |
| IGS | Information Gathering Satellites |
| IGY | International Geophysical Year |
| IISL | International Institute of Space Law |
| IISU | Units like the ISRO Inertial Systems Unit |
| IMSMA | Information Management System for Mine Action |
| IMU | Inertial Measurement Units |
| INCOSPAR | Indian National Committee on Space Research |
| INFOSEC | Information Security |
| INFRAERO | Empresa Brasileira de Infra-Estrutura Aeroportuária |
| INPE | Instituto Nacional de Pesquisas Espaciais |
| INSAT | Indian National Satellite |
| INTELSAT | International Telecommunications Satellite Organization |
| IOT | In-Orbit Test |
| IPS | Interim Polar System |
| IR | Infrared |
| IRNSS | Indian Regional Navigation Satellite System |
| ISA | Israel Space Agency |
| ISAC | ISRO Satellite Centre |
| ISEG | International Space Exploration Group |
| ISLR | Integrated Side Lobe Ratio |
| ISMERLO | International Submarine Escape and Rescue Liaison Office |
| ISMS | Information Security Management System |
| ISO | International Standardization Organization |
| ISO | International Organization for Standardization |
| ISON | International Scientific Optical Network |
| ISR | Intelligence Surveillance and Reconnaissance |
| ISRO | Indian Space Research Organisation |
| ISS | International Space Station |
| ISTAR | Intelligence, Surveillance, Target Acquisition and Reconnaissance |
| ISTRAC | ISRO Telemetry, Tracking and Command Network |
| IT | Information Technology |
| ITA | Aeronautics Technological Institute |
| Italian SEGREDIFESA/DNA | Segretariato generale della difesa/Direzione nazionale degli armamenti |
| ITAR | International Traffic in Arms Regulations |
| ITSEC | Information Technology Security Evaluation Criteria |
| ITU | International Telecommunication Union |
| J/N | Jamming-to-Noise Ratio |
| JAPCC | Joint Air Power Competence Center |
| JAXA | Japan Aerospace Exploration Agency |

| | |
|---|---|
| JDA | Japanese Defense Agency |
| JFC | Joint Force Commanders |
| JFCC Space | Joint Functional Component Command for Space |
| JICA | Japan International Cooperation Agency |
| JMOD | Japanese Ministry of Defense |
| JRC | Joint Research Centre |
| JSDF | Japanese Self-Defense Forces |
| JSF | Japan Space Forum |
| JSpOC | Joint Space Operations Center |
| JTRS | Joint Tactical Radio System |
| KE | Kinetic Energy |
| KEW | Kinetic Energy Weapons |
| KIAM | Keldysh Institute of Applied Mathematics |
| KV | Kosmicheskie Voiska |
| L2C | Second Civil Signal |
| LCC | Life-Cycle Cost |
| LCOLA | Launch collision avoidance |
| LDEF | Long Duration Exposure Facility |
| LDP | Liberal Democratic Party |
| LEMV | Long-Endurance Multi-Intelligence Vehicle |
| LEO | Low Earth Orbit |
| LEOP | Launch and Early Orbit Phase |
| LoI | Letter of Intent |
| LPSC | Liquid Propulsion System Centre |
| LSC | Legal Subcommittee |
| LTBT | Limited Test Ban Treaty |
| LTSSA | Long-Term Sustainability of Space Activities |
| MAC | Mandatory Access Control |
| MAD | Mutual Assured Destruction |
| MALE | Medium Altitude Long Endurance |
| MARISS | MARitime Security Service |
| MBOC | Multiplexed Binary Offset Carrier |
| MCF | Master Control Facility |
| MCR | Mission Concept Review |
| MCS | Mission Control Segment |
| MCTI | Ministérios Ciência Tecnologia e Inovação |
| MD | Misnistério da Defesa |
| MDR | Mission Definition Review |
| MECB | Missão Espacial Completa Brasileira |
| MEO | Medium Earth Orbit |
| METI | Ministry of Economy, Trade, and Industry |
| MEXT | Ministry of Education, Culture, Sports, Science, And Technology |
| MHV | Miniature Homing Vehicle |

| | |
|---|---|
| MIIT | Ministry of Industry and Information Technology |
| MMMB | Multi-Mission Microsatellite Bus |
| MNE | Multinational Experiment |
| MOA | Ministry of Agriculture |
| MOD | Ministry of Defence |
| MOE | Ministry of Education |
| MoFA | Ministry of Foreign Affairs |
| MOLR | Ministry of Land and Resources |
| MOSA | Modular Open Systems Architecture |
| MOST | Microvariability and Oscillations of Stars |
| MOST | Ministry of Science and Technology |
| MoU | Memorandum of Understanding |
| MSDF | Maritime Self-Defense Force |
| MSFD | Maritime Self-Defense Force |
| MTCR | Missile Technology Control Regime |
| MUSIS | Multinational Space-Based Imagery System |
| NADs | National Armaments Directors |
| NASA | National Aeronautics and Space Administration |
| NATO | North Atlantic Treaty Organization |
| NAVWAR | Navigation Warfare |
| NCIA | NATO Communication and Information Agency |
| NDRC | National Development and Reform Commission |
| NDS | Nuclear Detonation Detection System |
| NEO | Near-Earth Object |
| NEOSSat | Near Earth Object Surveillance Satellite |
| NFAT | National Frequency Allocation Tables |
| NGEO | Next Generation Electro-Optical reconnaissance satellite |
| NGO | Non-Governmental Organisation |
| NISPOM | National Industrial Security Program Operating Manual |
| NOAA | National Oceanic and Atmospheric Administration |
| NOSS | Naval Ocean Surveillance Satellite |
| NPOESS | National Polar-Orbiting Operational Environmental Satellite System |
| NPT | Nuclear Non-Proliferation Treaty |
| NRO | National Reconnaissance Office |
| NRSC | National Remote Sensing Centre |
| NSA | National Security Agency |
| NSAU | National Space Agency of Ukraine |
| NSC | National Security Council |
| NSDA | National Space Development Agency |
| NSG | Nuclear Supplier's Group |
| NSO | Netherlands Space Office |
| NSP | National Space Policy |
| NSSS | National Security Space Strategy |

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|---|---|
| OCCAR | Organisation Conjointe de Coopération en matière d'ARmement |
| OFAC | Office of Foreign Asset Control Regulations |
| OKIK | Otdelni Komando-izmeritelnii Komplex |
| ONSP | Office of National Space Policy |
| OODA | Observe; Orient; Decide; Act |
| OPIR | Overhead Persistent-Imaging Infrared |
| OPSEC | Operational Security |
| ORBAT | Order of Battle |
| ORD | Operational Requirements Document |
| ORFEO | Optical and Radar Federated Earth Observation System |
| ORR | Operational Readiness Review |
| ORS | Operationally Responsive Space |
| OS | Open Service |
| OST | Outer Space Treaty |
| OTM | On-the-Move |
| OTV | Orbital Test Vehicle |
| OWG | Operational Working Group |
| P[Y]) | Pseudorandom Code |
| PA | Project Agreements |
| PAROS | Prevention of an Arms Race in Outer Space |
| PCA | Permanent Court of Arbitration |
| PDR | Preliminary Design Review |
| PEC | Photoelectric Cell |
| PFI | Privately Financed Initiatives |
| PFI | Private Finance Initiative |
| PHAROS | Portail d'Accès au Renseignement de l'Observation Spatiale |
| PL | Republic of Poland |
| PMF | Production Master Files |
| PMR | Professional Mobile Radio |
| PNAE | Programa Nacional de Atividades Espaciais |
| PNT | Position, Navigation, and Timing |
| PoC | Points of Contact |
| PPS | Precise Positioning Service |
| PSC | EU Political and Security Committee |
| PSLR | Peak to Side Lobe Ratio |
| PSLV | Polar Satellite Launch Vehicle |
| PSSI | Prague Security Studies Institute |
| QR | Qualification Review |
| QZSS | Quasi-Zenith Satellite System |
| R&D | Research and Development |
| RAP | Recognised Air Picture |
| RASCAL | Responsive Access, Small Cargo, Affordable Launch |
| RF | Radio Frequency |

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|---|---|
| RFI | Radio Frequency Interference |
| RFP | Request for Proposal |
| RMA | Revolution in Military Affairs |
| RORSAT | Radar Ocean Reconnaissance Satellites |
| ROSCOSMOS | Russian Federal Space Agency |
| RS | Responsive Space |
| RSC | Responsive Space Capabilities |
| RSP | Recognized Space Picture |
| RTD | Research and Technological Development |
| RTGs | Radio-Thermal Generators |
| RTO | Research and Technology Organization |
| RV | Re-entry Vehicles |
| RVSN | Raketnye Voiska Strategicheskogo Naznacheniia |
| SAC | Space Applications Centre |
| SACT | Strategic Allied Command Transformation |
| SALT | Strategic Arms Limitation Treaties |
| SAMRO | SAtellite Militaire de Reconnaissance Optique |
| SAR | System Acceptance Review |
| SAR | Search and Rescue System |
| SAR | Synthetic Aperture Radar |
| SARAL | Satellite for Argos and Altika |
| SASAC | State-owned Assets Supervision and Administration Commission of the State Council |
| SASTIND | State Administration of Science, Technology and Industry for National Defense |
| SatCom | Satellite Communications |
| SatNav | Satellite Navigation |
| SBAS | Satellite-Based Augmentation System |
| SBIRS | Space-Based Infra-Red System |
| SBSS | Space-Based Space Surveillance |
| SBV | Space-Based Visible Sensor |
| SCC | Security Consultative Committee |
| SCC | Space Control Center |
| SCSD | Special Committee on Space Development |
| SDA | Space Data Association |
| SDC | Space Data Center |
| SDF | Self-Defense Forces |
| SDI | Strategic Defense Initiative |
| SDR | System Definition Review |
| SDS | Space Data Systems |
| SDSC | Satish Dhawan Space Center |
| SGB | Brazilian Geostationary Satellite |
| SGDC | Geostationary Defense and Strategic Communications Satellite |
| SHEFEX | Sharp Edge Flight Experiment |

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|---|---|
| SHF | Super High Frequency |
| SHSP | Strategic Headquarters of Space Policy |
| SIGINT | SIGnals INTelligence |
| SINDAE | National Systems of Space Activities |
| SLR | Satellite Laser Ranging |
| SLV-3 | Satellite Launch Vehicle 3 |
| SMS | Security Management System |
| SNN | U.S. Space Surveillance Network |
| SOA | State Oceanic Administration |
| SOF | Strength of Functionality |
| SOI | Space Object Identification |
| SOLAS | International Convention for the Safety of the Life at Sea |
| SOPA | Space Object Proximity Awareness |
| SP | Special Perturbations |
| SPA | Space Plug-and-Play Avionics |
| SPADATS | Space Detection and Tracking System |
| SPASEC | Security Panel of Experts |
| SPOT | Système Probatoire d'Observation de la Terre |
| SPS | Standard Positioning Service |
| SRBs | Solid Rocket Boosters |
| SRR | System Requirements Review |
| SS | Space Segment |
| SSA | Space Situational Awareness |
| SSC | Swedish Space Corporation |
| SSCG | Space Security Coordination Group |
| SSID | Service Set Identifier |
| SSN | SafeSeaNet |
| SSN | Space Surveillance Network |
| SSS | Space Surveillance System |
| STA currently MEXT | Japan's Science and Technology Agency |
| STM | Space Traffic Management |
| STSC | Scientific and Technical Subcommittee |
| SW | Software |
| TA1 | Technical Arrangement to the European Research Grouping Arrangement No 1 |
| TAA | Technical Assistance Agreements |
| TAL | Transoceanic Abort Landing |
| TAMG | Technical Arrangement Management Group |
| TAS-I | Thales Alenia Space Italia |
| TC | Telecommand |
| TCBM | Transparency and Confidence Building Measure |
| TCBMs | Transparency and Confidence Building Measures |
| TCBMs | Transparency and Confidence-Building Measures |
| TDRSS | Tracking and Data Relay Satellite System |

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|---|---|
| TELEDIFE | Direzione Informatica, Telematica e Tecnologie Avanzate |
| TEMPEST | Telecommunications Electronics Material Protected from Emanating Spurious Transmissions |
| TIES | Tactical Imagery Exploitation System |
| TM | Telemetry |
| TOE | Target of Evaluation |
| TRANSEC | Transmission Security |
| TTRDP | Trilateral Technology Research and Development Projects |
| TWG | Technical Working Group |
| UAS | Unmanned Air Systems |
| UAV | Unmanned Aerial Vehicles |
| UFO | Ultra High Frequency Follow-On |
| UGS | User Ground Segment |
| UHF | Ultra High Frequency |
| ULA | United Launch Alliance |
| UNCLOS | United Nations Convention on the Law of the Sea |
| UNCOPOUS | United Nations Committee on the Peaceful Uses of Outer Space |
| UNGA | United Nations General Assembly |
| UNIDIR | United Nations Institute for Disarmament Research |
| UNOOSA | United Nations Office for Outer Space Affairs |
| UN-SPIDER | UN Platform for Space-based Information for Disaster Management |
| USAF | United States Air Force |
| USLM | United States Munitions List |
| VHR | Very High Resolution |
| VKS | Voenno-kosmicheskie Voiska |
| VLM | Veículo Lançador Microsaélite |
| VLS | Veículo Lançador de Satélite |
| VoIP | Voice Over Internet Protocol |
| VPK | Voenno-promychlennaïa komissiia |
| VPN | Virtual Private Network |
| VRKO | Voiska Raketno-kosmicheskoj Oborony |
| VSSC | Vikram Sarabhai Space Centre |
| VVKO | Voiska Vozdushno-kosmicheskoj Oborony |
| W | Warfare |
| WAAS | Wide-Area Augmentation System |
| WAN | Wide Area Network |
| WCDMA | Wideband Code Division Multiple Access |
| WEP | Wired Equivalency Protocol |
| WEU | Western European Union |
| WGS | Wideband Global Satcom |

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|---|---|
| WMD | Weapons of Mass Destruction |
| WMO | World Meteorological Organization |
| WRC | World Radiocommunication Conference |
| XDR | Extended Data Rate |
| XIPS | Xenon Ion Propulsion System |

# Contents

## Volume 1

## Volume 2

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# Part I

# International Space Security Setting

# International Space Security Setting: An Introduction

# 1

Peter L. Hays

## Contents

**Abstract**
This article provides an introduction to Section One of the *Handbook of Space Security* by overviewing major issues and themes that frame discourse about space security. Section One contains 14 chapters that include foundational discussions about definitional, governance, theoretical, legal, and deterrence themes for space security as well as more focused discussions about responsive space, cyber security, critical infrastructure, safety, traffic management, sustainability, export controls, and transparency- and confidence-building measures. Together, these themes and issues provide a comprehensive setting for refining and advancing our dialogue about international space security.

## 1.1 Foundational Themes

Defining and scoping space security is probably the single most important issue for any dialogue about this topic. Traditionally space security was primarily defined in bipolar terms as part of the strategic balance between the United States and the Soviet Union, and it was focused on military and environmental aspects of accessing and using space. ▶ Chapter 2, "Defining Space Security" chapter by

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Michael Sheehan explains how this traditional definition has been expanded to include a broader perspective on security that emphasizes the use of space for security and defense, the security of assets in space against natural and man-made threats, as well as security from threats originating in space. Broadening the scope of space security to include a growing number of significant space actors and emphasize the increasing importance of commercial interests has advantages, but also carries certain risks, including difficulties in addressing these issues in comprehensive yet discreet ways.

Governance and theoretical issues form other foundational aspects of space security. Effective governance is needed for humanity to derive more benefits from space; space governance also seeks to ensure space is used in stable and sustainable ways. Eligar Sadeh identifies two key obstacles to more enlightened space governance: difficulties in attaining collective action in relation to the commons of space and problems with developing shared understanding about strategic stability and advancing strategic assurance for sustainable uses of space as a shared strategic goal. Max Mutschler's chapter describes how international relations theory can be used to explain various patterns of security cooperation in space and illuminates why there have been only limited successes thus far in achieving space security cooperation: Neorealism explains this lack of cooperation with the difficulties to achieve balanced gains; neoinstitutionalism sees the establishment of effective rules and mechanisms to verify the compliance of states as a main hurdle; and from a Constructivist/Liberal perspective the main problem lies in the dominant beliefs about the value of unilateral space policies. More broadly, my chapter asserts that spacepower theory can describe, explain, and predict how individuals, groups, and states can best derive utility, balance investments, and reduce risks in their interactions with the cosmos. Such foundational theory should be more fully developed and become a source for critical insights on finding better ways to generate wealth in space, making trade-offs between space investments and other important goals, reordering terrestrial security dynamics as space becomes increasingly militarized and potentially weaponized, and seizing exploration and survival opportunities that only space can provide.

Chapters exploring the laws of war for space and the role of space in deterrence complete the foundational part of Section One. Professor Steven Freeland explains how regulation of space is embedded in international law and explicates the major themes of the Outer Space Treaty (OST), the main source of space law. As technology advances, space has been increasingly used during the course of armed conflict, notwithstanding the "peaceful purposes" provisions of the OST. Reconciling these seemingly incompatible concepts and developments is difficult and requires an understanding of how and to what extent the international law principles of jus in bello – international humanitarian law – apply to the conduct of these activities. Freeland describes how the rising number of "dual-use" satellites further complicates matters and asserts that there is a growing need to reach consensus on additional legal regulation for armed conflict that may involve use of space capabilities. Ambassador Roger Harrison asserts that whether or not weapons are actually deployed in space, the era in which satellites could operate without potential threat is over. He examines trends that could be encouraged and actions that should be taken to reduce the possibility of space becoming a theater, or a catalyst, for hostilities. He concludes that prospects for strengthening deterrence may not depend so much on state activity as on the nature of the space environment as well as on leadership by commercial space operators.

## 1.2 International Space Security Focus Areas

Responsive space is a recent catchphrase referring to aspirations for space capabilities to support a wide range of mission areas in flexible ways, become more affordable, and be developed and employed more quickly. Nina-Louisa Remuss explores security-related dimensions of responsive space and examines how the well-known approach developed by the US Department of Defense can inform a European path toward improving responsive space capabilities. Dario Sgobbi and his coauthors examine the strong interrelationships between space and cyber security. Although many aspects of space and, especially, cyber security must be far better developed, the authors assert that using systems engineering concepts and methodologies is key to tackling challenges in both these fields simultaneously and to achieving space systems that are truly cyber secure.

Despite increased emphasis over the past 20 years on critical infrastructure protection as an essential foundation for ensuring the safety and security of citizens and the functioning of states, Markus Hesse and Marcus Hornung find that too often critical space infrastructure is overlooked. For example, Global Positioning System timing signals currently provide the “heartbeat” that synchronizes all global telecommunications networks, yet there is a lack of appreciation for this dependency and underdeveloped policies to ensure protection of this critical space infrastructure. As space infrastructure grows in importance, it is imperative that the United States, European Union, and others find better ways to develop these needed policies. Space safety is necessary for the sustainable development of space yet, as Joe Pelton and his coauthors describe, safety considerations are too often an afterthought for space security issues. Without improved space safety practices and standards from launch, to on-orbit operations, to reentry, billions of dollars of space assets, many astronaut lives, and even people on Earth could all be increasingly in peril. A related topic of growing importance is the concept of space traffic management. William Ailor’s chapter begins by providing an overview of the evolution of the near-Earth space environment, discussing the current situation, and projecting how future developments such as the growing space debris population and active debris removal will affect that environment. Just as the growth in air travel led to air traffic management, assuring that future space systems will have minimal interference to their operations requires a system to warn operators of potential collisions and other hazards: a space traffic management system.

Space sustainability is another recent catchphrase that refers to a set of issues relating to carrying out space activities safely and without interference as well as concerns about ensuring continuity of benefits derived on Earth from space activities.

Peter Martinez, as a long-time international space policy expert, is in an ideal position to review the role of the various relevant United Nations (UN) entities in ensuring space sustainability and provide a detailed review of the Working Group on the Long-Term Sustainability of Outer Space Activities within the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space (UN COPUOS). In addition, his chapter discusses the relationship of the work in UN COPUOS with related work being done in the Conference on Disarmament, the UN Group of Governmental Experts (GGE) on Transparency- and Confidence-Building Measures (TCBMs) in Outer Space Activities, and the initiative by the European Union to propose a draft international Code of Conduct for outer space activities. Ulrike Bohlmann explains how the Cold War drove both innovation in space technology and imposition of controls on the export of these technologies. Balancing national security and commercial interests has been and remains difficult due to the Janus-faced, "dual-use" nature of space technology, serving scientific and commercial interests on the one hand and strategic, defense-related objectives on the other. Finally, Jana Robinson, from her perch with the European External Action Service, describes TCBMs as traditional tools of diplomacy and international relations that can be applied to space activities. She reviews the increasing demand for TCBMs, focuses on the multilateral dimension of TCBMs, and overviews the main space TCBM-related efforts to date, including the more recent ones being undertaken in the UN framework and by the European Union.

## 1.3 Conclusions

This overview of Section One of the *Handbook of Space Security* provides a comprehensive introduction to major issues and themes that shape humanity's dialogue about space security. The 14 chapters in Section One include foundational discussions about definitional, governance, theoretical, legal, and deterrence themes as well as more focused discussions about responsive space, cyber security, critical infrastructure, safety, traffic management, sustainability, export controls, and transparency- and confidence-building measures. These chapters provide a comprehensive foundation for the more detailed and focused discussions of space security themes and issues in the remainder of the *Handbook of Space Security*.

# Defining Space Security

# 2

Michael Sheehan

## Contents

**Abstract**

Space security relates to guaranteed access to space and the ability to freely exploit space for various purposes. Traditionally, space security was defined in military terms in relation to the strategic balance between the United States and the Soviet Union. Since the end of the Cold War, a two-dimensional model of military and environmental dimensions of space security has developed. This in turn is beginning to be superceded by a three-sector understanding which distinguishes between the uses of space for security and defense: the security of assets in space against natural and man-made threats and security from threats originating in space. Expanding the definition of space security has advantages but also carries certain risks.

## 2.1 Introduction

"Space security" is a subject that is much discussed but rarely defined. Traditionally, it has been associated with the military security of states, and this is still the

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predominant understanding of the term. It certainly remains the case that a fundamental aspect of "space security" is the contribution that satellites make to the military security of states and the maintenance of international stability and balances of power, as well as the military threats to satellites and their ability to support international security. However, there has been a widening of the understanding of space security in recent years so that, while the military dimension remains fundamental, other crucial issues have been brought within the scope of the concept.

The pursuit of security has become a fundamental objective of state behavior, and in that sense it was inevitable that the concept would eventually be applied to human space activities. This change reflects to some extent the fact that in the last three decades there has been a significant evolution in the meaning attached to the term "security" more generally. During the Cold War, "security" was understood in specific and very limited ways. Security referred to threats against the state and specifically to the military threats represented by the armed forces of other states or insurgent movements. The problem with this narrow definition of security was that it did not reflect the everyday reality of people in the world. While the armed forces of another country might represent a clear security threat for the people of some countries, in many others they would not, while issues like food and water shortages or endemic diseases would be the issues that presented the real security threats to the survival of populations. A definition of security was needed therefore that could embrace these kinds of diverse problems within a single framework. As a result, while military security was retained as a crucial security sector, new ones such as economic, societal, and environmental securities were added to the concept.

Changes in the understanding of space security mean that it now similarly embraces a broad understanding of the requirement of freedom of access to and use of space by all states who wish to use it for the socioeconomic benefit of their populations. Satellites play a crucial role in international efforts to promote terrestrial environmental security and for many states are vital in terms of their efforts to increase human security. At the same time, the traditional view that space is a place for securing long-standing national objectives is also still prominent. The United States, for example, sees the ability to use space as a vital national interest.

Space security involves a number of different aspects. It includes the security of satellites and spacecraft in orbit, the security of access to space, and also the contribution to the security of people on Earth made by various types of satellites. Although these three dimensions will be looked at separately in this chapter, in reality they are interconnected. The security of satellites in orbit, for example, is crucially affected by what is happening to their ground elements. The human security contribution of satellites is threatened by both military and environmental threats to satellites in space.

## 2.2 Existing Definitions of Space Security

Since the beginning of the space age in the 1950s, two basic principles have dominated thinking about the relationship of space activities to international law.

These are the concepts of the right of access to space and freedom of navigation in space. There is therefore a consensus among governments that space security involves efforts to ensure the long-term sustainability of Earth orbit for a range of beneficial uses and governments continue to promote freedom of access to and use of space for those same human security purposes.

This is reflected in existing definitions of space security such as that used by Canada, which describes space security simply as "the secure and sustainable access to, and use of, space." The annually published *Space Security Index* uses identical terms to this definition but adds, "and freedom from space-based threats" (Estabrooks 2006, p. 93). A similar but more precise definition by the Space Generation Council, which specifically focuses on its political dimension, is "secure and sustainable access to, and use of outer space in accordance with international laws and treaties, free from the threat of disruption."[1] All these definitions capture the idea that making space "secure" means making it a sustainable environment over the long term for the conduct of human activities in a range of practical areas. It is notable that in these definitions the word "threat" is not limited to purely military issues but rather is implicitly allowed to embrace any potential obstacle to the effective use of the space environment by human beings. The definitions reflect the idea of space as a domain in which states and non-state actors will wish to carry out a variety of legal activities unhindered by dangers created by the activities of others or blocked by either technological issues or the effects of the natural space environment. This has encouraged the increasing popularity of the idea of space as a specific environment and one that is a common heritage of humanity. For the authors of the Space Security Index, "This broad definition encompasses the security of the unique space environment, which includes the physical and operational integrity of manmade assets in space and their ground stations, as well as security on Earth from threats originating in space-based assets" (Jaramillo 2011, p. 7). However, this definition, while broad, still fails to fully capture the important aspect of the contribution made by satellites to security on Earth.

The Space Security Index publication surveys developments in space security by assessing annual changes in eight indicators of space security. These are:

- The space environment
- Space situational awareness
- Laws, policies, and doctrines
- Civil space and global utilities
- Commercial space
- Space support for terrestrial military operations
- Space systems protection
- Space systems negation

Because the SSI definition is not fully comprehensive, it needs to be supplemented. Space security is not something which can be reduced to a single meaning or easily summarized in a single sentence. An emerging definition is

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[1] Cornell A, Space Generation Advisory Council

a three-dimensional one which embraces the satellite contribution to human security, such as that proposed by Mayence, which sees space security as being simultaneously:

*Outer space for security*: the use of space systems for security and defense purposes

*Security in outer space*: how to protect space assets and systems against natural and/or human threats or risks and ensure a sustainable development of space activities

*Security from outer space*: how to protect human life and Earth's environment against natural threats and risks from outer space (Mayence 2010, p. 35)

In this tripartite framework, the two existing post-Cold War understandings of space security are present. Space is defined as an area of activity where environmental and potential military threats pose difficulties for its successful routine utilization. However, a third dimension is added, which is the use of space to promote the general security of human beings on Earth through such means as communications for rescue and disaster management, monitoring of extreme weather conditions, improved agricultural production, and so on.

## 2.3 Military Space Security

Questions of definition are prominent when addressing the issue of military space security. For most of the Cold War period, there were only two states with a wide array of military space capabilities, the Soviet Union and the United States. Because these states deployed dedicated military satellites, there was also a fairly clear dividing line between military and civilian satellites. In the current era, however, neither of these two conditions applies. Space has become a realm where a large and growing community of states depends upon national space assets to a considerable degree, and considerations of affordability have encouraged the multiplication of dual-purpose satellites that serve both military and civilian functions. Many countries have also developed other technologies, such as long-range surface-to-surface missiles, that could be adapted to the antisatellite (ASAT) role or possess technologies such as the European and Japanese robotic resupply spacecraft used to service the International Space Station, which could, at least in theory, also perform as ASATs. In addition, many of the technologies that would be useful for verifying a space arms control agreement would be, by their very nature, potential ASATs themselves, for example, satellites which can maneuver to inspect other satellites or lasers that can track satellites.

As with security more generally, space security during the Cold War was understood in terms of the military security of the state. It embraced roles such as the use of satellites for military reconnaissance, for communications and early warning of ballistic missile attack, and for targeting of weapon systems as well as issue of the threats to strategic stability posed by ballistic missile defenses and potential antisatellite weapon systems. There was also an important focus on the contribution made by reconnaissance satellites used for arms control verification. Toward the end of the Cold War, the capabilities of reconnaissance and navigation

**Table 2.1** Intentional threats to satellite systems

| Type of threat | Vulnerable satellite systems component |
|---|---|
| *Ground based* | |
| Physical destruction | Ground stations; communication networks |
| Sabotage | Links |
| *Space based (antisatellite)* | |
| Interceptors (space mines and space-to-space missiles) | Satellites |
| Directed energy weapon (e.g., laser, electromagnetic pulses) | Satellites and control center/data links |
| *Interference and content oriented* | |
| Cyber attacks (malicious software, denial of service, spoofing, data interception) | All system and communication networks |
| Jamming | All systems |

satellites advanced to the point where the significance of satellites as “force multipliers,” capable of directly influencing events on the battlefield, began to affect discussions of space security, particularly in terms of increasing the likelihood of ASAT operations in wartime.

From a military perspective, “space security” encompasses several themes. These include the use of space assets to enhance the effectiveness of terrestrial armed forces (force multipliers), “benign” space militarization in the form of early warning of missile attack and arms control verification, threats to satellites posed by terrestrial and space-based military capabilities, and threats to the space environment posed by military activities. In the longer term, it might eventually also include possibilities of space-based weapons, for either ASAT operations in orbit, space interception of warheads as part of a ballistic missile defense network, or even attacks against ground or air targets from space (Table 2.1).

In this regard, the implications of “space security” differ for those states that rely significantly on space assets for the effectiveness of their military capabilities and those which do not. For those without major military space reliance, the protection of space *itself* as an environment free from debris and electronic interference is the key to space security. Diplomatic efforts to preserve space as a weapon-free environment will also be prominent in order to protect the capabilities represented by commercial- and development-related satellites. For the military space powers however, and particularly the United States, these kinds of requirement are supplemented by the need to pursue the acquisition of policies and capabilities that promise military space security in peace- and wartime and the ability to use satellites as force multipliers which significantly enhance the effectiveness of terrestrial military capabilities but which thereby may threaten the benign physical environment sought by other space powers.

For those states reliant on military space assets, space needs to be a secure environment in which force multiplier military operations can take place. It needs to be populated by satellites and vehicles that are themselves reasonably secure against accidental damage or intentional attack, and in the event of war against an opponent similarly equipped, the capacity to neutralize or eliminate the adversary's military space capabilities needs to exist in order to both deny military advantages to the adversary and protect one's own.

This in turn has many implications. Satellites are systems composed of four distinct elements. These are the orbiting satellite itself, the ground stations that control it, and the uplink and downlink communication channels that enable it to carry out its appropriate functions. If the satellite system is to be made secure, all four dimensions must be protected. Moreover, although popular discussions of "war in space" and antisatellite warfare tend to focus on the use of space-based weapons to destroy orbiting satellites, the reality is that the orbiting vehicle is by far the most difficult part of the satellite system to attack and would, if destroyed by an attack while in orbit, produce highly undesirable side effects in the form of debris fields in orbit. It is much more likely therefore that the "terrestrial" elements of the satellite system would be under the greatest threat in wartime. Nevertheless, although the potential dangers created by the debris issue encourage resort to nondestructive ASAT techniques, the use of destructive kinetic or directed energy weapons against satellites cannot be ruled out as a possibility in wartime should the nondestructive techniques fail to achieve their objectives.

Therefore, in order to use space effectively, ground-based facilities are crucial, as is the atmospheric airspace through which electronic signals travel to and from satellites in orbit. This is not purely a military issue but is also true of human spaceflight, for example, where again the launch sites and ground control are crucial and where the flight to space and return to Earth are highly dangerous and security-specific activities. Thus, the term "space security" embraces more than just activities occurring beyond Earth's atmosphere. In relation to military space security, for example, the existence of reliable launch and ground control facilities and the capacity to reconstitute such capabilities quickly if they should be lost in wartime are important questions, as are the issues of ensuring the continued effectiveness of communications with orbiting platforms. This again means that the secure "space" environment must embrace the physical as well as electromagnetic lines of communication linking the terrestrial and orbiting elements of the space systems.

In an effort to make space a more stable and secure environment for both military and civilian purposes, a number of states have proposed the creation of an arms control regime for space. In attempting to develop such a regime to reduce threats to space systems, definitions are once again important. There need to be reasonably clear definitions of what constitutes a "weapon" in this context and also what constitutes "in space." The Union of Concerned Scientists has offered a series of definitions that attempt to address these issues. A space weapon is defined as "any device or component of a system designed to inflict physical harm through deposition of mass and/or energy on any other object." "Weapons in space" are defined as "those that travel on a complete or partial orbit, or are placed at a stable point beyond Earth orbit." In addition "a component that is part of a system not exclusively based in space, such as a relay for a ground-based laser, would be considered a space-based weapon" (United Nations Institute for Disarmament Research 2004, pp. 45–46).

These definitions are extremely helpful, but it is very difficult for the states and other actors involved in space security to agree on definitions in this area. The Union of Concerned Scientists definition of "space weapon," for example, assumes a destructive attack on the satellite, but a satellite that experiences electronic jamming would not be covered by this definition, because it would not have suffered physical harm. Yet it would still have been attacked and would no longer be able to perform its proper function.

From a strict point of view, any technology that can interfere with a satellite is an ASAT and should therefore be banned or regulated. However, to implement such a policy comprehensively would mean banning a huge range of legitimate space activities, such as launching robotic resupply spacecraft to the International Space Station. There are also arguments for making a distinction between destructive and nondestructive ASAT techniques and concentrating efforts at control on the destructive approaches because they produce long-lasting environmental side effects, whereas nondestructive techniques do not. Producing an arms control agreement in this area is a question of balance and compromise, but it is made much harder by the difficulties in clearly and collectively defining many of the key terms. This is a major obstacle to the achievement of an international treaty that could regulate such technologies. Indeed, it may never be possible to effectively define a space weapon, and the international community may have to abandon attempts to achieve a precise definition if a treaty is to be achieved.

Such an arms control treaty, if it were to be achieved, would essentially be a peacetime confidence-building measure. There needs to be a distinction between the meaning of space security in peacetime and space security considerations in wartime. If the analogy of aviation security is taken, it would embrace governance issues to avoid aircraft collisions, concerns about terrorism, efforts to ensure that technology standards are maintained to ensure passenger safety, and so on. But should the airspace of a particular country or countries become a war zone, there is no assumption that it would be "business as usual"; rather many peacetime activities such as civil aircraft flight would be suspended for the duration of the hostilities but be resumed thereafter. Similarly, the creation of space security is designed to create a stable regime for a variety of peacetime activities, but in wartime, at least war involving two large industrialized states with major space dependence, many of these would have to be suspended. A specific problem for space, unlike airspace, is that certain potential military actions in wartime, by generating clouds of debris, might leave the low Earth orbit environment so damaged that it might be impossible to use it for *any* purposes for decades after hostilities ended. Indeed, Philip Baines of the Canadian Department of Foreign Affairs has declared that government war gaming of scenarios where weapons have been used to attack other satellites to achieve national space security has always produced the same outcome, "the loss of LEO for the next 1,000 years" (Baines 2010, p. 16 (the claim is repeated on p. 17)).

The definition of space security needs to be broader than simply the military dimension, because otherwise it would become synonymous with other concepts such as “space power.” David Lupton gave the first formal definition of space power, describing it as “the ability of a nation to exploit the space environment in pursuit of national goals and purposes and includes the entire astronautical capabilities of the nation” (Lupton 1988, p. 7). A later definition by Hyatt et al. termed it “the ability of a state or non-state actor to achieve its goals and objectives in the presence of other actors on the world stage through control and exploitation of the space environment” (Hyatt et al. 1995, p. 6). The parallels seem even more marked when discussions of space power go on to analyze its national, military, civil, and commercial space components; their space-based, ground-based, and launch systems; and the use of terminology such as “environmentally influenced characteristics.” All these elements have their counterparts in the concept of space security.

These definitions have obvious similarities to the definitions of space security given below. But space power is not the same thing as space security. The former is a national security concept and relates to national security objectives. The latter is an international security concept and relates to effective international governance of the space environment. It encompasses crucial military issues but is a broader concept than military security.

Nor are problems with defining a distinct meaning for space security limited to the military domain. The emerging difficulties of safely managing orbital space have led to the development of the idea of “space traffic management.” The International Academy of Astronautics published a study of the concept in 2006 which defined space traffic management as “the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical and radio-frequency interference” (Constant-Jorgensen et al. 2006). Most of this statement would work just as well as a definition of space security.

The traditional boundaries between the military space sector and other sectors have increasingly broken down since the end of the Cold War. The clear dividing lines between, for example, military and commercial spaces are no longer absolute. One of the striking features of the American military dominance in the 1991 and 2003 Gulf Wars was that there was a massive reliance on civilian satellite systems to accomplish military goals. In 1991, for example, the US military supplemented its military reconnaissance satellites by using the US LANDSAT and French SPOT civilian systems. In addition, over 80 % of all US military communications during the conflict were delivered via civilian communication satellites. At the same time, the Navstar GPS positioning satellite system, designed as a military satellite, has been made available to civilian users and has become an indispensible tool for an astonishing variety of purposes in countries around the world. A large and increasing number of states have deployed dual-purpose satellites which can perform both civilian and military tasks. In addition, many initiatives that would enhance the civilian aspects of space security, such as a “rules of the road” agreement or improved capabilities for tracking orbital debris, would still have military implications, since they would make it easier for military analysts to distinguish between hostile actions and satellite failures caused by environmental factors.

All this might suggest that the distinction between military and civilian spaces should now be dismissed. However, for analytical purposes, the distinction remains important. While it is crucial to be aware of the overlaps between the military and other space sectors and of the policy implications of some of these interconnections, nevertheless, there are key issues that fall distinctively into one sector or another and need to be defined and analyzed on that basis.

## 2.4 Environmental Space Security

In contemporary studies of space security, it is increasingly common to delineate two distinct subareas. The first is the traditional military domain, both in terms of efforts to make national military space assets more secure and in relation to efforts to delay or prevent the deployment of weapons in space. The second category may be termed environmental space security and involves issues relating to the crowding of Earth orbit, such as the orbital debris problem and the problems of interference in satellite communication frequencies, as well as the disputes over access to orbital slots in geostationary Earth orbit.

The greatly increased use of near-Earth orbital space necessitates seeing space itself as an endangered environment, where human activities in the form of debris created by redundant or damaged spacecraft pose threats to the long-term sustainability of crucial orbital regions. Seeing orbital and interplanetary space as producers of both security and insecurity lends itself also to understanding remote but potentially significant dangers such as asteroid impact as a space security issue and problems such as satellite operation in the Van Allen belts as a space environmental security issue. It is necessary therefore to look at “space security” in terms of these distinct, but interconnected dimensions.

As a geographical region, space is clearly capable of being conceptualized as an example of “environmental security.” The United States has recognized this by emphasizing the concept of “space sustainability,” that is, the ability of the space environment to continue to be a place where space activities can be successfully conducted. Significantly, the United States believes that the sustainability of the space environment is vital to the US national interests, (National space policy of the United States 2010, p. 3) a crucial statement, since the United States has historically used the phrase, “vital to US national interests,” to indicate that this is something the United States considers to be so important that it would be prepared to go to war in order to defend it. While linking the concept of space sustainability to national security may not be politically helpful, the concept has the potential to enrich understandings of space security. It fits easily with a broad “human security” approach to space, it draws attention to the crucial issue of the long-term management and use of space, and it links the military, scientific, and economic dimensions of space security.

**Table 2.2** Unintentional threats to satellite systems

| Type of threat | Vulnerable satellite system component |
|---|---|
| *Ground based* | |
| Natural occurrences (including earthquakes and floods; adverse temperature environments) | Ground stations; control centers and data links |
| Power outage | |
| *Space based* | |
| Space environment (solar, cosmic radiation; temperature variation) | Satellites; control centers and data links |
| Space objects (including debris) | |
| *Interference based* | |
| Solar activity; atmospheric and solar disturbances | Satellites; control centers and data links |
| Unintentional human interference (caused by terrestrial and space-based wireless systems) | |

Source: US General Accounting Office

Although space is effectively infinite in geographical terms, in the current era, the areas of space used by humans are fairly limited and overwhelmingly dominated by activities in Earth orbit. With more states and companies launching satellites, the environment is becoming increasingly crowded, particularly at 36,000 km in the geosynchronous Earth orbit (GEO). Because of this, orbital overcrowding can exist, and thus, despite its size, space is for practical human purposes, a “limited resource” and, surprisingly, a resource that can be “damaged” (at least temporarily), by its users, in the sense of debris or frequency interference preventing a satellite from operating normally. Orbital slots in the most popular orbits and optimum frequencies for satellite communication are in relatively limited supply. There are therefore resource issues in effect.

In 2009, the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) agreed to include the long-term sustainability of outer space activities as a new item in its mandate. It established four working groups to cover the sustainability issue. These addressed:

1. Sustainable space utilization supporting sustainable development on Earth
2. Space debris, space operations, and tools to support collaborative space situational awareness
3. Space weather
4. Regulatory regimes and guidance for actors in the space arena (Table 2.2)

The most dramatic space environment issue concerns the fact that the effective use of orbits, particularly low Earth orbit (LEO), is threatened by the buildup of orbital debris. In other satellite operations, fluctuations in “space weather events” such as solar flares are also an issue. Interference with satellite communication frequencies overlaps with military space security, because such interference can be deliberate or accidental.

There are around 650 operational satellites in orbit, but there are nearly 12,000 pieces of space debris 10 cm or larger being tracked by NASA. In addition, NASA estimates that there are probably several hundred thousand pieces of debris that are too small to currently track but which would still be able to cause damage to satellites and spacecraft. Most of this debris consists of the abandoned upper stages of launch rockets or satellites that have ceased functioning. NASA defines space debris as "any man-made object in orbit about the Earth which no longer serves a useful purpose." Because of the extremely high relative impact velocities that objects in orbit possess, even comparatively small pieces have very high impact velocities and can have catastrophic effects if they collide with a space vehicle. Like space weather, they can degrade the operation of satellites in a variety of ways depending on the size of the debris. A piece as small as a micron can still do damage to a satellites-sensitive optical systems, while a fragment which is still only a centimeter in size can seriously damage or even completely destroy a satellite. They also pose serious risks to astronauts operating in orbit, particularly when engaged in an extravehicular activity. In addition to these threats, it is possible that a war in space, by creating a dense debris field in LEO, might also cause sufficiently large amounts of sunlight to reflect off the fragments so that there would be serious light pollution, even a permanent "lingering twilight" around the Earth instead of true darkness.

In a broad definition of space security, embracing environmental concerns, space weather is significant. Space weather, charged particles and magnetic fields ejected from the sun, can cause significant disruptions to satellites, ranging from temporary interference with onboard systems to complete failure, particularly for satellites operating in geostationary Earth orbit. Solar flares deliver x-rays, ultraviolet rays, and gamma radiation which can interfere with radar and telecommunications and produce radio interference. The sun also discharges solar proton events which have been shown to have a wide variety of impacts on human security including "satellite disorientation, spacecraft electronics damage, spacecraft solar panel degradation, extreme radiation hazard to astronauts, launch payload failure, high altitude aircraft radiation, shortwave radio fades, ozone layer depletion, cardiac arrest, dementia and cancer" (Marusek 2007, p. 3). Space storms can also heat up the Earth's atmosphere, causing it to expand and increase the drag on satellites operating in low orbits, thereby shortening their lifetime. Major space weather episodes can also pump up the radiation in the Van Allen belts by as much as 10,000 times their normal levels, damaging electronic components on board satellites. In 2011, the UK added space weather to its national risk register.

## 2.5 Human Security and Space

Security has been defined as "the assurance people have that they will continue to enjoy those things that are most important to their survival and well-being" (Soroos 1997, p. 236). For something to be defined as a "security" issue, there needs to be a sense in which it poses a real threat to human well-being or survival. If a "security" issue requires that there is such an "existential" threat, can the environmental issues in Earth orbit be seen as security issues? Is interference with the optimum efficiency of a frequency, or damage to an inanimate piece of metal, an "existential threat" in any meaningful sense?

In fact such issues can be seen as security questions and in a very real way. Satellites are used for an enormous range of purposes, and many of them have the potential to produce large-scale loss of life if the satellite capability is lost. A 2011 report by the British Royal Academy of Engineering noted that global navigation systems alone are crucial for the following functions for UK users: "transport, agriculture, fisheries, law enforcement, highways management, services for vulnerable people, energy production and management, surveying, dredging, health services, financial services, information services, cartography, safety monitoring, scientific and environmental studies, search and rescue, telecommunications, tracking vehicles and valuable or hazardous cargoes and quantum cryptography" (Royal Academy of Engineering 2011, p. 13).

Threats to orbiting satellites, whether from military or environmental sources, are crucially important precisely because satellites have come to play such a fundamental part in providing security to human beings on Earth. Because of the expansion in the general meaning of security that has taken place in recent decades, satellites are clearly relevant to providing these kinds of security. Although discussions of space security have historically tended to be dominated by debates about "space weaponization," the reality is that most states and commercial entities exploit space for a vast range of civil purposes, so that space has now become crucial for human prosperity and security on Earth.

The impact of satellite capabilities on human security can be seen in a wide range of areas. One such is disaster management, which has been reflected in the signing of the "Tampere Convention on the Provision of Telecommunication Resources for Disaster Mitigation and Relief Operations" of 1998 and the "Charter on Cooperation to Achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters" of 2000. Satellites were used to coordinate disaster relief operations after the Haiti earthquake of 2010 and the Fukushima nuclear accident in 2011.

But the scope of satellite contributions to terrestrial security goes well beyond disaster response and now embraces almost all aspects of human security. Examples include educational programs, including school and college use, but also programs for education of remote rural populations on issues such as crop management and birth control. Meteorology is used by most countries, but in those subject to particularly severe weather such as tropical storms, they serve a crucial purpose in allowing shipping and coastal communities to prepare for the effects of life-threatening weather systems. Satellites play an increasingly important role in the continuation of the green revolution in developing countries, allowing monitoring of environmental damage, from both natural and human causes. Soil temperature and moisture content of soils are monitored from space to allow the choice of optimal planting times; crops are also monitored for the presence of disease infestation and threats such as drought, floods, and migrating pests such as locust swarms. Monitoring of snow lines in areas such as the Himalayas allows early warning of flooding in India and Bangladesh. Satellites are used to detect underground water supplies and mineral resources, to track shoals of fish, and to plan irrigation systems. India uses satellites to assess the quality of land being considered for building or road development, so that areas of high agricultural productivity will not be lost, and uses them to direct its fishing fleets to minimize their time at sea. In January 2012, satellite imagery was used by the United Nations to monitor the conduct of the referendum in southern Sudan on separation and independence from Sudan. On a broader scale, satellite imagery was crucial in detecting the expansion of the holes in the ozone layer and in monitoring the increase in global temperatures and associated effects such as loss of polar ice cover, which confirmed the dangers of global warming. In these and countless other ways, satellites now directly contribute to human security.

This is important in defining space security in two ways. It means that the military dimension of space security is critical not just in terms of the impact such conflict might have on terrestrial warfare, or even of the damage to the space environment itself, but also that the huge knock-on effect on human security must be considered if these satellite capabilities were lost. Secondly, it means that the terrestrial dimension of human security needs to be considered as one of the components of space security in its own right, thereby highlighting the enormous stake that humanity has in the continued secure exploitation of space.

## 2.6 Risks Involved in Expanding the Definition of Space Security

The advantage of expanding conceptions of space security is that it moves certain issues significantly higher up the political agenda and it also allows the difficulties faced by groups and even individuals to be seen as security concerns, rather than simply the protection of the state. Using the term security, rather than “threat” or “problem,” is politically significant. For governments, the word “security” has real political power. An issue that is seen as a security problem moves to the top of the political agenda, jumping ahead of mere “problems” in the queue for resources and political attention. Security also has advantages over alternative terms such as “threat” because it can be related to the broad spectrum of human security.

At the same time, it is also important to note that the move to broader understandings of security, to “securitize” new issue areas, has been controversial and many of the reservations expressed in these debates can be held to apply also in the case of space security. If more and more issues are brought into the realm of “security,” there is logically a point at which the term is so all encompassing that in practice it means very little and becomes simply another word for “dangers” or “risks,” and eventually the concept would have no coherent meaning and therefore no value as a guide to policy.

One attempt to avoid this problem has been to try to limit the definition of the term “security” to those issues that pose “existential threats” and limit it further to dangers that emanate from the decisions of human beings, rather than to include problems that emerge simply from the workings of the natural environment, such as volcanic eruptions, or, in the case of space, the effects of solar storms or naturally created debris fields (Buzan et al. 1998, p. 21). However, in the case of space, this approach has limited appeal. Space is a particularly hostile environment in which to operate. A definition of space security which did not reflect the very real dangers and difficulties originating in the natural environment would be unrealistic and unhelpful. In addition, there are issue areas where the human and naturally produced dangers intersect. For example, a key aspect of efforts to limit the dangers of antisatellite systems is being able to distinguish between satellite failures that are the result of human aggression and those which have been produced by the effects of the natural environment or, for that matter, simple technological malfunction. A robust definition of space security therefore needs to be able to encompass a very wide range of factors.

There are other risks involved in expanding the term security beyond the military dimension. Attaching the word “security” to an issue makes it more politically important and gives it a degree of priority in terms of government attention and resources, which can be seen as a positive development. But historically, because “security” was traditionally linked to military threats, security has been seen as being related to survival, to being about threats to the existence of a state or group of people. As a result, the use of extraordinary measures to deal with the threat was legitimate, including the use of force. The danger involved in extending the term “security issue” to new areas such as the orbital debris problem therefore is that it will end up being subsumed within a military mind-set, which is inappropriate and which would make the problem harder, not easier, to deal with. Because military security sees “us” as threatened by “them,” for example, the debris issue might come to be seen as a problem created by particular states which should be punished in some way, rather than as an environmental issue for all space-going states that requires cooperative measures to successfully address. Using the term “security” runs the risk that the emphasis will always be on the possibility of violent conflict, rather than human insecurity, and issues would therefore tend to be understood as military disputes rather than foreign policy concerns, which would make them harder to resolve. From this perspective, “de-securitizing” some space issues might well be preferable, since this would make it easier to produce mutually acceptable solutions using cooperative diplomacy. It might still be better to speak of threats or dangers in some contexts, rather than security issues. Expanding the definition of space security needs to be done with an awareness of the issues at stake and the problems involved in so doing.

## 2.7 Conclusion

Defining space security is difficult, but not impossible, and it is certainly necessary. The definition needs to be broad, so that it encompass human and environmental as well as military dimensions. It should embrace not only the security of man-made objects and humans in space, but also the terrestrial dimensions of launch-sites, ground stations and communications links. In addition it should include the security of terrestrial objects and persons against attacks from space, including the human security implications of such attacks. Thus it should embrace, but expand the definitions given earlier in this chapter. A modified working definition would be secure and sustainable access to, and use of, outer space in accordance with international laws and treaties, free from the threat of disruption, as well as security of terrestrial human and state security from threats emanating from space.

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# Obstacles to International Space Governance

# 3

Eligar Sadeh

## Contents

### Abstract

International space governance is essential to realize benefits that space assets provide. The overall goal of space governance is to ensure the sustainable uses of space for security, economic, civil, and environmental ends. Concomitantly, there are obstacles to space governance that must be overcome to optimize the realization of this goal. Two key obstacles are indentified and discussed in this chapter. One obstacle relates to attaining collective action in relation to the commons of space. A second obstacle concerns that of strategic stability in the space domain and how best to advance strategic assurance for sustainable uses of space as a shared strategic goal.

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## 3.1 Introduction

This chapter examines obstacles to international space governance. The more that different states, nongovernmental actors, and commercial players depend on space, the more that laws, policies, rules, norms, best practices, and compliance mechanisms to maximize benefits related to uses of space are needed. Benefits can be realized through governance that secures the space domain for peaceful and sustainable uses; protects space assets from threats that include orbital debris, risks from irresponsible behavior, interference and possible attacks, and space weather; and derives value from space assets for security, economic, civil, and environmental applications and value-added services (Sadeh 2013). These ends are framed by different models for space governance. There are two models identified and discussed herein in the context of obstacles to international space governance. This includes global commons and strategic stability (Sadeh 2010).

The model of global commons relates to governance based on voluntary actions, self-restraint, and self-regulation. This, by and large, depicts the current environment of governance. One key obstacle to space governance highlighted by this model is that incentives to trade off national interests and gains in return for collective action and international benefits are generally not present (Gallagher 2013). Further, any degree of collective action is difficult to sustain in the context of competitive security relationships among major spacefaring states and the increasing number and variety of space actors worldwide, many of which are commercial and non-state actors. All this makes space not only more competitive but more congested as well.

The model of strategic stability is governance anchored on shared strategic goals, such as the realization of the various security, commercial, civil, and environmental benefits that can be gained from space. A central obstacle to overcome lies in advancing credible strategic assurance. Although strategic assurance includes deterrence and protection related to space assets, it is also directed at international space governance to enable sustainable uses of space, freedom of access and use of space, and freedom from threats to space assets (Rendleman 2013). Without assurance, sustainable use of space is undermined and space assets can be contested.

## 3.2 Global Commons: Obstacle of Collective Action

The space domain is considered a global commons in that the domain lies beyond the sovereign jurisdiction of states, is governed by international law, and is available for all actors to access and use. In the case of the space, this includes free space itself, orbital paths around the Earth, and celestial bodies. These commons are in joint supply and use, as well as nationally non-appropriable. Joint supply and use signifies equal potential availability to the commons by all states. Non-appropriability specifies that states cannot extend their jurisdiction and sovereignty to the commons. It is impossible to exclude states from sharing in the benefits of the commons or from suffering the consequences caused by damage to the commons. Joint supply and non-appropriability constitute free access and free use and, in the case of the commons of space, freedom of action in space (Sadeh 2011).

A commons that is unregulated (i.e., no governance) can result in a "tragedy of the commons" (Hardin 1968). This situation is rooted, for instance, in rational self-interested state behavior regarding the commons. The tragedy is a function of damage to the commons caused by free access and free use, like the proliferation of orbital debris, the possibility of interference and attacks on space assets, and harmful contamination of space and celestial bodies. To mitigate these tragedies, collective action is necessary. As such, the commons of space posits a collective action problem as to how to formulate and implement space governance to restrain and regulate at some level free access and free use.

For example, the most recent (2010) *National Security Strategy* of the United States puts forward a goal of creating a "just and sustainable international order that can foster collective action to confront common challenges." Such an order can be fostered through global governance. Further, the strategy calls for building a "rules-based international system that can advance our own interests by serving mutual interests." The range of how these rules are manifested spans from formal treaties and agreements to rule-making by institutional arrangements that are voluntary.

### 3.2.1 Outer Space Treaty Regime

The fact that space is legally defined as a commons underlies freedom of action there and highlights the collective action problem. The free use of and free access to the space environment for peaceful purposes that include civil, commercial, and military uses is supported by the Outer Space Treaty (OST) regime. This regime provides the basic legal framework for governing space as a global commons and serves as the basis for addressing obstacles to collective action and benefits.

Nevertheless, the OST regime falls short in several ways in overcoming collective action obstacles to space governance. One, the regime does not provide detailed rules or an authoritative process for deciding what types of space activities are inconsistent with its key principles, when the use of space might damage common interests, and how benefits from space activities should be shared (Gallagher 2013). In fact, the regime tends to reflect the tragedy of the commons since self-interested users, like spacefaring states, maximize their gains from using space without regard for any negative effects on other users and on the space domain itself.

Averting tragedy in space involves either a central governing authority to make rules, verify compliance, and respond to violations, or less formal means of self-restraint and self-regulation to ensure sustainability of the domain. With respect to the latter, given that a central governing authority does not exist and is not likely, customary law, international norms, codes of conduct on behavior and use, transparency and confidence-building measures, and diplomacy can all help to overcome collective action obstacles to space governance. These means, however, depend on users placing a high value on collective benefits and, thus, a high degree of self-restraint and self-regulation regarding irresponsible behavior that can undermine space governance.

Despite positive prospects at collective action within the context of the OST regime, as well as a willingness for self-restraint and self-regulation, the advent of congested space and irresponsible uses of space raise the risk that space users will cause problems for each other, whether purposeful or not. Two important examples deal with minimizing and mitigating orbital debris that can damage space assets and coordinating the use of Earth observation missions and data. In these cases, spacefaring actors prefer self-governance and international coordination to maintain political and operational flexibility and to ensure freedom of action in space.

### 3.2.2 Orbital Debris

There are approximately 16,700 debris objects in orbit large enough to be tracked as of April 2013, and an unknown number of smaller debris that are either invisible to sensors or that cannot be tracked, but nonetheless, are potentially dangerous. Included are fragmentation debris (satellite breakup debris and anomalous event debris), spacecraft, mission-related debris (objects dispensed, separated, or released as part of a planned mission), and rocket bodies in orbit around Earth. With cascading effects (debris colliding with debris in a cycle of debris creation), some orbits will become more dangerous, and others may no longer be useable in the future. Major spacefaring states are aware of the problem, and they have encouraged voluntary debris mitigation guidelines. These guidelines have had some positive impact as to collective action.

With no collective action (no active mitigation measures are implemented), fragmentation debris together with cascading effects shifts linear debris growth patterns to exponential ones. To compound the problem, irresponsible space behavior, such as the Chinese antisatellite (ASAT) weapon test conducted in January 2007, which destroyed a Chinese satellite, and orbital conjunctions, like the February 2009 collision between an operational Iridium satellite and a dysfunctional Russian Cosmos communications satellite, resulted in thousands of additional debris fragments that threaten space assets to this day.

Though the majority of operational and active satellites are vulnerable to orbital debris, impacts that cause physical harm are not common place as of yet. Albeit, two notable cases of impact include the Iridium-Cosmos case mentioned above and one additional notable case in 1996 that involved a French satellite and an *Ariane* upper rocket body. Modeling of the debris threat has as well shown low risk of debris impacts on large spacecraft. Moreover, improved surveillance and modeling of conjunctions allow for maneuvers of larger spacecraft.

This does not undercut the argument that debris is a collective action problem. The failure to prevent debris proliferation in low Earth orbit (LEO) could severely restrict uses of the more commonly used orbital paths and orbital inclinations. Hence, mitigation is needed in LEO. To add, the debris issue in geostationary orbit (GEO) is potentially serious and costly due to the relative permanency of orbit (no passive debris removal through orbital decay), the narrow orbital band that exists at GEO, and the high economic values of GEO orbital slot allocations with lucrative footprints on Earth for telecommunication services.

The very functional necessity of addressing the debris issue advances collective action. This is no better illustrated than by the Inter-Agency Space Debris Coordination Committee (IADC). The IADC includes the national space agencies of the United States, Italy, France, China, Canada, Germany, European Space Agency, India, Japan, Ukraine, Russia, and the United Kingdom. The approach taken by the IADC encompasses alternatives ranging from the promulgation of voluntary actions that states can take to reduce debris to the establishment of guidelines and standards to govern launch vehicles and their payloads. Technical approaches to reduce debris include passivation, parking orbits, and hardware designs.

Spacefaring states at the national level have also made progress on debris mitigation. Beginning in the 1990s, the United States, the European Space Agency (ESA), and other spacefaring countries developed national guidelines to reduce the production of debris during launch and with on-orbit operations, to move GEO satellites into graveyard orbits at the end of their service life, and to put defunct LEO satellites into decay orbits. Following such best practices involves additional costs, complicates operations, and shortens the useful life of satellites. Therefore, national requirements, compliance, and enforcement levels vary.

To harmonize and strengthen national practices, the United Nations Committee on Peaceful Uses of Outer Space (UNCOPOUS) asked the IADC to develop international guidelines for orbital debris mitigation that were adopted by UNCOPUOS in 2007 and endorsed by the United Nations (UN) General Assembly in 2008. The guidelines, known as the *Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space*, are an achievement for space governance given the pledge not to deliberately create debris. In a 2009 UNCOPUOS report, it was concluded that "…implementation of the voluntary guidelines for the mitigation of space debris at the national level would increase mutual understanding on acceptable activities in space, thus enhancing stability in space and decreasing the likelihood of friction and conflict."

Of note is that these are voluntary guidelines for the mitigation of space debris reflected in existing best practices. Albeit the debris mitigation guidelines invite states to implement through relevant national mechanisms, the vague language of the guidelines allows each space user to decide how many design and operational changes are reasonable to limit debris production, minimize breakup potential, reduce the probability of accidental collision, and avoid intentional destruction in ways that produce long-lived debris. More specifically, the *Space Debris Mitigation Guidelines* of the UN limit debris released during normal operations; minimize the potential for breakups during operational phases; limit the probability of accidental collisions in orbit; avoid intentional destruction and other harmful activities; minimize potential for post-mission breakups resulting from stored energy; limit the long-term presence of spacecraft and launch vehicle orbital stages in LEO; and limit the long-term interference of spacecraft and launch vehicle orbital stages with GEO. Since compliance is voluntary, the guidelines remain weak. For instance, only 11 of 21 GEO spacecraft that ended their service life in 2009 were disposed of properly (Choc and Jehn 2010).

Nonetheless, the formulation of international guidelines for orbital debris is an important step to more formalized collective action on the debris issue. This is important as the OST regime deals with space objects that are registered as a legal remedy for liability issues. Hence, questions remain as to how one would determine a legal definition of debris, how registration of debris is to be dealt with, and whose debris is causing harm, especially if that harm is in the space environment and under the fault-based liability regime per the *Convention on Registration of Objects Launched into Outer Space*.

Although there is collective action progress with regard to debris mitigation illustrated by the IADC, national efforts, and the UN guidelines, long-term sustainability in managing space on the basis of the global commons model has shortcomings as the policy preference for voluntary actions, self-restraint, and self-regulation over more formal, fully developed, and binding arrangements will tend to lead to self-interest to triumph over collective action when two are in conflict. Collective action is impeded because spacefaring states resist doing what would make sense for the long-term sustainable management of space as a global commons, especially if they believe that access to and use of space can be controlled for gains relative to potential competitors (Gallagher 2013). The United States, for example, invokes “space as a global commons” as a way to assert their own right to use space without interference from others, without acknowledging that other users have similar rights and that all rights in space confer corresponding responsibilities.

### 3.2.3 Earth Observations

The case of Earth observations concerns as well collective action issues and obstacles therein. International cooperation pertaining to Earth observations by satellites directed at assessing global environmental change is represented by a collective action milieu. The goal of this collaborative milieu is to advance scientific knowledge of the Earth’s environment to understand and predict human-induced and natural global environmental change phenomena.

One of the crucial factors in this case of international cooperation is the ability of transnational networks of Earth system scientists to work together in analyzing global change data and to translate those analyses into policy-relevant actions. This involves both coordinating missions and addressing data policy issues dealing with conditions and access to data, data pricing, periods of exclusive data use, and data archiving. Cooperation aims to meet scientific and operational needs as well as satisfy data access and data exchange requirements for all parties as effectively as possible.

Political considerations concerned with data policy, national sovereignty, and national security issues influence collective action in the area of Earth observations (Sadeh 2011). The existence of disparate and incompatible data access policies among various satellite types and programs is reinforced in the retention of data by its producers, the requirement of licenses to use data, and the pricing of data above marginal costs of fulfilling user requirements. Harmonizing policies over these issues is a collective action hurdle to surmount (Sadeh 2005).

The Committee on Earth Observation Satellites (CEOS) plays a central role in advancing harmonization. The primary objectives of CEOS are to optimize the benefits of Earth observations through cooperation of its members in mission planning and in developing compatible data products, formats, services, applications, and policies; aid both its members and the international user community through international coordination of Earth observation activities; and exchange technical information to encourage compatibility among the different Earth observation systems (Committee on Earth Observations Satellites 1997). CEOS data exchange principles have been adopted for global environmental change research use and for operational public benefit use with the agreement to make data available to each member in these user categories with no period of exclusive use and on a nondiscriminatory basis. There is a commitment to provide data at the lowest possible cost to researchers and to harmonize and preserve all data needed for long-term global change research and monitoring.

To further advance coordination among national Earth observing systems, the Group of Eight leading industrialized countries (G8) during a 2003 meeting supported additional collaboration. The G8 recommendation led to the establishment of the Group on Earth Observations. Today, this group includes eighty governments and the European Commission as well as additional intergovernmental, international, and regional organizations. Even though participation and funding are voluntary, the Group on Earth Observations advances collaboration in systems architecture and interoperability, data management, and capacity building associated with Earth observing systems.

On one hand, there exists collective action to avoid duplication, coordinate coverage, and to take other steps to synchronize operations, as advanced by CEOS and the Group on Earth Observations. Yet, the national sovereignty of the natural resources being observed – air quality and land use, for example – can conflict with coordination. Since remote sensing data undercuts the ability of the state to control both the creation and the application of knowledge, there are concerns with sovereignty and national security. One problem in using space-derived Earth observations deals with platforms owned by one country to assess the natural resources of other countries, particularly when the resources have large economic value (Macauley 2013). With regard to civil systems (excludes military and commercial systems), UN space law principles of remote sensing allow observations of other countries within the context of cooperation (United Nations 1986). To illustrate, the principles require that space-collected observations of sovereign resources of the sensed country are provided to the sensed country.

As soon as the primary data and the processed data concerning the territory under its jurisdiction are produced, the sensed state shall have access to them on a nondiscriminatory basis and on reasonable cost terms. The sensed state shall also have access to the available analyzed information concerning the territory under its jurisdiction in the possession of any state participating in remote sensing activities on the same basis and terms, particular regard being given to the needs and interests of the developing countries (United Nations 1986, Principle XII).

Sovereignty issues are also a concern in the case of commercial remote sensing systems. Proliferation of high-resolution imagery with intelligence value posits national security repercussions for several reasons. First, increased certainty of an adversary's capabilities may negate the foundation for deterrence. Second, the possibility exists of misinterpretation and international deception leading to shifts in balances of power and conflict. And third, asymmetrical access to satellite imagery and processing capabilities could provide substantial advantages for some states over their neighbors – developed states over developing ones with destabilizing influences on the international system.

As a result, the state is forced into "sovereignty bargains" that reiterates collective action. To illustrate, the US military may have no choice but to accept certain sovereignty bargains, which implies constraints and limits on freedom of action. An important issue that emerges from this conclusion has to do with what set of constraints are acceptable. For example, is the body of international space law and other international agreements that limit military uses of space as explained next in this chapter a sufficient set of constraints, or will sovereignty bargains engender other constraints, like voluntary codes of conduct on behavior in space?

## 3.3 Strategic Stability: Obstacle of Strategic Assurance

The strategic stability model relates to collective action on the basis of shared strategic goals. With this model, the obstacle to space governance lies in credible strategic assurance. A space assurance strategy depends on several elements that must all be viewed as shared strategic goals: lawful means of space protection, deterrence to protect space assets, and global engagement (Rendleman 2013).

### 3.3.1 Lawful Means of Space Protection

Realizing the protection of space assets as a shared strategic goal begins with lawful means of space protection. The existing system of treaties, customary law, the laws of armed conflict, and other legal principles restrict conflict and threats to space assets. Under treaty and customary law, the right to respond to attacks against space systems, and to perform deterrence or protection activities, is limited. The use of force is allowed only in cases of self-defense or in accord with authorization of the UN Security Council to maintain international peace and security (Blount 2008).

Space warfare activities are also constrained by the laws of armed conflict (Blount 2008). These laws are a body of international law that establishes boundaries on the use of force during armed conflicts through application of principles and rules. The principles and rules combine elements of treaty and customary law at the international and national levels. As it concerns space warfare, this body of law sets limits on when, and to what degree, force may be used for targeting. Also, self-defense acts that seek to, or actually damage, the space environment are unlawful under the *Environmental Modification Convention* and the OST regime. Together with obligations to avoid and minimize the creation of orbital debris, there exist legal constraints on taking action to destroy or damage any space system. More specifically, the potential for resulting debris as a result of such action violates the duty to avoid the harmful contamination of space (Frey 2010) as well as the UN and IADC guidelines on debris explained earlier.

More broadly, international law places limits on military uses of space as one key facet of strategic stability. These laws play a role in maintaining space as a commons (Sadeh 2011). The relevant laws and constraints are highlighted below.

- *Limited Test Ban Treaty* and *Comprehensive Test Ban Treaty* (supplanted the limited one), which prohibit the conduct of nuclear weapons tests in outer space. Neither the United States nor China ratified the *Comprehensive Test Ban Treaty*. Nevertheless, the treaty has near universal adherence and, as such, establishes a norm to follow even for those states that have not ratified the agreement. In general, multilateral treaties and customs adopted by a large number of subjects of international law are considered universal.
- Outer Space Treaty, which prohibits the deployment of weapons of mass destruction in space and the stationing of military bases in space or on celestial bodies and calls for "peaceful uses" of space that is understood as no aggressive uses of space that harm or interfere with another state's access and use of space. OST also prohibits harmful contamination of the space environment.
- *Anti-Ballistic Missile (ABM) Treaty* between the United States and Russia, which many legal experts viewed as preventing a weaponization of space since it prohibited the deployment of space-based ABM systems that do include most types of kinetic-kill and kinetic energy (KE) space weapons that could be developed and deployed. Even though the United States withdrew from this treaty in 2002 rendering it null and void, it was effective in advancing an international norm of restraint on the deployment of space weapons.
- *Convention on Registration of Objects Launched into Outer Space*, which requires states to register objects launched into space with the UN. This obligation helps to enable space situational awareness (SSA) and supports the view that such awareness should be shared and transparent to the extent possible without harming national security.
- *Environmental Modification Convention*, which prohibits military use of environmental modification techniques in space.
- *Moon Agreement*, which sought to demilitarize the Moon and celestial bodies, and declare the Moon the "common heritage of mankind." The Moon Agreement's declaration of the Moon as the common heritage of mankind differs from

the "province of all mankind" of the OST in that it establishes the natural resources of the Moon as a common property resource for all mankind. If this is accepted, the Moon Agreement requires that lunar resources, once exploitation commences, be shared equitably through an international arrangement, such as an international regime. The *Moon Agreement* has little legal validity since no spacefaring powers have ratified it. However, such an arrangement based on the common heritage of mankind principle is part of the UN-based *Law of the Sea* as it applies to the exploitation of the deep seabed and the associated regime of governance in the International Seabed Authority.

### 3.3.2 Deterrence to Protect Space Assets

One way to prevent threats to space assets is to persuade potential aggressors that any benefits from interference are outweighed by expected costs. This is the overall basis for deterrence. The concept of deterrence can be applied to think about how to overcome the obstacle of protection of space assets from threats as a shared strategic goal. Deterrence on the basis of international norms and entanglement is useful in this regard (Harrison et al. 2009).

International norms include treaty law and customary law, arms control treaties, test bans, formal and informal weapons moratoria, confidence-building measures, and "rules of the road." The question of concern for deterrence is whether these mechanisms have deterrent effects that are shared and mutual among those that abide by the norms.

The OST regime represents a universal set of international norms that are based on treaties and customary law. In relation to deterrence, the regime bans the stationing of nuclear, but not conventional, weapons in orbit and military activity on the lunar surface, stating that the Moon and other celestial bodies must be used for peaceful purposes. There is no evidence that any limits of OST have been violated or that nuclear weapons, more specifically, have been deployed, or are likely to be deployed, outside the atmosphere. All this represents a shared notion of deterrence based on self-restraint.

Arms control agreements also curtail aggressive actions in space. For example, the key space powers, namely, Russia and the United States, tolerated each other's use of space in stabilizing ways, such as in the case of space-based surveillance for arms control purposes. Further, they both practiced reciprocal restraint regarding activities that destabilize the sustainable uses of space, like attacks on space-based surveillance systems. The provisions of the strategic and intermediate range nuclear arms limitation agreements ban interference with national technical means of verification that is enabled by surveillance satellites, and both Russia and the United States extended the noninterference ban to the entire military space constellation of the other. This has brought a level of stability and predictability to the strategic balance in space. In addition, neither space power pursued dedicated and operational ASAT options nor did they put conventional weapons in space that could be used for preemptive attacks on space assets. All this demonstrates a high degree of mutual self-restraint even though both powers engaged in some exploratory ASAT work as a hedge and both had other latent retaliatory options if their satellites were attacked.

Verifiable testing bans can also be effective, as the *Partial Test Ban Treaty* and the *Comprehensive Test Ban Treaty* have shown. Arms control agreements that verifiably limit testing can strengthen deterrence by decreasing an adversary's confidence of success, enhance warning of a change in the strategic environment, and mitigate an ASAT arms race. Further, an adversary is unlikely to launch a preemptive attack with weapons that have never been tested under realistic conditions. Such tests in space, particularly KE ASATs, would be observed, and for policy and operational reasons, KE ASATs make little national sense given debris issues. The United States, for instance, has renounced for now the option of deploying and testing ASATs. The preference is on diplomacy to sway a would-be space attacker. This approach outweighs the use of offensive counterspace options.

Despite norms, law, and self-restraint with ASAT deployment and use, the United States and other space powers are still concerned about attacks on their space assets. Russia and China also worry that US space and missile defense advantages will cause the United States to be less cautious in regional crises that affect their interests (Arbatov 2010; Li Bin and Nie Hongzhen 2008). To draw global attention to these potentially destabilizing issues, Russia and China became vocal proponents for negotiating on "Prevention of an Arms Race in Outer Space" (PAROS) in the Conference on Disarmament (CD). This agenda item has gained near universal support in annual UN General Assembly resolutions, but the United States has consistently objected on the basis that it is neither possible to define the nature of a space-based weapon nor develop an effectively verifiable agreement for banning either space-based weapons or terrestrial-based antisatellite systems (House 2008).

In 2008, Russia and China introduced a draft treaty – *Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects* (PPWT) – which extends the OST's ban on weapons of mass destruction in space to prohibit placing all types of orbiting weapons, including all types of force against space assets. However, the draft treaty also outlaws US deployment of space-based missile defense interceptors, but not debris-generating ASAT tests or the proliferation of ASAT capabilities. Given US objections to PAROS and PPWT as a result of this, general concerns with other arms controls issues, the lack of legally binding provisions, and issues regarding enforcement and compliance of any potential agreement, the CD is at a standstill. Moreover, the CD is hobbled by the fact that consensus is required, even for procedural matters – a fact that is aggravated by the linkages in the long-standing agenda between nuclear disarmament, space security, and conventional disarmament issues, which each have different priority for different states (Hitchens 2010).

Informal international norms can also be effective. For example, China followed its ASAT test in 2007 with informal assurances that such tests would not be repeated. The United States did not intervene diplomatically to stop the test, protesting only the resulting debris field. In this case, the United States was abiding by its own strictures about freedom of action in space. Still, the political outcome of the Chinese test confirmed the existence of a norm of self-restraint sufficient to persuade the Chinese not to pursue this sort of testing in the future.

Deterrence by entanglement is the notion that state actors will be deterred from attacking others because of interdependence (Harrison et al. 2009). The degree of globalized interdependence that characterizes the modern world is without precedent and ties together spacefaring states in a system of international trade and finance. Satellites are one vital communication node in this trade and finance system.

Any threats or generalized breakdowns in the system of trade and finance could not easily be repaired. For example, the destruction of satellite communications would destroy global wealth. Reconstruction of the financial system without space assets to restore confidence in reliable trade and financial transactions would be formidable and time-consuming tasks. Even an attack on a small proportion of the commercial satellite infrastructure would have consequences for the wealth of all globalized economies. It is difficult to envision any national gains by interference or an attack on these space assets that would offset potential economic losses.

Entanglement extends beyond trade and financial transactions that rely on satellite communications to all the various applications of position, navigation, and timing (PNT) satellite data. The United States, for example, ended the encoding of PNT data in 2000, which degraded the signal provided by its Global Positioning Systems (GPS) constellation that was originally built for military purposes. Since then, the precise GPS signal is available globally as a public utility. PNT data is now built into electric and transportation grids worldwide, among a vast number of other systems and devices, creating a degree of technological dependence and entanglement. The GPS case demonstrates deterrence by entanglement; when a system proliferates globally for civil and commercial uses, attempts to deny military functions would result in global repercussions.

Telecommunication satellite services also highlight deterrence by entanglement. Communication systems originally built for civilian purposes followed by commercial uses now carry as well 80 % of all military telecommunications bandwidth for the United States. Hostile action to disrupt military communications over commercial satellite systems would draw into the crisis numerous other governments whose own military, civilian, and commercial traffic is carried by the same satellites. Because the use of commercial satellite-based transponders is market based and constantly shifting, an aggressor's planning would be complicated by the inability to know or effectively predict which other friendly, neutral, or potentially adversarial states would be affected at any given moment by interference with a particular commercial satellite. Further, global markets for satellite services imply that broad economic consequences will take place with any attack on commercial satellites. This web of mutual dependence and shared consequence acts as a deterrent regarding threats to these space assets (Harrison et al. 2009).

An additional dimension of entanglement is tied to international cooperation associated with multinational operations. This is an important component of an effective global engagement strategy to assure access to space capabilities for a state and for its allies and partners (Rendleman 2013). The United States engages in a wide range of such activities as a matter of national policy. The 2010 National Space Policy, 2011 National Security Space Strategy, and other US national security strategy documents, like the National Defense Strategy, increasingly emphasize international cooperation to achieve important national interests.

The United States must strengthen and expand alliances and partnerships. The United States alliance system has been a cornerstone of peace and security for more than a generation and remains the key to our success, contributing significantly to achieving all US objectives. Allies often possess capabilities, skills, and knowledge we cannot duplicate. We should not limit ourselves to the relationships of the past. We must broaden our ideas to include partnerships for new situations or circumstances, calling on moderate voices in troubled regions and unexpected partners. In some cases, we may develop arrangements limited to specific objectives or goals, or even of limited duration. Although these arrangements will vary according to mutual interests, they should be built on respect, reciprocity, and transparency.

"International cooperation can complicate adversary plans and intentions, and creates more stakeholders in the orderly use of the space environment. Deterrence can be greatly reinforced if an adversary has to contend not only with a U.S. response, but with an international response also" (Sheldon 2008). Multinational engagement supports deterrence by denying national benefits of an attack. Engagement also spreads the risk of attacks against satellite system by infusing redundancy into the systems with multiple platforms and by sharing capabilities on allied or friendly space systems.

### 3.3.3 Global Engagement

The approach to protect the space domain is rooted in reconciling national interests with collective action on the basis of international governance. Diplomacy and international engagement help to realize this end. To illustrate, customary and treaty-based restrictions of international law afford all members of the global space community credible confidence that they can all have assured access to space. By and large, there are relatively few restrictions on the use of space for military or other purposes within the framework of peaceful and nonaggressive uses as highlighted earlier. With minimal legal restrictions, governance is needed by all spacefaring states and actors to operate safely and securely in the domain. The system of treaties, conventions, and agreements help regularize space activities and, as such, help protect the capabilities of the systems that have been, or are about to be, placed on orbit. The positive attributes of this system of law, as well as shortcomings and obstacles to overcome, were discussed earlier. Global engagement as used here focuses on ways to augment existing space law. This includes capacity building, confidence-building measures, and codes of conduct.

In the area of capacity building, much of the work of UNCOPUOS is dedicated to this end, which includes information sharing and education. Of note is the work of the UN Program on Space Application that is aimed at building capacity through international workshops, training courses, and pilot projects on issues, like satellite navigation systems. UNCOPUOS also oversees implementation of the recommendations emanating from the UNISPACE international conferences (UN Conference on the Exploration and Peaceful Uses of Outer Space) with the goal of identifying and taking actions designed "to maximize opportunities for human development through the use of space science and technology and their applications." Similarly, UNCOPUOS follows the UN Platform for Space-based Information for Disaster Management (UN-SPIDER). This program, which started in 2006, seeks "to provide universal access to all countries and all relevant international and regional organizations to all types of space-based information and services relevant to disaster management to support the full disaster management cycle."

Despite funding issues for these capacity building programs, it should be clear to states that such activities are necessary for ensuring the safety and security of space assets; newcomers to the arena require assistance not only to most efficiently benefit from the use of space but also to avoid harmful impact on others (Hitchens 2010). More specifically, the adoption of best practices is required by all spacefaring states for any notion of effective governance. The most recent success related to this was the development of a set of voluntary guidelines for space debris mitigation discussed earlier. Also, space powers can work to build more capable systems, while sharing the costs and benefits with others, such that all users would have strong incentives to protect the systems and to respond against threats.

Specific conference-building measures are essential to global engagement and the international governance of space. Confidence-building measures advance opportunities for transparency between potential adversaries as well as improve dialogue that can prevent any future dispute from evolving into armed conflict. Measures can involve data sharing, business investments, education, and information campaigns performed at global, national, and local levels (Rendleman 2013). In the case of the United States, proposals for cooperative steps to improve strategic stability in space have eschewed binding legal limits in favor of dialogue and confidence-building measures. This is broadly aimed at a strategic dialogue among spacefaring powers to provide mutual reassurance in the space domain.

The United States and Europe support transparency measures as a way forward for confidence building – to test intentions and to dispel misperceptions that could generate unwarranted suspicions, arms buildups, and fears of attack (Gallagher 2013). Other space powers, like Russia and China, have a less favorable view of transparency. While Russia and China have agreed to extensive verification when necessary for confidence in compliance with legally binding arms control treaties that serve their security interests, they have usually rejected requests to provide sensitive information without a legal agreement regulating its provision and use. That reluctance is partly cultural, but it is also strategic; the weaker player, relative to the United States, has greater reason to worry about sharing information that might reveal their vulnerabilities, especially in the absence of any constraints on the stronger player's capabilities or actions. Nevertheless, Russia has for several years sponsored UN General Assembly resolutions calling upon states to propose confidence-building and transparency measures directed to the prevention of an arms race in outer space.

The development of norms through codes of conduct for the use of space can lay the foundation for more robust efforts to address threats to space assets and to avoid conflict. A code of conduct entails a body of voluntary rules for best practices, procedures, and behavior in space activities. The European Union (EU) has put forward a voluntary code – *Code of Conduct for Outer Space Activities* – to promote responsible uses of the space commons. The code reiterates principles that spacefaring states have endorsed in the OST regime and through the adoption of best practices. At the same time, it does not add greater clarity or put forward new mechanisms to decide how those principles should be applied.

One key behavioral guideline in the code deals with debris – to avoid actions that generate space debris that damage or destroy space assets. Such a collective action norm inhibits behavior driven by national interests. Yet, multilateral adoption of the code, particularly by relevant space powers, remains an obstacle to overcome. The United States has decided not to endorse or sign the European code, although the United States decided in 2012 to join with the EU and others to develop a new agreement on an international code of conduct for space activities. Such a code of conduct "will help maintain the long-term sustainability, safety, stability, and security of space by establishing guidelines for the responsible use of space."

## 3.4 Conclusions

International governance is inextricably tied to shared strategic goals among spacefaring states. In regard to space, these goals are to secure the space domain for peaceful use, to protect space assets from all threats, and to derive maximum value from the use of space. Global governance, among other factors, entails treaties, norms, intergovernmental organizations for rule-making, international agreement, monitoring capabilities, and joint decision-making. The case for governance is one to promote the security, prosperity, and values of spacefaring states through multilateral cooperation to safeguard and optimize the use of space as a global commons (Gallagher 2013).

National interests are served by rules to provide reassurance that weaker players will not exploit vulnerabilities of space powers, that developing spacefaring states will behave responsibly, and that rising space powers will want to join the status quo of space as a global commons. Mutual interests are served when rule-based orders attract multilateral support and sustained compliance. This implies that the United States, for example, must also provide credible reassurance that it will follow the rules itself, that it will not use its military and technological advantages in ways that harm others, and that it will support international governance arrangements and institutions, which give other states a meaningful voice in decisions that affect global security and prosperity.

As discussed in this chapter, the OST regime lacks formal institutional mechanisms to promote international governance for the peaceful uses of space, to monitor compliance, and to make collective decisions about the application of space rules. Albeit there are international bodies that discuss, negotiate, and implement different aspects of space governance, like the IADC related to orbital debris, and there is a role for international norms and deterrence – they are all ultimately based on a model of self-restraint and self-regulation. Ideally, approaching space governance more formally in law and more comprehensively can overcome key obstacles – collective action and strategic assurance – to more effective space governance.

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# Security Cooperation in Space and International Relations Theory

# 4

Max M. Mutschler

## Contents

**Abstract**

This chapter resorts to international relations theory to explain various patterns of security cooperation in space. There have been several attempts for security cooperation but the success was limited. While neorealism explains this lack of cooperation with the difficulties to achieve balanced gains, for neoinstitutionalism, the central hurdle is the establishment of effective rules and mechanisms to verify the compliance of states. For a constructivist/liberal account, the main problem lies in the dominant beliefs about the value of unilateral space policies. Taken together these three theoretical perspectives provide a comprehensive account of security cooperation in space.

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## 4.1 Introduction

This chapter[1] deals with the issue of security cooperation in space from the perspective of international relations theory. Security cooperation means "collaboration between conflictuous parties" (Müller 2002, p. 370). This is a rather broad definition, which comprises such different phenomena as the relations of previous enemies in the framework of a postwar settlement, arms control and nonproliferation, or a system of collective security, as it is institutionalized in the Charter of the United Nations (UN) and embodied in the UN Security Council. "Security cooperation implies relying for an essential objective, national survival, on the resources, intentions, and activities of other states, which is hard to reconcile with the notion of security being guaranteed exclusively by self-help" (Müller 2002, p. 370). Usually, the puzzle for theories is to explain the existence of security cooperation. However, it is also important to find explanations for the lack of cooperation in the security field. This holds true even more when it comes to space security, a policy field still dominated by national approaches.

In general, space-faring countries seek to develop and make use of space capabilities in order to increase their respective national power. Still, the history of international space politics has seen several attempts for security cooperation in space. The next section provides the reader with a short history of security cooperation in space. We will see that in most cases, the success of security cooperation was limited.

How can we explain these limits – but also the slight progress – of security cooperation in space? Having elaborated on the history of security in space, the following section recurs on three different strands of international relations theory to answer this question. All three theories – neorealism, neoinstitutionalism, and constructivism/liberalism – provide different pieces of the puzzle and should be treated as complimentary rather than exclusive.

## 4.2 A Short History of Security Cooperation in Space

### 4.2.1 Superpower Security Cooperation During the Cold War

While the Soviet Union was first to put a satellite into orbit by launching Sputnik in 1957, the United States pioneered the use of satellites for the purpose of reconnaissance. The superpowers realized the immense value of the use of space for military purposes and sought to agree on certain regulations for the use of space. The UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) was tasked with the elaboration of comprehensive legal principles for the peaceful use of outer space. The most important outcome of the work of UNCOPUOS was the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (in short: Outer Space

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[1] This chapter is partly based on Max M. Mutschler (2013).

Treaty, OST) of 27 January 1967, which had been unanimously adopted as a UN General Assembly resolution in December 1966.

The OST, until today, is the basic legal framework governing the use of outer space. It states the fundamental principle that space is free from "national appropriation by claim of sovereignty" (art. II). Exploration and use of outer space shall, according to article I of the OST, be "the province of all mankind." In the preamble, the OST proclaims the use of space "for peaceful purpose." Whereas a definition of "peaceful" is missing in the text, it was well understood that the parties regarded "peaceful" to be defined according to the original US perspective as "nonaggressive." Article III of the treaty commits parties to "carry on activities in the exploration and use of outer space, including the Moon and other celestial bodies, in accordance with international law, including the Charter of the United Nations." This means that one has to take a look at the UN Charter for a more detailed definition of "peaceful purpose." Article 2(4) of the charter obliges states to refrain from the use of force. However, article 51 of the UN Charter clearly proclaims the right of self-defense. Again, this allows the interpretation of "peaceful" as "nonaggressive" and implicitly legitimizes the military use of space for such uses as reconnaissance.

The Outer Space Treaty does not ban the deployment of conventional weapons in space, and the phrasing discussed above allows the interpretation that it is legal to deploy conventional weapons in space, if the deployment is intended not for aggressive use but for self-defense only (Schrogl 2005, pp. 69–70, 73). Wolter (2006, pp. 1–23) argues that this does not mean that the United States and the Soviet Union wanted to make the deployment of space weapons lawful. On the contrary, he argues that the superpowers by their insistence that outer space activities shall serve the benefit of all mankind put the OST in the context of disarmament and the avoidance of an arms race in space, because the legal status of outer space was oriented from the beginning to the interest of mankind as a whole.

What is explicitly banned is the deployment of weapons of mass destruction in space. In article IV of the OST, the parties agree "not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner." This clause was the reaction of the superpowers to the technological possibility that the other side might attempt to place nuclear weapons in orbit in order to threaten its opponent from space. With the improvement of missile technology and the existence of intercontinental ballistic missiles (ICBMs), however, the military advantage of such weapons would have been limited to a psychological factor. Consequently, the banning of such weapons by the OST was rather uncontroversial.

In sum, the Outer Space Treaty codified the doctrine, first developed by the United States but later accepted also by the Soviet Union, that the use of satellites for military but nonaggressive purposes was legitimate. However, with the exception of weapons of mass destruction, the two superpowers could not bring themselves to declare space a sanctuary free from the arms dynamic. This was certainly due to the fact that both of them had started with research on anti-satellite (ASAT) weapons. Already in the early

1960s, the United States tested its first ASAT missiles. The results, however, were not encouraging and the project was stopped in 1963 (Webb 2009, p. 28). The Soviet Union, on its part, began testing a co-orbital anti-satellite weapon in 1968. A satellite packed with explosives was placed in an orbit close to a target satellite and was then steered into it. The first test series ended in 1971 and demonstrated that the Soviet Union possessed the capability to place these so-called "hunter-killer" satellites into space that could destroy other satellites.

Between 1978 and 1979 three rounds of negotiations on ASAT arms control were held. The US negotiators initially wanted a comprehensive ban on dedicated ASATs, but this would have meant for the Soviets to dismantle their existing capacities, which they were unwilling to do. The Soviet negotiators, in turn, sought to limit the US space shuttle program, arguing that the shuttle might be used to interfere with Soviet satellites and hence could be considered an ASAT weapon. Limitations on its shuttle program, on the other hand, were unacceptable for the United States, and no agreement was reached (Wertheimer 1987; Weber and Drell 1988).

Reagan's idea of a Strategic Defense Initiative (SDI), the development of a comprehensive capability for ballistic missile defense, would have included the deployment of active defense weapons in space, using "exotic" technologies such as lasers and particle beams. This brought the program the nickname "Star Wars." A wide range of key technologies for kinetic as well as directed energy weapons were studied (Mowthorpe 2004, pp. 17–19). In addition, the United States under Reagan started to think again about ASAT weapons and developed a system where a high-flying F-15 aircraft was armed with heat-seeking missiles that could target satellites. This system was successfully tested in 1984 (Sheehan 2007, p. 97, 103). It is not surprising that this general posture of the Reagan administration did not improve the outlook of space weapons arms control.

In August 1981, the Soviet Union had proposed a draft treaty on the Prohibition of the Stationing of Weapons of Any Kind in Outer Space to the 36th Session of the UN General Assembly. The central obligations of this proposal read:

> States Parties undertake not to place in orbit around the earth objects carrying weapons of any kind, install such weapons on celestial bodies, or station such weapons in outer space in any other manner, including on reusable manned space vehicles [. . .]. (Art. 1)
>
> Each State Party undertakes not to destroy, damage, disturb the normal functioning or change the flight trajectory of space objects of other States Parities, if such objects were placed in orbit in strict accordance with article 1, paragraph 1 of this treaty. (Art. 3)

This proposal did not go much further than the Soviet position in bilateral talks with the United States under Carter – although the space shuttle was no longer problematic as such, but only as a weapons platform. However, given the fact that this would not have meant dismantling the Soviet ASAT system, the United States dismissed the proposal. In 1983, the Soviet Union was ready for more concessions and declared a unilateral moratorium on putting weapons into space. In addition, it put forward an amended version of its draft treaty, which included provisions that would have meant the dismantlement of the existing Soviet ASAT systems. However, the US reaction was again negative. Verification or rather its limits were now the main argument of the Reagan administration to dismiss the proposal.

Many observers interpreted this insistence on “waterproof” verification as an excuse for not starting serious negotiations (Stares 1985, pp. 231–233; Weber and Drell 1988, pp. 415–416). Weber and Drell (1988, p. 416) speak of “a missed opportunity for revitalizing limited cooperation in space.”

### 4.2.2 Multilateral Attempts for Arms Control

Security cooperation in space was an issue in multilateral fora, too. Since 1981, the UN General Assembly annually reaffirms a call to undertake the necessary steps for the prevention of an arms race in space. In 1985 the issue was finally referred to the Conference of Disarmament (CD) in Geneva, and the Ad Hoc Committee on the Prevention of an Arms Race in Outer Space (PAROS) was set up. Right from the start, the big split in the committee was between a majority of states that wanted to start actual negotiations on the banning of space weapons on the one side and the United States that rejected such proposals on the other side. The large majority of states held the opinion that the legal standards set up by the development of space law so far (especially the OST) could not by themselves prevent an arms race in space and should therefore be amended. The United States, in contrast, insisted upon its position that there was no danger of an arms race in outer space and therefore new treaty stipulations on the use of space were not needed. Thus over the first 10 years of its existence, PAROS was not able to agree on a negotiating mandate. Even worse, in 1995 the mandate of the committee (which was to be renewed annually) could no longer be extended, since the PAROS issue was linked with the establishment of other ad hoc committees, for example, on the negotiation on a Fissile Material Cut-off Treaty (FMCT), and no agreement on the general work program of the CD could be found. As a result, no substantial talks on the question of PAROS have taken place in the CD since 1995 (Wolter 2006).

Under the administration of Bush senior and particularly in light of the breakup of the Soviet empire, the whole SDI program was reevaluated and finally reoriented toward the protection from more limited ballistic missile attacks. Little attention was paid to space security cooperation during the 1990s. This changed after 2001. Moltz (2011) characterizes the time after 2001 as a period that fundamentally challenged space security. According to him, this is basically the result of the change of administration, which, together with the new president George W. Bush, brought into office a group of neoconservative thinkers that perceived US space systems as vulnerable and concluded that the weaponization of space could be the cure to this problem. The appointment of Donald Rumsfeld as Secretary of Defense already signaled a support for policies to weaponize space. Until this appointment, Rumsfeld had chaired the Commission to Assess United States National Security Space Management and Organization, the so-called Space Commission, which had been established by Congress in 1999 and issued its report in January 2001 (Commission to Assess United States National Security Space Management and Organization 2001). This report regarded the US interests in space as a top priority of national security policy. It warned of what was called a “Space Pearl Harbor,” an attack on

US space systems. In order to avoid such an attack, the United States, the report argued, would have to "develop the means both to deter and to defend against hostile acts in and from space" (Commission to Assess United States National Security Space Management and Organization 2001, p. 10). The US National Space Policy (White House 2006), released in October 2006, reserved the United States the right to deny the use of space to adversaries. In consequence, research programs that could produce technologies in order to execute space control received increased funding.

The claim for space control by the United States worried other space-faring nations. Russia and China in particular did not like to see their access to space being conditional upon the goodwill of the United States. In September 2003, in the hope to stop the US drive toward the deployment of space weapons, the Russian President Vladimir Putin pledged at the United Nations that Russia would follow a unilateral no-first-deployment policy on offensive space weapons. The other side of the coin is the threat that Russia would not accept the deployment of space weapons by another state without reaction. China already went one step further in showing that it would not be willing to accept the US dominance of space. In January 2007 China successfully tested an ASAT weapon. This was the first ASAT test in over 20 years. A ground-launched ballistic missile destroyed one of China's own weather satellites, producing a huge amount of space debris. There are hints at previous Chinese tests in 2005 and 2006, where no satellites were destroyed (Webb 2009, p. 30).

However, China and Russia were particularly active in the PAROS debate at the Conference on Disarmament, too. They issued several working papers to the CD and in February 2008 presented a revised version of their earlier ideas by proposing a draft Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force Against Outer Space Objects (PPWT) (Conference on Disarmament 2008a). The central obligation as stated in article II of the draft treaty reads as follows:

> The States Parties undertake not to place in orbit around the Earth any objects carrying any kinds of weapons, not to install such weapons on celestial bodies and not to place such weapons in outer space in any other manner; not to resort to the threat or use of force against outer space objects; and not to assist or induce other States, groups of States or international organizations to participate in activities prohibited by this treaty.

The proposal of China and Russia was openly criticized by the United States, in particular for the fact that it bans the deployment of weapons in space, but not earth-based ASAT weapons. Another point of critique was the lack of concrete provisions on the verification of such a treaty (Conference on Disarmament 2008b). The change of administration in the United States in 2009 did not bring about a change of this criticism by the United States. Considering the fact that the proposed PPWT would limit eventual US plans for highly sophisticated space weapons such as space-based missile defense, while it would place no limits on the development of earth-based ASAT weapons as the one tested by China in 2007, makes one understand the US criticism.

### 4.2.3 A Code of Conduct for Space?

The deadlock of the negotiations within the Conference on Disarmament on formal arms control in space led to a search for alternatives. Proposals were made that do not suggest formal agreements to ban certain weapons technologies, but instead aim to set standards of behavior in space, so-called rules of the road, as they were already discussed as an alternative to arms control between the United States and the Soviet Union in the late 1970s. Rather than in the form of a formal treaty, these standards of appropriate behavior could take the form of a code of conduct, which would only be "politically binding." A model for such a code of conduct has been proposed by the Henry L. Stimson Center (The Henry L. Stimson Center 2004, 2007). An important element of such a code would be a ban on the so-called harmful interference with satellites. Such "harmful interference" includes the destruction or damaging of satellites as well as any temporary interference with the normal operation of the spacecraft. A code of conduct that includes a ban on the described methods of harmful interference has the advantage that states would not need to agree on a definition of space weapons and on modes to verify their nonexistence (Black 2008).

The idea of a code of conduct was taken up by the European Union in December 2008 when the Council of the European Union approved a Draft Code of Conduct For Outer Space Activities (Council of the European Union 2008) (hereafter simply referred to as Code of Conduct, or CoC) (Rathgeber et al. 2009; Dickow 2009). The EU discussed this draft with countries outside Europe and, based on this feedback, issued revised versions of the CoC in September 2010 and June 2012 (the draft versions of the CoC can be retrieved from http://www.eeas.europa.eu/non-proliferation-and-disarmament/outer-space-activities/, 22/06/2013). At the center of the Code of Conduct, as proposed by the EU, is the endorsement of the responsibility of states to avoid harmful interference in space and to refrain from activities which would generate long-lived space debris. In addition, the CoC codifies particular confidence-building measures regarding the notification of outer space activities, the registration of space objects, information-sharing on space activities, and consultation. It stipulates biennial meetings of subscribing states, as well as the establishment of a central point of contact and an outer space activities database (for a critical discussion of the CoC, in particular its shortcomings in comparison with arms control, see Mutschler 2010, pp. 16–18; Mutschler and Venet 2012).

The United States did not endorse the EU proposal for a CoC. However, it declared its willingness to seek to negotiate an International Code of Conduct for Outer Space Activities, together with the EU and other nations. Several other states are more critical toward a CoC. While Russia and China, in light of their proposal in the CD, still prefer a solution that is closer to the concept of formal arms control, other states criticize that they were not involved in the discussion process early enough.

An early critique combined with an alternative proposal for space security cooperation was formulated in June 2009, when Canada submitted a working paper to the CD. This working paper pointed at the central problem of a rules-of-the-road approach: “[. . .] that it allows for a proliferation path for anti-satellite weapons [. . .]” (Conference on Disarmament 2009, p. 3). Instead, it would be better for space security if states agreed “[. . .] not [to] test or use a weapon against any satellite so as to damage or destroy it” (Conference on Disarmament 2009, p. 3). In addition, Canada suggested two more rules – not to place weapons in outer space and not to test or use any satellite itself as a weapon to inflict damage or destruction on any other object. The question whether these three rules take the form of a formal treaty or are given as pledges by the states remains open. Canada points out that these rules do not need a complicated definition of space weapons, since the prohibition focuses on the effects of the weapons, such as damaging or destroying satellites. Furthermore, Canada makes the point that the test ban would only refer to testing activities that can be monitored by national or multinational technical means. In sum, what Canada suggested with its working paper is a comprehensive but pragmatic space weapons ban that is based on a “general purpose” criterion.

In sum, it seems fair to say that the history of security cooperation in space has seen quite a number of attempts to come to formal or informal agreements between space-faring countries. After the agreement on several general principles and norms enshrined by the Outer Space Treaty, most of these attempts – were it superpower arms control negotiations or the search for solutions in multilateral fora – collapsed or are currently blocked. The EU initiative for a Code of Conduct has at least created a new focal point for the discussion; whether the initiative will be successful remains to be seen. The next section reviews theories of international relations in order to find explanations for this state of affairs.

## 4.3 Explaining Security Cooperation in Space

### 4.3.1 A Neorealist Account

Neorealism, which is based on the seminal work of Kenneth N. Waltz (1959, 1979), established a systemic theory of international relations, which draws conclusions about the behavior of the units of the system –states – from the structure of the system. The defining feature of this structure is anarchy. The anarchical structure produces a self-help system in which every state is responsible for its own security, simply because there is no institution at the international level and thus above the state that could ensure security. The internal characteristics of the units, for example, the respective political systems of the states, are treated as irrelevant for the explanation of international politics; states are seen as unitary actors that differ only with regard to their “capabilities” – their power, usually measured in terms of military and economic indicators. As “like units,” all states share the central goal of survival, which in an anarchical environment means that states are compelled to maximize their security. Power and the power position of a state are of crucial importance in this regard. From the perspective of neorealism, states are extremely sensitive toward power and carefully evaluate their actions in light of their consequences for their power position. This has important implications for the realist position on international cooperation.

According to neorealist accounts, the unequal distribution of gains is a central obstacle to international cooperation. In an international system characterized by anarchy, states cannot tolerate relative losses in comparison with their rivals (Waltz 1979; Grieco 1988, 1990). This holds true in particular with regard to arms control agreements that seek to limit or ban whole categories of weapons. If there are different levels of technological development with regard to the weapon technology, the states with lesser capability would naturally gain more from an arms control agreement than those states that have the technological edge. This is the case with regard to space weapon technology, too.

There is a wide consensus in the literature that the United States is unequivocally ahead of other countries in the field of space technology. Other space-faring countries such as China have the capability to develop and procure comparatively simple ASAT weapons but they cannot match the technological base of the United States. Taking this into account, it makes perfect sense for Russia and China to make a proposal like the PPWT, which would ban the deployment of sophisticated, space-based weapons while allowing the development of ground-based ASAT technology. It certainly also makes sense for the United States to oppose such an agreement (Hansel 2010, p. 97). We have already seen similar patterns of behavior during the Cold War when the Soviet Union proposed arms control measures that would have left existing Soviet ASAT capabilities untouched while eventually placing limits on the space shuttle program of the United States.

While neorealism can explain the lack of formal security cooperation, it has more difficulties explaining the fact that we have seen a more tacit form of security cooperation in space between the two superpowers of the Cold War. While both superpowers tested ASAT weapons, they refrained from full-scale development and deployment of such weapons. Neorealism can argue that this is the result of a rough balance of power between the US and the Soviet Union. This would also be an elegant explanation for the United States' renewed efforts to develop space weapon technology after the Cold War, when US power was no longer held in check by a peer competitor. However, this explanation is not without problems. Already in the 1970s, the United States had the technological edge with regard to space technology. Why didn't the United States cash in this technological advantage to maximize its power? There is another problem for the neorealist account. One might argue that a ban on space weapons that applies to comparatively simple weapons (e.g., ground-launched ASATs) as well as highly sophisticated ones (e.g., space-based lasers) would offer balanced gains from security cooperation in space. Such a package deal would improve the security of all space-faring states without discriminating against anyone. Advanced *and* less advanced space powers would face limitations on their weapon options. As the United States depends heavily on their space systems for military purposes like navigation, it should have a special interest in keeping space safe.

### 4.3.2 A Neoinstitutionalist Account

Neoinstitutionalists like Robert Keohane (1984, 1989) are much more optimistic with regard to international cooperation. While they acknowledge the anarchical structure of the international system, they argue that there is a high degree of interdependence between states which creates strong incentives to cooperate in order to maximize their utility. In an interdependent world, states have many mutual interests. Zero-sum games are the exception, not the rule. However, these mutual interests do not automatically lead to international cooperation. There can be problems that inhibit collective action. One collective action problem is central to most neoinstitutionalist accounts: the fear of cheating. How can states ensure that other parties stick to the agreement and will not cheat? In cases of security cooperation, the fear of cheating is usually particularly pronounced.

One solution to this problem which is pointed out in the literature on international cooperation is the establishment of an international regime that sets up rules that define cheating and help to monitor compliance (Keohane 1984, 1989). States do not know whether they can trust their partners and whether they can expect them to stick to their commitments. At this point, regimes enter the stage. They reduce the risks of cooperation through various mechanisms: They define what cooperation means in the first place. This allows states to recognize defection when they see it. In addition, regimes can include monitoring agreements. These agreements ensure that states share information on the compliance of cooperation partners. This lowers the risks of cooperation by increasing the probability for the would-be cheater to be identified as such, thereby reducing the expected utility of cheating. Therefore, monitoring agreements included in regimes help states to trust in mutual commitments.

Neoinstitutionalists would argue, with regard to space security cooperation, that the high degree of interdependence in space provides a good basis for cooperation. Satellites provide important services for modern societies: in particular in the fields of communication, earth observation, and navigation. These services have become important to many civilian sectors, such as transportation, finance, or science; but they also play a crucial role for modern militaries (see ▶ Chaps 30, "Space Applications and Supporting Services for Security and Defense: An Introduction," ▶ 31, "Earth Observation for Defense," ▶ 32, "Earth Observation for Security and Dual Use," ▶ 33, "Telecommunications for Defense," ▶ 34, "Telecommunications for Security and Dual Use," ▶ 35, "Positioning, Navigation and Timing for Security and Defense," and ▶ 36, "Eavesdropping" of Part 3 of this book). Space-faring countries should therefore be interested in the sustainable use of outer space. An arms race in space that is accompanied by further ASAT tests has the potential to endanger space sustainability. The ASAT tests of the Soviet Union and the United States during the time of the Cold War already left hundreds of pieces of traceable debris in space, of which some are still out there today. The Chinese ASAT test in January 2007 generated more than 2,000 pieces of wreckage larger than 10 cm that will remain in space for decades and endanger the orbits of many satellites (Neuneck 2008, p. 136).

The interdependence stems from the fact that no state is in a position to guarantee space sustainability alone. If one state decides to develop ASAT weapons, it can be expected that other states will follow. International cooperation is needed to avoid an arms race. As states are interested in securing the benefits from the sustainable use of space, states can be expected to be interested in cooperation. At this point, though, the fear of cheating comes into play. No state wants to abandon the development of space weapons only to find out that other stated have developed these technologies. The classical solution would be the establishment of an international arms control regime banning space weapons and drawing up provisions for verifying compliance. The fact that we have not seen such a regime so far is puzzling from a neoinstitutionalist perspective.

One might argue that with regard to a space weapons ban, verification is particularly hard. In order to verify compliance, it is first of all necessary to define what compliance means. In particular, the whole issue of defining the term "space weapon" is troublesome. At the core of this problem lies the inherent dual-use character of most space technologies. We have already discussed the Soviet complaints about the potential of the space shuttles to be used as ASAT weapon. In fact, any maneuverable spacecraft could be used for certain ASAT purposes just by steering it into another space object. In particular, comparatively cheap and highly maneuverable microsatellites could be developed for the civilian purpose of inspecting other satellites. These could, however, be turned into space-based ASAT weapons without changing the technology as such. As we can see from this example, it is impossible to define a space weapon on the basis of pure technology (Baseley-Walker and Weeden 2010).

A definition that distinguishes space weapons clearly from other space technologies is impossible to establish. However, there are alternatives, such as a purpose-centered definition according to which a space weapon would be any device (whether land-, sea-, air-, or space-based) purposely designed to damage or destroy an object in orbit or any space-based device designed to attack targets on earth (Moltz 2011, pp. 42–43; Grego and Wright 2010, pp. 7, 20). It is certainly hard to verify intentions, but the verification of testing could help. If a state wants to have the option of space weapons, it will feel a strong need to test respective technologies, and such activities can be monitored. Space is a very transparent medium. This allows for remote tracking, surveillance, and observation with a number of means, such as optical, infrared, radar, electronic, or electromagnetic technologies (Hagen and Scheffran 2003). While further improvement of the respective national capabilities for space situational awareness is important for arms control in space, the fact that the United States clearly took notice of the Chinese ASAT test in 2007 illustrates that the monitoring of such tests by national technical means is possible.

Opponents of arms control in space might point out that any space-faring state could use its civilian space program to disguise such tests. This is correct, but the very point of a strategy of reciprocity is not that cheating becomes impossible but that each party can react to cheating with appropriate measures. A future space arms control agreement should be designed as to allow each party to state a suspicion of cheating and to debate the case with the other parties. If the suspicion cannot be invalidated, the respective party is free to react with reciprocal measures ("tit for tat"). An international regime is not a guarantee for successful arms control in space; but its purpose is to give arms control in space a chance in the first place.

Given the interest of states in the sustainable use of space, it remains puzzling to the neoinstitutionalist account that we haven't seen more space security cooperation.

### 4.3.3 A Constructivist/Liberal Account

Constructivist accounts of international relations criticize rationalist approaches like neorealism and neoinstitutionalism for treating states' identities and interests as exogenously given and thereby "blackboxing" the processes that lead to those identities and interests. In consequence, rationalist approaches are seen as incomplete because they cannot account for changes of the actors' interests that are independent of material factors. According to constructivists, the demand for cooperation – whether in the security field or elsewhere – depends on the actors' perception of the problems at hand. These perceptions, in turn, are a product of the causal and normative beliefs of the actors (Goldstein and Keohane 1993; Hasenclever et al. 2002, pp. 136–137). In the words of Emanuel Adler (1997, p. 367): "Between international structures and human volition lies interpretation. Before choices involving cooperation can be made, circumstances must be assessed and interests identified." The process when decision-makers realize the limits of their interpretation of the world, base their interpretations upon new knowledge, and consequently change their decisions can be called "learning" (Nye 1987).

In order to analyze learning processes, a constructivist account of security cooperation has to open the blackbox of the state and look closely at the origins of those causal and normative beliefs about security cooperation and why and how they emerge, develop, and have an impact upon policy. Various constructivist authors acknowledge that "ideas do not float freely" (Risse-Kappen 1994). Ideas and beliefs need agents that carry them, and these agents have to act within power structures and lobby for their ideas to get politically selected. This reference to domestic structures and actor coalitions connects the debate about the role of knowledge and ideas with what can be seen as one strand of the liberal school of thought in international relations, according to which international politics are dependent on the constellation of the societal structures and interests of states. For those liberal authors, of whom Andrew Moravcsik (1997, 1998) is probably the most renowned, states are seen as transmission belts for the dominant societal preferences, as they are represented by various interest groups.

An important role in the process of learning is ascribed to so-called epistemic communities (Haas 1997) – networks of experts who share certain ideas and knowledge from which they derive policy recommendations. They are social actors who provide new interpretations of reality and thereby often act as "norm entrepreneurs" (Finnemore and Sikkink 1998; Johnson 2006). Frequently, epistemic communities emerge in a national context but then, as a result of the transnational exchange between experts from different countries, transform into a transnational epistemic community. Such a transnational epistemic community can, due to its "larger diffusion network," have a stronger and more sustained influence than purely national communities (Haas 1997, p. 17).

This constructivist/liberal account would explain the limited security cooperation in space by recurring to the dominant beliefs about the value of unilateral behavior if compared with security cooperation in space. As long as the United States seeks space superiority and states like China believe in the value of asymmetric strategies in space – positions that are based upon the beliefs that this (a) is feasible and (b) furthers national security – we should not expect much security cooperation in space. At the same time, however, constructivists and liberals draw our attention to the point that such beliefs are not fixed and that they can change if states reconsider the negative consequences of unilateral strategies: in other words, that states “learn.”

I have already pointed out that the debris resulting from an arms race in space would negatively affect the usability of space for everybody. This insight would be an important component of such a learning process. Moltz (2011) speaks of “environmental learning” and points out that we can observe such learning processes in the history of space politics. During the Cold War, neither the United States nor the Soviet Union wanted to compromise the military use of space or realized the problems of conducting ASAT tests in the space environment. This would be one explanation for the mutual restraint both superpowers exercised when it came to the development of space weapons. In a similar vein, one could explain the new emphasis of the Obama administration on the establishment of norms for responsible behavior in space and the whole discussion of an international code of conduct for space activities as a result of a learning process which was spurred by the Chinese ASAT test in 2007.

However, it does not suffice if such learning is limited to one state alone. Essential knowledge of the *why* and *how* of cooperation must be shared among the major space-faring countries. Accordingly, it would be a major step toward more security cooperation in space if a strong transnational epistemic community emerged in this field (Mutschler 2013). According to liberal assumptions about international politics, the success of learning, however, depends on the formation of winning coalitions of actors that are the drivers of learning. Accordingly, a transnational epistemic community making the case for increased security cooperation in outer space would probably need the support of other actors. Moltz (2011, pp. 297–304) refers to the growing commercial space industry as an important player that could become more influential, and, having a vested interest in the sustainable use of space, would apply political pressure to halt debris-creating activities.

## 4.4 Conclusions

We have seen in the short history of international space politics that states have attempted to cooperate not only with regard to the field of civilian space exploration but also with regard to security issues. Several efforts were made to establish an arms control regime for space that would go beyond the norms of the Outer Space Treaty. While a formal agreement on arms control in space was not reached, states displayed and display some degree of restraint when it comes to the development of space weapons; the debate about norms and rules outer space continues, as the recent debate about an international code of conduct for space activities illustrates.

However, space-faring countries still see the use of space capabilities as a means to increase their respective national power, which is why more space security cooperation faces tremendous obstacles.

Theories of international relations can help us bring some order into the complex situation regarding space security cooperation and its limits. All three accounts that were presented here have something to say on the issue and provide different pieces of the puzzle. Neorealism, with its emphasis on the distribution of power, points out that balanced gains are a precondition for security cooperation in space. Achieving such balanced gains is possible but not easy, given the different levels of technologic development of space-faring states. Neoinstitutionalism in turn draws our attention to the interdependence of international space politics, which creates incentives for cooperation in the first place. However, it also alerts us of the need to establish effective rules and mechanisms, especially to verify the compliance of states with agreed rules.

Both the neorealist and the neoinstitutionalist account tell us a lot about security cooperation in space, in particular about the problems it faces. However, we have seen that these approaches that treat states as rational and unitary actors cannot provide a fully satisfactory explanations of the facts at hand. Hence, they need to be complemented by a constructivist/liberal account that opens up the blackbox of the state and looks at the formation of national interests regarding security cooperation in space. This perspective can acknowledge the problems for security cooperation in space pointed out by the other accounts. However, it makes the case that the main problem lies in the dominant beliefs about the value of unilateral behavior in space. These beliefs are the result of internal struggles for interpretation; hence they are not fixed. This allows us to explain the slight, albeit not insignificant learning processes regarding cooperation in space that we can observe, and it preserves the hope that we might see more security cooperation in space in the future.

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# Spacepower Theory

# 5

Peter L. Hays

## Contents

**Abstract**

Spacepower theory is useful in describing, explaining, and predicting how individuals, groups, and states can best derive utility, balance investments, and reduce risks in their interactions with the cosmos. Spacepower theory should be more fully developed and become a source for critical insights as humanity wrestles with our most difficult and fundamental space challenges and guide us toward better ways to generate wealth in space, make tradeoffs between space investments and other important goals, reorder terrestrial security dynamics as space becomes increasingly militarized and potentially weaponized, and seize exploration and survival opportunities that only space can provide. This chapter briefly reviews noteworthy efforts to develop spacepower theory and then considers ways it could help to refine current US space policy and address some of the most significant challenges and issues surrounding space security, space commercialization, and environmental sustainability and survival.

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## 5.1 Introduction

The opinions expressed in this chapter are mine and do not imply endorsement by the Office of the Director of National Intelligence or any other US Government agency.

The goal of spacepower theory is to describe, explain, and predict how individuals, groups, and states can best derive utility, balance investments, and reduce risks in their interactions with the cosmos. These are long-term, broad, indeterminate, and ambitious goals – it is hardly surprising that some 55 years into the space age humanity has yet to develop spacepower theory able to address them in comprehensive and accepted ways. Incomplete and immature theory inhibits our ability to identify, pursue, and sustain major space objectives. More mature spacepower theory would provide critical insights as humanity wrestles with our most difficult and fundamental space challenges and guide us toward better ways to generate wealth in space, make tradeoffs between space investments and other important goals, reorder terrestrial security dynamics as space becomes increasingly militarized and potentially weaponized, and seize exploration and survival opportunities that only space can provide. This chapter briefly reviews noteworthy efforts to develop spacepower theory and then considers ways it could help to refine current US space policy and address some of the most significant challenges and issues surrounding space security, space commercialization, and environmental sustainability and survival.

Current perceptions that more robust spacepower theory is needed are undoubtedly most acute in the United States. For decades, space capabilities gave the United States important asymmetric advantages that provided foundational elements of America's strength in the information age. These advantages are now being undermined by many factors including the rise of China as a near-peer competitor with significant space and counterspace capabilities, emergence of a growing number of increasingly competent space actors, and US uncertainties and missteps in determining and implementing its best strategy for developing and employing space capabilities. The trajectory of spacepower development is approaching or may have already reached an inflection point where business as usual will no longer improve or even maintain US advantages – a point where the United States must implement different approaches or face diminishing returns from its space investments and the loss of space leadership. Attempting to identify and act upon inflection points is associated with Clauswitzian theories for terrestrial military operations and now holds obvious appeal to Americans pondering their space future. More mature and robust spacepower theory could help provide a more broad and stable foundation for the United States to develop a more deliberate, comprehensive, long-term, and consistent space strategy that would draw on all instruments of power from all levels of government, foster unity of effort in national space activities, improve the viability of the US space industrial base, and, in particular, craft better ways to leverage state-of-the-world commercial and international space capabilities.

Despite its importance, movement toward developing better spacepower theory is likely to be slowed by discouraging attributes associated with spacepower that include lack of acceptance that such theory is needed, very large investments and long timelines, requirements for sustained popular and political support, and prospects for only potential or intangible benefits. These factors can erode acceptance of and support for improving spacepower theory at both the personal and political levels, but they also point to the need for an incremental approach and reinforce the long-term benefits of theory in providing guidance, stability, and predictability. Indeed, more robust spacepower theory could provide an essential foundation for improving the structure and predictability of humanity's interactions with the cosmos. Perhaps more than any other approach, the issues spacepower theory addresses, the precedents from which it is drawn, and the pathways ahead it helps to illuminate could help guide the future development of spacepower.

## 5.2 Noteworthy Efforts to Develop Spacepower Theory

Many studies touch on aspects of spacepower theory, but few focus solely on this topic and fewer still address the topic comprehensively and have widespread acceptance. This section very briefly considers some of the most noteworthy efforts as well as elements of major and enduring themes and analogies any robust spacepower theory would need to address. The first major, comprehensive, and focused effort to develop spacepower theory began in 1997 when the Commander of US Space Command, General Howell M. Estes III, commissioned Dr. Brian R. Sullivan to write a book on this topic. James Oberg then became the leader of the effort and he published *Space Power Theory* in 1999 (Oberg 1999). Oberg draws on his academic background in astrodynamics and computer science as well as more than 20 years experience with the National Aeronautics and Space Administration (NASA) Space Shuttle program to present a cogent narrative about the importance of spacepower that is particularly strong on the technical underpinnings of spacepower and emphasizes the need for space control. The book provides a strong foundation for spacepower theory, details the range of elements that contribute to its development, reviews how major space-faring states developed and used spacepower, and discusses a number of significant technical and political impediments to its development. Unfortunately, the political dimension of Oberg's spacepower theory is less well developed, because his analysis does not provide much focus on the ways the attributes of spacepower relate to strategy or the development and employment of power in other domains.

By contrast, Everett Dolman, a professor at the School of Advanced Air and Space Studies at Air University, provides a spacepower theory that is focused almost entirely on the political rather than technical aspects of spacepower. *Astropolitik: Classical Geopolitics in the Space Age* (Dolman 2001) explains how the physical attributes of outer space and the characteristics of space systems shape the application of spacepower and then uses this *astropolitical* analysis to develop a compelling vision for the United States to reject the Outer Space Treaty (OST) regime, promote free-market capitalism in space, and use space to help provide global security as a public good. His book is intellectually grounded in the best traditions of geopolitics, has something genuinely new to say, makes vital contributions to the dialogue about the interrelationships between space and national security, and is easily the most important book on space and security since the publication of Walter A. McDougall's Pulitzer prize–winning . . . *the Heavens and the Earth: A Political History of the Space Age* in 1985. *Astropolitik* is a stunning intellectual achievement and the first book that can legitimately claim to present a comprehensive theory of spacepower. It challenges conventional thinking about the status quo for space and has generated a great deal of controversy and provoked many responses. To be sure, many of the major points Dolman asserts are open to debate, such as whether space will actually become a virtually limitless source of wealth, what technologies and strategies the United States might employ to assert dominance over low-Earth orbit (LEO), and how and why domestic and international political forces might come to align with his astropolitical prescriptions. But one mark of a great book is that it helps to define and structure subsequent debate; *Astropolitik* has clearly advanced the study of spacepower theory by providing the language and lines of argumentation for future discourse.

Three other works are noteworthy additions to this field: M. V. Smith's *Ten Propositions Regarding Spacepower*, John J. Klein's *Space Warfare: Strategy, Principles and Policy*, and the National Defense University's (NDU) edited volume *Toward a Theory of Spacepower: Selected Essays* (Smith 2001; Klein 2006; Lutes et al. 2011). *Ten Propositions Regarding Spacepower* is written from the perspective of an Air Force officer who spent several years integrating space-related capabilities into numerous exercises and real-world combat; the study seeks to answer the philosophical question "what is the nature of spacepower?" Smith describes the nature of space power by presenting 10 propositions, supporting each with historical evidence: Space is a distinct operational medium; the essence of spacepower is global access and global presence; spacepower is composed of a state's total space activity; spacepower must be centrally controlled by a space professional; spacepower is a coercive force; commercial space assets make all actors space powers; spacepower assets form a national center of gravity; space control is not optional; space professionals require career-long specialization; and weaponizing space is inevitable. Smith's propositions build from and are consistent with main themes in Oberg's and Dolman's works, but they independently advance spacepower theory by providing a more comprehensive and thorough exposition of the attributes of spacepower and its employment.

John J. Klein is a naval aviator; his work builds from and modifies for space the classic maritime theory presented by Julian Corbett in *Some Principles of Maritime Strategy* and first published in 1911. Corbett's theory about maritime activity is among the best developed and comprehensive of all theories designed to explain military operations in terrestrial domains. Klein assesses airpower, seapower, and maritime strategies, finding that maritime strategy is most suitable for application to space; builds from Mahan's and Corbett's ideas about sea lines of communications to discuss the importance of celestial lines of communications; and asserts that there is an overemphasis on power and offensive space operations in current American spacepower thought. Klein's work advances spacepower theory by creating tight linkages with Corbett's well-developed maritime theory and providing a firm foundation for further refining spacepower theory.

The NDU spacepower theory study was commissioned by the Department of Defense (DoD) as the result of deliberations during preparation of the 2005

Quadrennial Defense Review. The study was a team effort to produce an edited volume and does not attempt to present a single point of view about spacepower theory. Instead, the study published 30 chapters written by national and international space experts and organized into six sections: introduction to spacepower theory; economics and commercial space perspectives; civil space perspectives; national security space perspectives; international perspectives; and evolving futures for spacepower. The strength of this approach is that it presents the most broad and wide-ranging perspectives ever assembled about spacepower theory, but weaknesses also stem from this approach, because there is no unified perspective or even many major common themes that emerge from the work. The overarching goal of the study was to foster dialogue and incubate further development of spacepower theory; it is hoped that the study's broad and wide-ranging perspectives will encourage advancement of spacepower theory along multiple paths.

Major and enduring themes and analogies any robust spacepower theory should address include: perspectives on the growing use and importance of space, debates about the economic potential of space, debates over the need for and inevitability of space weaponization, perspectives of space as a frontier to be tamed, and perspectives that link space to humanity's purpose and destiny. Another set of factors shaping spacepower theory are the oft-invoked analogies between spacepower and seapower or airpower. Seminal theorists who developed important perspectives on sea and air operations include: Alfred Thayer Mahan, Julian Corbett, Giulio Douhet, William "Billy" Mitchell, and John Warden.[1] Some of the key concepts that these theorists developed or applied to the air and sea mediums are command of the sea, command of the air, sea lines of communication, common routes, choke points, harbor access, concentration and dispersal, and parallel attack. Several of these concepts have been appropriated directly into various strands of embryonic space theory; others have been modified slightly then applied. For example, Mahan's and Corbett's ideas about lines of communications, common routes, and choke points have been applied quite directly onto the space medium. Seapower and airpower concepts that have been modified to help provide starting points for thinking about spacepower include harbor access and access to space, and command of the sea or air and space control. But, of course, to date, no holistic spacepower theory has yet emerged that is fully worthy of claiming a place alongside the seminal seapower and airpower theories listed above. There are also many fundamental questions concerning the basic attributes of the space medium and how appropriate it is to analogize directly from seapower or airpower theory when attempting to build spacepower theory. Few concepts from seapower theory translate directly into airpower theory, and it is not reasonable to expect either seapower or airpower theory to apply directly for the distinct medium of space.

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[1] Several of these individuals were quite prolific; the following list represents their best known works: Mahan (1980), Corbett (1988), Douhet (1983), Mitchell (1988), and Warden (1988). On the importance of these works see, Sumida (1997), Meilinger (1997), and Mets (1999).

## 5.3 Spacepower Theory and Current US Space Policy

The United States has the most developed, open, and mature process for promulgating national space policy, and these space policies contain many elements that would be needed in robust and comprehensive spacepower theory. This is not to suggest that US space policy is the same as or can substitute for spacepower theory, but it does mean that attempts to develop spacepower theory need to be aware of and interact with these elements of US space policy. Widely accepted and comprehensive spacepower theory could help the United States refine its space policy, provide a stronger and more sustainable and consistent foundation for its implementation, and also improve its strategic-level management and organizational structures for implementing goals from the National Security Strategy, National Space Policy (NSP), and especially the combined National Security Space Strategy (NSSS) and Space Posture Review (SPR).[2]

The Obama Administration's National Security Strategy, released in May 2010, included helpful emphasis on space and several overarching yet demanding objectives that will require focused attention and considerable effort to pursue:

*Leverage and Grow our Space Capabilities*: For over 50 years, our space community has been a catalyst for innovation and a hallmark of US technological leadership. Our space capabilities underpin global commerce and scientific advancements and bolster our national security strengths and those of our allies and partners. To promote security and stability in space, we will pursue activities consistent with the inherent right of self-defense, deepen cooperation with allies and friends, and work with all nations toward the responsible and peaceful use of space. To maintain the advantages afforded to the United States by space, we must also take several actions. We must continue to encourage cutting-edge space technology by investing in the people and industrial base that develops them. We will invest in the research and development of next-generation space technologies and capabilities that benefit our commercial, civil, scientific exploration, and national security communities, in order to maintain the viability of space for future generations. And we will promote a unified effort to strengthen our space industrial base and work with universities to encourage students to pursue space-related careers (Obama 2010).

This is the first National Security Strategy since the Clinton Administration that places such specific focus on space in this top-tier policy statement. These ambitious goals also present challenges in terms of how they might align with spacepower theory and provide guidance for lower-level policies and strategies in pursing and achieving these objectives.

In June 2010, the Obama Administration issued a new NSP emphasizing broad continuity between its major objectives and the overarching themes of US space

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[2] Section 913 of the Fiscal Year 2009 National Defense Authorization Act (P.L. 110–417) directed the Secretary of Defense and Director of National Intelligence to submit a Space Posture Review to Congress by 1 December 2009. The Obama Administration delivered an interim SPR to Congress in March 2010 and completed this tasking with release of the NSSS on 4 February 2011.

policy originally developed by the Eisenhower Administration such as encouraging responsible use of space and strengthening stability in space. Other goals evolved directly from original US space policy objectives including expanding international cooperation, nurturing US space industry, and increasing assurance and resilience of mission-essential functions enabled by commercial, civil, scientific, and national security spacecraft and supporting infrastructure. In particular, the NSP indicates the United States will "ensure cost-effective survivability of space capabilities" and "develop and implement plans, procedures, techniques, and capabilities" necessary for mission assurance including "rapid restoration of space assets and leveraging allied, foreign, and/or commercial space and nonspace capabilities to help perform the mission" (National Space Policy of the United State of America 2010). There are also some areas of new or changed emphasis such as the more enthusiastic approach toward transparency- and confidence-building measures (TCBMs) including "concepts for space arms control if they are equitable, effectively verifiable, and enhance the national security of the United States and its allies" (National Space Policy of the United State of America 2010, p. 7) that replaced the 2006 NSP language about opposing "development of new legal regimes or other restrictions that seek to prohibit or limit U.S. access to or use of space" (U.S. National Space Policy 2006).

Despite making some advances, the Obama NSP falls short of appropriately and comprehensively addressing several of the most important space challenges the United States currently faces and does not objectively cover a range of factors that should be included in any robust spacepower theory. While more stress on cooperation and responsible behavior in space is useful, the new policy inappropriately neglects any discussion of US space leadership and relative advantages space can provide. It overcorrects the competitive tone in the 2006 NSP by emphasizing just the cooperative dimensions of space and avoids the reality that space is inherently a domain of both cooperation *and* competition as states and other actors pursue their economic and security interests. Moreover, the NSP does not provide sufficient guidance or criteria for determining what constitutes responsible behavior in space. For example, the NSP does not even specifically address the January 2007 Chinese anti-satellite (ASAT) test, a dangerously irresponsible act that reawakened global concerns about space as a militarily contested domain and created a persistent debris cloud comprised of more than 25 % of all cataloged objects in Low-Earth Orbit (LEO).[3] Another troubling part of the new policy calls out space stability and sustainability as vital national interests. The United States does have a strong interest in developing and maintaining space activities in stable

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[3] "Fengyun 1-C Debris: Two Years Later," *Orbital Debris Quarterly News*, Johnson Spaceflight Center: NASA Orbital Debris Program Office, vol. 13, no. 1 (January 2009): 2. As a result of the 11 January 2007 Chinese ASAT test, the U.S. Space Surveillance Network has catalogued 2,378 pieces of debris with diameters greater than 5 cm, is tracking 400 additional debris objects that are not yet catalogued, and estimates the test created more than 150,000 pieces of debris larger than 1 $cm^2$. Unfortunately, less than 2 percent of this debris has reentered the atmosphere so far and it is estimated that many pieces will remain in orbit for decades and some for more than a century.

and sustainable ways but to enumerate these particular objectives as vital national interests – a term of art the United States has traditionally reserved for its most important interests as a clear signal it will use military force if needed to defend them – inappropriately links these nebulous objectives to the use of military force, implies the United States has the ability to maintain space stability and sustainability, and erodes the meaning of the term vital national interests. In addition, while the relatively rapid coordination and approval of the NSP is laudable, it appears that part of this speed and consensus was achieved by barely addressing controversial areas or avoiding them altogether. Many areas need attention now and should be carefully considered, but the NSP does not provide enough guidance to begin addressing several urgent current issues such as national space transportation policy. Finally, and perhaps most importantly, the NSP fails to address how the United States will improve top-level management and organizational structures, provide clear lines of authority and responsibility, or ensure they have the durability needed to affect change, despite the fact that structural deficiencies have been a consistent theme of almost every commission studying space issues and candidate Obama's pledge to reestablish a space council at the White House.

As the strategic environment of space becomes increasingly complex and hostile, it is more important than ever for the United States to consider appropriate spacepower theory and implement an effective strategy for adapting to these changes. The United States has now promulgated its first comprehensive NSSS, a document signed by the Secretary of Defense and Director of National Intelligence and released on 4 February 2011 (Secretary of Defense and Director of National Intelligence 2011). Details revealed by the NSSS substantiate how space is growing increasingly congested, contested, and competitive: DoD is tracking over 22,000 man-made objects in space (including 1,100 active satellites), there are hundreds of thousands of additional debris pieces too small to track with current sensors but that could still damage satellites in orbit, and there is also increasing congestion in the radiofrequency spectrum due to satellite operations by more than 60 states and consortia and as many as 9,000 satellite communications transponders expected to be in orbit by 2012 (Secretary of Defense and Director of National Intelligence 2011, pp. 1–2).

In addition space is increasingly *contested* in all orbits. Today space systems and their supporting infrastructure face a range of man-made threats that may deny, degrade, deceive, disrupt, or destroy assets. Potential adversaries are seeking to exploit perceived space vulnerabilities. As more nations and non-state actors develop counterspace capabilities over the next decade, threats to US space systems and challenges to the stability and security of the space environment will increase. Irresponsible acts against space systems could have implications beyond the space domain, disrupting worldwide services upon which the civil and commercial sectors depend (Secretary of Defense and Director of National Intelligence 2011, p. 3).

And with respect to increasing competition, while the United States “maintains an overall edge in space capabilities,” its “competitive advantage has decreased as market-entry barriers have lowered;” its “technological lead is eroding in several areas;” “US suppliers, especially those in the second and third tiers, are at risk due to inconsistent acquisition and production rates, long development cycles, consolidation of suppliers under first-tier prime contractors, and a more competitive foreign market;” and the US share of world satellite manufacturing revenue has dropped from an average of more than 60 percent during the 1990s to 40 percent or less during the 2000s (Secretary of Defense and Director of National Intelligence 2011).

To address these challenges, the NSSS seeks three strategic objectives: strengthening safety, stability, and security in space; maintaining and enhancing the strategic national security advantages afforded to the United States by space; and energizing the space industrial base that supports US national security (Secretary of Defense and Director of National Intelligence 2011, p. 4). The strategy advocates five strategic approaches to pursue these objectives: promoting responsible, peaceful, and safe use of space; providing improved US space capabilities; partnering with responsible nations, international organizations, and commercial firms; preventing and deterring aggression against space infrastructure that supports US National Security; and preparing to defeat attacks and to operate in a degraded environment (Secretary of Defense and Director of National Intelligence 2011, pp. 5–11). Pursuit and implementation of these strategic objectives will be difficult, but the NSSS correctly assesses the most significant changes in the space strategic environment and presents a responsible way for the United States to address these changes that begins to approach the comprehensive advances needed for spacepower theory.

## 5.4 Spacepower Theory, Hard Power, and the Quest for Sustainable Security

There are a number of hard power issue areas where spacepower theory might provide insights on space security including the Outer Space Treaty (OST) regime and other TCBMs, space situational awareness (SSA), space weaponization, and the rise of China as a major factor in space security. The OST regime is by far the most important and comprehensive mechanism in shaping space security. Although there is some substance to arguments that the OST only precludes those military activities that were of little interest to the superpowers and does not bring much clarity or direction to many of the most important potential space activities, the treaty nonetheless provides a solid and comprehensive starting point for spacepower theory and is an important foundation for thinking about additional theoretical structures needed to advance spacepower. Moreover, there is broad consensus on the merits and overall value of the OST regime; space-faring actors are much more interested in building upon this foundation than in developing new structures.

Spacepower theory should provide guidance on the most effective ways to confront the OST regime. Some theories would advocate abandoning this regime; most others would seek ways to improve and build upon the OST regime including working toward achieving more universal adherence by all space-faring actors to the regime's foundational norms and expanding the regime beyond just states to include all important space-faring actors. Beginning work to include major non-state space actors in the OST would be a significant step that would require substantial expansion of the regime and probably would need to be accomplished incrementally. The security dimensions of the regime have opened windows of opportunity, and important precedents have been set by expanding participation in the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) and the World Radio Conferences of the International Telecommunications Union (ITU) to include non-state actors as observers or associate members. Some form of two-tiered participation structure within the OST regime might be appropriate for a number of years, and it could prove impractical to include non-state actors in a formal treaty, but steps toward expanded participation should be carefully considered, both to capture the growing spacepower of non-state actors and to harness their energy in helping achieve more universal adherence to the regime. Perhaps most importantly, these initial steps would help promote a sense of stewardship for space among more actors and increase attention on those parties that fail to join or comply with these norms. Other particular areas within the OST regime that spacepower theory should address, perhaps through creation of a standing body with specific implementation responsibilities, include the Article VI obligations for signatories to authorize and exercise continuing supervision over space activities and the Article IX responsibilities for signatories to undertake or request appropriate international consultations before proceeding with any activity or experiment that would cause potentially harmful interference.

Another key area for security and spacepower theory for the United States and other leading space-faring actors that would help better define OST implementation obligations and demonstrate leadership in fostering cooperative spacepower would be improvements in how SSA data is developed and shared globally. Due to increasing use of space by more actors, the growing number of active satellites, and, especially, recent deliberate and accidental debris creating events caused by the Chinese ASAT test in January 2007 and the February 2009 collision between Iridium and Cosmos satellites, there is now more worldwide interest in spaceflight safety and considerable motivation for improvements in developing and sharing SSA data with more users in more timely and consistent ways. Spacepower theory should provide guidance on the most effective approaches toward achieving these objectives. One approach would be continuation and improvements in US Government efforts to create a data center for sharing SSA data globally including ephemeris, propagation data, and pre-maneuver notifications for all active satellites.[4] Another approach would be to transition and operate such a data center under international auspices[5] and perhaps create an international space traffic management organization that would be somewhat analogous to the International Civil Aviation Organization (ICAO). A final approach would build from recent commercial efforts in creating the Space Data Association (SDA) and encourage the commercial sector, rather than governments, to play the leading role in developing a center to provide SSA data globally. In each case, processes would need to be developed and refined for users to voluntarily contribute data to the center, perhaps through a GPS transponder on each satellite, and for spaceflight safety data to be constantly updated, freely available, and readily accessible so that it could be used by satellite operators to plan for and avoid conjunctions.

Spacepower theory should also address difficult legal, technical, and policy issues that inhibit progress on sharing SSA data that include bureaucratic inertia, liability, and proprietary concerns; nonuniform data formatting standards and incompatibility between propagators and other cataloging tools; and security concerns over exclusion of certain satellites from any public data. Some of these concerns could be addressed by working toward better cradle-to-grave tracking of all cataloged objects to help establish the launching state and liability; using opaque processes to exclude proprietary information from public databases to the maximum extent feasible; and indemnifying program operators, even if they provide faulty data that results in a collision, so long as they operate in good faith, exercise reasonable care, and follow established procedures.

Theories for operating in other domains and history suggest there are very important roles for militaries both in setting the stage for the emergence of international legal regimes and in enforcing the norms of those regimes once they emerge. Development of any TCBMs for space, such as rules of the road or codes of conduct, should draw closely from the development and operation of such measures

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[4] SSA issues are framed by specialized concepts and jargon. Conjunctions are close approaches, or potential collisions, between objects in orbit. Propagators are complex modeling tools used to predict the future location of orbital objects. Satellite operators currently use a number of different propagators and have different standards for evaluating and potentially maneuvering away from conjunctions. Maneuvering requires fuel and shortens the operational life of satellites. Orbital paths are described by a set of variables known as ephemeris data; two-line element sets (TLEs) are the most commonly used ephemeris data. Much of this data is contained in the form of a satellite catalog. The United States maintains a public catalog at space-track.org. Other entities maintain their own catalogs. Orbital paths constantly change, or are perturbed, by a number a factors including Earth's inconsistent gravity gradient, solar activity, and the gravitational pull of other orbital objects. Perturbations cause propagation of orbital paths to become increasingly inaccurate over time; beyond approximately 4 days into the future predictions about the location of orbital objects can be significantly inaccurate. For more about SSA concepts see Weeden (2009). For discussion about ways to share SSA data and other space security ideas fostered by meetings between the Department of Defense Executive Agent for Space and the Chief Executive Officers of commercial satellite operators see McGlade (2007).

[5] For an outstanding and detailed analysis of the benefits and challenges related to creation of an international data center see Cox (2007).

in other domains such as sea or air. The international community should consider the most appropriate means of separating military activities from civil and commercial activities in the building of these measures, because advocating a single standard for how all space activities ought to be regulated or controlled is inappropriately ambitious and not likely to be helpful. The U.S. Department of Defense requires safe and responsible operations by warships and military aircraft, but they are not legally required to follow all the same rules as commercial traffic and sometimes operate within specially protected zones that separate them from other traffic. Moreover, operational security considerations dictate that these military forces often do not provide public information about their location and planned operations. More robust spacepower theory as well as full and open dialogue about these issues will help us develop space rules that draw from years of experience in operating in other domains and make the most sense for the unique operational characteristics of space.

Other concerns surround the implications of various organizational structures and rules of engagement for potential military operations in space. Spacepower theory should help us address key questions such as whether military space forces should operate under national or only international authority, who should decide when certain activities constitute a threat, and how such forces should be authorized to engage threats, especially if such engagements might create other threats or potentially cause harm to humans or space systems. Clearly, these and a number of other questions are very difficult to address and require careful international vetting well before the actual operation of such forces in space. In addition, we should consider the historic role of the Royal and U.S. Navies in fighting piracy, promoting free trade, and enforcing global norms against slave trading, as well as the current international effort to combat piracy off the Horn of Africa. What would be analogous roles in space for the US military and other military forces today and in the future and how might the United States and others encourage like-minded actors to cooperate on such initiatives? Attempts to create legal regimes or enforcement norms that do not specifically include and build upon military capabilities are likely to be divorced from pragmatic realities and ultimately frustrating efforts.[6]

Robust and comprehensive spacepower theory should also address the viability and utility of various top-down and bottom-up approaches to TCBMs. The OST regime was developed through top-down methods, but since that success, many factors have made this approach increasingly difficult. The most serious of these problems include: disagreements over the proper forum, scope, and object for negotiations; basic definitional issues about what is a space “weapon” and how they might be categorized as offensive or defensive and stabilizing or destabilizing; and daunting concerns about whether adequate verification mechanisms can be found for any comprehensive and formalized TCBMs. These problems relate to

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[6] On the role of militaries in enforcing legal norms and analogies between the law of the sea and space law, see DeSutter (2006).

a number of very thorny, specific issues such as whether the negotiations should be primarily among only major space-faring actors or more multilateral, what satellites and other terrestrial systems should be covered, and whether the object should be control of space weapons or TCBMs for space; the types of TCBMs which might be most useful (e.g., rules of the road or keep out zones) and how these might be reconciled with the existing space law regime; and verification problems such as how to address the latent or residual ASAT capabilities possessed by many dual-use or military systems or how to deal with the significant military potential of even a small number of covert ASAT systems.

New space system technologies, continuing growth of the commercial space sector, and new verification technologies interact with these existing problems in complex ways. Some of the changes would seem to favor TCBMs, such as better radars and optical systems for improved SSA, attribution, and verification capabilities; technologies for better space system diagnostics; and the stabilizing potential of redundant and distributed space architectures that create many nodes by employing larger numbers of hosted payloads and less expensive satellites. Many other trends, however, would seem to make space arms control and regulation even more difficult. For example, very small satellites are becoming increasingly capable and might be used as virtually undetectable active ASATs or passive space mines; proliferation of space technology has radically increased the number of significant space actors to include a number of non-state actors that have developed or are developing sophisticated dual-use technologies such as autonomous rendezvous and docking capabilities; satellite communications technology can easily be used to jam rather than communicate; and growth in the commercial space sector raises issues such as how quasi-military systems could be protected or negated and the unclear security implications of global markets for dual-use space capabilities and products.

There is disagreement about the relative utility of top-down versus bottom-up approaches to developing space TCBMs and formal arms control, but, following creation of the OST regime, the United States and many other major space-faring actors have tended to favor bottom-up approaches, a point strongly emphasized by US Ambassador Donald Mahley in February 2008: “Since the 1970s, five consecutive U.S. administrations have concluded it is impossible to achieve an effectively verifiable and militarily meaningful space arms control agreement” (Ambassador Mahley 2008). Yet this assessment may be somewhat myopic since strategists need to consider not only the well-known difficulties with top-down approaches but also the potential opportunity costs of inaction and recognize when they may need to trade some loss of sovereignty and flexibility for stability and restraints on others. Because the United States has not tested a kinetic energy ASAT since September 1985 and has no program to develop a dedicated ASAT system, would it have been better to exchange the option to maintain this capability for pursuit of a global ban on testing kinetic energy ASATs, and would such a norm have produced a restraining effect on development and testing of the Chinese ASAT? This may have been a lost opportunity to pursue TCBMs but is a complex, multidimensional, and interdependent issue shaped by a variety of other factors such as inabilities to distinguish between ballistic missile defense and ASAT technologies, reluctance to limit technical options after the end of the Cold War, the emergence of new and less easily deterred threats, and the demise of the Anti-Ballistic Missile (ABM) Treaty.

To circumvent significant challenges with top-down approaches, there are a number of ongoing attempts to make progress through primarily incremental, pragmatic, technical, and bottom-up steps. Examples of this approach include the December 2007 adoption by the United Nations General Assembly of the Inter-Agency Debris Coordination Committee (IADC) voluntary guidelines for mitigating space debris, work toward an International Code of Conduct for outer space activities, the Long-Term Sustainability of Space Activities effort at UN COPUOS, and the United Nations Group of Governmental Experts on TCBMs (Council of the European Union 2008; United Nations General Assembly Resolution 62/217 2008).

Moreover, the Chinese, in particular, apparently disagree with pursuing only bottom-up approaches and, in ways that seem both shrewd and hypocritical, are currently developing significant counterspace capabilities while simultaneously advancing various top-down proposals in support of prevention of an arms race in outer space (PAROS) initiatives and moving ahead with the joint Chinese-Russian draft treaty on Prevention of Placement of Weapons in Outer Space (PPWT) introduced at the Conference on Disarmament in February 2008. Thus far, the Chinese have seemed quite disinterested in pursuing space TCBMs; they are moving further and faster than any previous space-faring actor and recently tested a dedicated high-altitude ASAT system able to hold geostationary satellites at risk, a capability never pursued by the superpowers at the height of the Cold War. With respect to the PPWT in particular, while it goes to considerable lengths in attempting to define space, space objects, weapons in space, placement in space, and the use or threat of force, there are still very considerable definitional issues with respect to how specific capabilities would be defined. An even more significant problem relates to all the terrestrial capabilities that are able to eliminate, damage, or disrupt normal functioning of objects in outer space such as the Chinese direct ascent ASAT. One must question the utility of a proposed agreement that does not address the significant security implications of current space system support of network-enabled terrestrial warfare, does not deal with dual-use space capabilities, seems to be focused on a class of weapons that does not exist or at least is not deployed in space, is silent about all the terrestrial capabilities that are able to produce weapons effects in space, and would not even ban development and testing of space weapons, only their use.[7] Given these glaring weaknesses in the PPWT, it seems plausible that it is designed as much to continue political pressure on the United States and derail US missile defense efforts as it is to promote sustainable space security.

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[7] Reaching Critical Will, "Preventing the Placement of Weapons in Outer Space: A Backgrounder on the draft treaty by Russia and China."

Since Sino-American relations in general and space relations in particular are likely to play a dominant role in shaping spacepower theory and the quest for sustainable security during this century, proposed Sino-American cooperative space ventures or TCBMs are worthy of special consideration. For example, the United States could make more specific and public invitations for the Chinese to become involved with the International Space Station program and join other major cooperative international space efforts. The United States and China could also work toward developing non-offensive defenses of the type advocated by Philip Baines (Baines 2003). Kevin Pollpeter explains how China and the United States could cooperate in promoting the safety of human spaceflight and "coordinate space science missions to derive scientific benefits and to share costs. Coordinating space science missions with separately developed, but complementary space assets, removes the chance of sensitive technology transfer and allows the two countries to combine their resources to achieve the same effects as jointly developed missions" (Pollpeter 2008). Michael Pillsbury outlined six other areas where US experts could profitably exchange views with Chinese specialists in a dialogue about space weapons issues: "reducing Chinese misperceptions of U.S. Space Policy, increasing Chinese transparency on space weapons, probing Chinese interest in verifiable agreements, multilateral versus bilateral approaches, economic consequences of use of space weapons, and reconsideration of U.S. high-tech exports to China" (Pillsbury 2007). Finally, Bruce MacDonald's report on *China, Space Weapons, and U.S. Security* for the Council on Foreign Relations offers a number of noteworthy additional specific recommendations for both the United States and China. For the United States, MacDonald recommends: assessing the impact of different US and Chinese offensive space postures and policies through intensified analysis and "crisis games," in addition to wargames; evaluating the desirability of a "no first use" pledge for offensive counterspace weapons that have irreversible effects; pursuing selected offensive capabilities meeting important criteria – including effectiveness, reversible effects, and survivability – in a deterrence context to be able to negate adversary space capabilities on a temporary and reversible basis, refraining from further direct ascent ASAT tests and demonstrations as long as China does, unless there is a substantial risk to human health and safety from uncontrolled space object reentry; and entering negotiations on a kinetic energy ASAT testing ban. MacDonald's recommendations for China include: providing more transparency into its military space programs; refraining from further direct ascent ASAT tests as long as the United States does; establishing a senior national security coordinating body, equivalent to a Chinese National Security Council; strengthening its leadership's foreign policy understanding by increasing the international affairs training of senior officer candidates and establishing an international security affairs office within the PLA; providing a clear and credible policy and doctrinal context for its 2007 ASAT test and counterspace programs more generally and addressing foreign concerns over China's ASAT test; and offering to engage in dialogue with the United States on mutual space concerns and become actively involved in discussions on establishing international space codes of conduct and confidence-building measures (MacDonald 2008).

## 5.5 Spacepower Theory, Harvesting Energy, and Creating Wealth in and from Space

Moving from hard to soft power considerations, spacepower theory can help to guide space-faring actors in a number of important areas including further developing and refining the OST regime, adapting the most useful parts of analogous regimes such as the Law of the Sea and Seabed Authority mechanisms, and rejecting standards that stifle innovation, inadequately address threats to humanity's survival, or do not provide opportunities for rewards commensurate with risks undertaken. Revising and further developing the OST regime could be a key first step toward seeking better ways to harvest energy and create wealth in and from space. Expanding participation in the OST as discussed above might also be helpful, but other steps such as reducing liability concerns and improving legal incentives for harvesting energy and generating wealth are likely to be even more effective in pursuit of further commercial development of space. Of course, as with security, more comprehensive and robust spacepower theory would be helpful in considering a range of objectives and values that are in tension and require considerable effort to change or keep properly balanced. The OST has been extremely successful thus far with respect to its primary objective of precluding replication of the colonial exploitation that plagued much of Earth's history. The international community should now consider whether the dangers posed by potential cosmic land grabs continue to warrant OST restrictions that stifle development of spacepower, and, if these values are found to have become imbalanced, how these restrictions might best be changed. Space-faring actors should use an expansive approach to consider how perceived OST restrictions and the commercial space sector have evolved and might be further advanced in a variety of ways including reinterpreting the OST regime itself, becoming more intentional about developing spacepower, creating space-based solar power capabilities, and improving export controls.

While the OST has thus far been unambiguous and successful in foreclosing sovereignty claims and the ills of colonization, it has been less clear and effective with respect to pragmatic property rights and commercialization issues. Part of the problem in this regard stems from the fact that OST is not linked to robust and mature spacepower theory; the regime is also embedded within a broader body of international law and that regime is evolving, sometimes in unclear ways and under different interpretations. Elements within the regime are of unclear and unequal weight: the Moon Agreement with its Common Heritage of Mankind (CHM) approach to communal property rights and equally shared rewards has some effect but more limited standing as customary international law due to its lack of signatories, especially among major space-faring states; moreover, it falls well short of the OST, a treaty that has been signed by 91 states and in force for over 40 years. Most fundamentally, however, the lack of clarity within space law about property rights and commercial interests is the result of the regime still being underdeveloped and immature. There is also a "Catch-22" factor at work since actors are discouraged from undertaking the test cases needed to develop and mature the regime because of the immaturity of the regime and their unwillingness to be guinea pigs in whatever legal processes would be used to resolve property rights and reward structures. The most effective way to move past this significant hurdle would be to create clear mechanisms for establishing property rights and processes by which all actors, especially commercial actors, can receive rewards commensurate with the risks they undertake. In addition, consideration should be given to reevaluating liability standards by assessing factors, including how much of a disincentive towards appropriate risk taking they may create and whether use of graduated or reduced liability standards might be more suitable in advancing positive incentives for more commercial space activity.[8] Finally, any comprehensive reevaluation of space property rights and liability concerns should also consider how these factors are addressed in analogous regimes such as the Seabed Authority in the Law of the Sea Treaty. Unfortunately, however, several of the analogous regimes like the Law of the Sea are largely premised on CHM approaches and may be somewhat better developed than the OST but are also currently underdeveloped and immature with respect to actual commercial operations, limiting the utility of attempting to draw from these precedents.

Provisions of the OST regime are probably the most important factors in shaping commercial space activity, but they are clearly not the only noteworthy legal and policy factors at work influencing developments within this sector. Commercial space activity was not that significant during the Cold War, but that has changed radically. In the 1960s, the United States was first to begin developing space services such as communications, remote sensing, and launch capabilities but did so within the government sector. This approach began to change in the 1980s, first with the November 1984 Presidential Determination to allow some commercial communication services to compete with Intelsat, and continued with subsequent policies designed to foster development of a commercial space sector. By the late 1990s, commercial space activity worldwide was outpacing government activity, and although government space investments remain very important, they are likely to become increasingly overshadowed by commercial activity. Other clear commercial and economic distinctions with the Cold War era have even more

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[8] Although Art VII of the OST discusses liability, that article was further implemented in the Convention on International Liability for Damage Caused by Space Objects, commonly referred to as the Liability Convention. Under the Liability Convention, Article II, a launching state is absolutely liable to pay compensation for damage caused by its space object on the surface of the Earth or to aircraft in flight. However, under Articles III and IV, in the event of damage being caused elsewhere than on the surface of the Earth by a space object, the launching state is liable only if the damage is due to its fault or the fault of persons for whom it is responsible (i.e., commercial companies), under a negligence standard. The challenge is how best to evolve the existing space law regime with its two-tiered liability system based on either absolute liability or fault/negligence, depending upon the location of the incident, into a structure that might provide more incentives for commercial development of space. The formal citation for the Liability Convention is: Convention on International Liability for Damage Caused by Space Objects (resolution 2777 (XXVI) annex) — adopted on 29 November 1971, opened for signature on 29 March 1972, entered into force on 1 September 1972.

significant implications for the future of spacepower: the Soviet Union was only a military superpower, whereas China is a major US trading partner and an economic superpower that recently passed Germany and Japan to become the world's second largest economy, and, if current growth projections hold, is on a path to become larger than the US economy before 2020. Because of its economic muscle, China can afford to devote commensurately more resources to its military, including a wide range of increasingly capable space and counterspace capabilities.

The United States and other major space-faring actors lack, but undoubtedly need, much more open and comprehensive visions for how to develop spacepower theory and advance spacepower. This study is one attempt to foster more dialogue about space security, but the process should continue, become more formalized, and be supported by enduring organizational structures that include the most important stakeholders in the future of spacepower. Spacepower theory should be a foundational part of creating and implementing spacepower and guide approaches "focused on opening space as a medium for the full spectrum of human activity and commercial enterprise, and those actions which government can take to promote and enable it, through surveys, infrastructure development, pre-competitive technology, and encouraging incentive structures (prizes, anchor-customer contracts, and property/exclusivity rights), regulatory regimes (port authorities, spacecraft licensing, public-private partnerships) and supporting services (open interface standards, RDT&E [research, development, test, and evaluation] facilities, rescue, etc.)" (Garretson 2009). In addition, consideration should be given to using other innovative mechanisms and nontraditional routes to space development, including a much wider range of federal government organizations and the growing number of state spaceport authorities and other organizations developing needed infrastructure. Finally, the United States should make comprehensive and careful exploration of the potential of space-based solar power its leading pathfinder in creating a vision for developing spacepower. Working toward harvesting this unlimited power source in economically viable ways will require development of appropriate supporting structures, particularly with respect to incentives, indemnification, and potential public-private partnerships.

Better spacepower theory should also provide guidance on better ways to implement global licensing and export controls for space technology. It is understandable that many states view space technology as a key strategic resource and are very concerned about developing, protecting, and preventing the proliferation of this technology, but the international community, and the United States in particular, needs to find better legal mechanisms to balance and advance objectives in this area. Many current problems with US export controls began after Hughes and Loral worked with insurance companies to analyze Chinese launch failures in January 1995 and February 1996. A congressional review completed in 1998 (Cox Report) determined these analyses violated the International Traffic in Arms Regulations (ITAR) by communicating technical information to the Chinese. The 1999 National Defense Authorization Act transferred export controls for all satellites and related items from the Commerce Department to the Munitions List administered by the State Department.[9] The stringent Munitions List controls contributed to a severe downturn in US satellite exports. To avoid these restrictions, foreign satellite manufacturers, beginning in 2002 with Alcatel Space (now Thales) and followed by European Aeronautic Defense and Space (EADS), Surrey Satellite Company, and others, replaced all US-built components on their satellites to make them "ITAR-free" (de Selding 2005; Barrie and Taverna 2006).

Following the recommendations for rebalancing overall US export control priorities in the congressionally mandated National Academies of Science (NAS) study (National Research Council 2009), the Center for Strategic and International Studies (CSIS) study on the space industrial base (Briefing of the working group on the health of the U.S. space industrial base and the impact of export controls 2008), and the congressionally mandated section 1248 report completed by the Departments of State and Defense that assessed risks associated with removing satellites and related components from the US Munitions List, both the Obama Administration and Congress are moving toward reforming US export controls in significant ways. The administration's proposal was advanced in August 2009 and called for "four singles:" a single export control licensing agency for both dual-use and munitions exports, a unified control list, a single enforcement coordination agency, and a single integrated information technology (IT) system supporting the export control process. There are two key reasons why the United States should move away from the priorities in its current space export control regime: First, an overly broad approach that tries to protect too many things dilutes resources and actually results in less protection for "crown jewels" than does a focused approach; and second, a more open approach is more likely to foster innovation, spur development of sectors of comparative advantage, and improve efficiency and overall economic growth.

## 5.6 Spacepower Theory, Environmental Sustainability, and Survival

The area where insights from spacepower theory undoubtedly could help provide the most significant contributions would be in improving environmental sustainability and humanity's odds for survival. More mature and robust spacepower

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[9] The January 1995 failure was a Long March 2E rocket carrying Hughes-built Apstar 2 spacecraft and the February 1996 failure was a Long March 3B rocket carrying Space Systems/Loral-built Intelsat 708 spacecraft. Representative Christopher Cox (R.-California) led a 6-month long House Select Committee investigation that produced the "U.S. National Security and Military/Commercial Concerns with the People's Republic of China" Report released on 25 May 1999. The report is available from http://www.house.gov/coxreport. In January of 2002, Loral agreed to pay the U.S. government $20 million to settle the charges of the illegal technology transfer and in March of 2003, Boeing agreed to pay $32 million for the role of Hughes (which Boeing acquired in 2000). Requirements for transferring controls back to State are in Sections 1513 and 1516 of the Fiscal Year 1999 National Defense Authorization Act. Related items are defined as "satellite fuel, ground support equipment, test equipment, payload adapter or interface hardware, replacement parts, and non-embedded solid propellant orbit transfer engines."

theory is needed, because advancements in these areas face a number of daunting challenges, including a high “giggle factor,” very long timelines that can be beyond our political and personal awareness, and potential returns that are uncertain and intangible. While difficult, work in these areas is absolutely critical, since it may hold the key to humanity’s very survival, and it must be pursued with all the resources, consistency, and seriousness it deserves. The quest to improve the ways spacepower theory can support environmental and survival objectives should focus in three areas: space debris, environmental monitoring, and planetary defense.

Human space activity produces many orbital objects; when these objects no longer serve a useful function, they are classified as space debris. Over time, human activity has generated an increasing amount of debris from a variety of causes; the number of cataloged debris objects has gone from about 8,000 to over 22,000 over the past 20 years. The most serious cause of debris is deliberate hypervelocity impacts between large objects at high orbital altitudes such as the Chinese direct ascent kinetic energy ASAT weapon test of January 2007. If current trends continue, there is growing risk that space, and LEO in particular, will become increasingly unusable. Fortunately, there is also growing awareness and earnestness across the international community in addressing this threat. Overall goals for space-faring actors with respect to space debris include minimizing its creation while mitigating and remediating its effects – spacepower theory can play an important role in raising awareness and providing guidance in all these areas. Key approaches to minimizing creation of debris and mitigating against its effects are commercial best practices and evolving regimes such as the IADC voluntary guidelines. Space-faring actors need to consider mechanisms to transition these voluntary guidelines into more binding standards and ways to impose specific costs such as sanctions or fines on actors that deliberately or negligently create long-lived debris. Fines could be applied toward efforts to further develop and educate space-faring actors about the debris mitigation regime as well as to create, implement, and improve remediation techniques. An additional potential source of funding for mitigation and remediation would be establishing auctions for the radio frequency spectrum controlled by the ITU that would be analogous to the spectrum auctions conducted at the national level by organizations like the Federal Communications Commission. Finally, it must be emphasized that techniques for remediating debris using lasers or other methods are likely to have significant potential as ASAT weapons, and very careful consideration should be given to how and by whom such systems are operated.

Space provides a unique location to monitor and potentially remediate Earth’s climate. It is the only location from which simultaneous in situ observations of Earth’s climate activity can be conducted and such observations are essential to develop a long-term understanding of potential changes in our biosphere. Because so much is riding on our understanding of the global climate and our potential responses to perceived changes, spacepower theory could play a particularly important role in helping us apply apolitical standards in getting the science right and controlling for known space effects such as solar cycles when making these observations and building climate models. If fears about global warming are correct and the global community wishes to take active measures to remediate these effects, space also provides a unique location to operate remediation options such as orbital solar shades.

It is also imperative that the United States and all space-faring actors use insights from spacepower theory and other sources to be more proactive, think more creatively, and transcend traditional approaches toward emerging threats to our survival. Spacepower theory can help to illuminate paths toward and develop incentives to create a better future. Space, perhaps more than any other medium, is inherently linked to humanity's future and very survival. We need to link these ideas together and better articulate ways spacepower can light a path towards genuinely cooperative approaches for protecting the Earth and space environments from cataclysmic events such as large objects that may collide with Earth or gamma ray bursts that have the potential to extinguish all life on Earth if we are unlucky enough to be in their path. Better knowledge about known threats such as near-Earth objects (NEOs) is being developed, but more urgency is required. The predicted near approach and potential impact of the asteroid Apophis on 13 April 2029 ought to serve as a critical real-world test for our ability to be proactive in developing effective precision tracking and NEO mitigation capabilities. In the near term, it is most important for national and international organizations to be specifically charged with developing better understanding of NEO threats and developing avoidance techniques that can be effectively applied against likely impacts. Ultimately, however, as any robust and comprehensive spacepower theory would tell us, we cannot know of or effectively plan for all potential threats but should pursue multidimensional approaches to develop capabilities to improve our odds for survival and one day perhaps become a multi-planetary species.

## 5.7 Conclusions

This chapter briefly reviewed noteworthy efforts to develop spacepower theory, considered ways it could help to refine current US space policy, and used it to address some of humanity's most significant space challenges including space security, space commercialization, and environmental sustainability and survival. Spacepower theory can describe, explain, and predict how individuals, groups, and states can best derive utility, balance investments, and reduce risks in their interactions with the cosmos; it should be more fully developed and become a source for critical insights. It could help to guide us toward better ways to generate wealth in space, make tradeoffs between space investments and other important goals, reorder terrestrial security dynamics as space becomes increasingly militarized and potentially weaponized, and seize exploration and survival opportunities that only space can provide.

There will be inevitable missteps, setbacks, and unintended consequences, but the inexorable laws of physics and of human interaction indicate that we will create the best opportunities for success in advancing spacepower by beginning long-term, patient work now rather than a crash program later. Spacepower theory should provide an essential foundation for this progress.

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# The Laws of War in Outer Space

## 6

Steven Freeland

## Contents

### Abstract

The international regulation of outer space is "embedded" in international law. It is not an esoteric and separate paradigm. Indeed, the main United Nations Space Treaty, the Outer Space Treaty, expressly confirms that the principles of international law apply to the use and exploration of outer space. Given the development of technology, outer space is more frequently being used during the course of armed conflict, particularly through the use of sophisticated satellite technology, notwithstanding the "peaceful purposes" provisions of that Treaty. Not only does this give

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rise to difficult international law issues relating to the use of force, but it also requires an understanding of how and to what extent the international law principles of *jus in bello* – international humanitarian law – apply to the conduct of these outer space activities. The position is complicated further by the growing number of “dual use” satellites that simultaneously provide capacity to both commercial/ civilian users and the military. This chapter examines a number of specific aspects of the *jus in bello* principles as they relate to the use of outer space, as well as more recent initiatives aimed at attempting to provide further clarity to the applicable rules. Although international humanitarian law does apply to activities in outer space, the existing principles may not be specific enough to provide appropriate regulation for the increasingly diverse ways in which outer space could be used during the course of armed conflict. There is therefore a growing need to reach a consensus on additional legal regulation directly applicable to the conduct of armed conflict that may involve the use of space technology.

## 6.1 Introduction

It is now more than 50 years since humankind began its “adventures” in outer space. On 4 October 1957, a Soviet space object, Sputnik I, was launched and subsequently orbited the Earth over 1,400 times during the following 3-month period. This milestone heralded the dawn of the space age, the space race (initially between the USSR and the United States), and the legal regulation of the use and exploration of outer space. Since then, laws have developed that significantly improve the standard of living for all humanity, through, for example, the facilitation of public services such as satellite telecommunications, global positioning systems, remote sensing technology for weather forecasting and disaster management, and television broadcast from satellites. The prospects for the future use of outer space offer both tremendous opportunities and challenges for humankind, and law will continue to play a crucial role in this regard.

One of the crucial elements in this matrix of legal regulation is the avoidance of armed conflict in outer space. It is no coincidence that the space race emerged at the height of the Cold War, when both the United States and the USSR strove to flex their respective technological “muscles.” This was a period of quite considerable tension, with the possibility of large-scale and potentially highly destructive military conflict between the (space) superpowers of the time always lurking in the background. Indeed, it was only a few short years after Sputnik I that the world held its breath during the so-called Cuban Missile Crisis in October 1962. Within this highly sensitive context, it was vital that efforts were made by the international community to regulate this new frontier – outer space – to avoid a buildup of weapons in space (in more modern parlance, referred to as the “prevention of an arms race in outer space” (PAROS)).

However, the conventional obligations and restrictions that were eventually agreed and codified in the major space treaties were, as described below, neither entirely clear nor sufficiently comprehensive to meet all of these challenges.

While most space scholars would interpret the relevant provisions as prohibiting military space activities in outer space, this was not followed by the practice of those who had the capability to utilize space technology. With the benefit of hindsight, it is now clear that space has been utilized for military activities almost from the time of the very infancy of space activities.

Since those early days, the situation has, if anything, become significantly more complex, with potentially drastic and catastrophic consequences. Just as the major spacefaring nations have been undertaking what might be termed "passive" military activities in outer space since the advent of space technology, outer space is increasingly now being used as part of active engagement in the conduct of armed conflict (Ricks 2001). Not only is information gathered from outer space – through, for example, the use of remote satellite technology and communications satellites – used to plan military engagement on Earth, but space assets are now used to direct military activity and represent an integral part of the military hardware of the major powers. It is now within the realms of reality to imagine outer space as an emerging theatre of warfare.

With these developments in mind, this chapter focuses on the (possible) application of the current laws of war to the use of outer space. While it is clear that outer space has been and is being used for military purposes, what is not straightforward is precisely how various aspects of these activities are regulated at the international level. Instead, what appears from an analysis of the current position is that, to the extent that existing *jus in bello* principles are applicable to space-related activities, there are undoubtedly some circumstances in which their scope of application might not be satisfactory or appropriate, particularly given the unique environment of outer space.

Accordingly, this chapter will first describe a concrete example of how space "weaponization" and "militarization" is continuing, with very serious political consequences. It will then briefly outline the fundamental principles governing the international legal regulation of outer space and focus more specifically on those that are most relevant to military and warfare-related activities that utilize space technology. Following on from this, there will be a brief description of the general principles that govern the laws of war, before a discussion of their relevance to outer space. This chapter will then outline a number of initiatives designed to (possibly) fill some of the lacunae that appear to exist within the current legal regime, before making some more general observations regarding the way forward in terms of legal regulation.

In the end, although the laws of war do (in theory) appear to apply to activities in outer space, the principles may not be specific enough to provide appropriate regulation for the increasingly diverse ways in which outer space could be used during the course of armed conflict. There is therefore a growing need to reach a consensus on additional legal regulation directly applicable to the conduct of armed conflict that may involve the use of space technology. This will require political will, close cooperation, and greater trust between the major space powers, supported by other States and the international community, if a legal regime that is capable of providing more certainty and comfort is to be established, so as to lessen the chances of a conflagration involving space assets, with all of the negative and unknown consequences that this would entail.

## 6.2 A Case in Point: The Development of Ballistic Missile Defense Systems

On 14 December 2001, in an effort to consolidate its policy of "space control," US President George Bush announced the withdrawal of the United States from the Treaty on the Limitation of Anti-Ballistic Missile Systems (ABM Treaty), by invoking Article 15 of that instrument.[1] The key reason given by President Bush for the decision to withdraw from the treaty was because it was outdated and a relic of the Cold War (Diamond 2001). However, there was a more practical purpose, since the ABM Treaty expressly prohibited the development, testing, and deployment of sea-based, air-based, space-based, and mobile land-based ABM systems.[2] As a result, withdrawal from the ABM Treaty removed conventional restrictions on the United States to develop what would otherwise have been expressly prohibited weapon systems and, in particular, space-based devices that it perceived as forming an integral part of its policy to ensure that it retained its military dominance.

The genesis of the 2001 decision by the Bush administration can be traced back to the first Gulf War. During that conflict, the Patriot batteries deployed by Israel helped make a case for the role of theatre missile defense. In light of this, pressure began building in the United States to either loosen or completely divest its antiballistic missile technology from the constraints of the ABM Treaty. On 5 December 1991, shortly after the conclusion of the Gulf War, the US Congress passed the Missile Defense Act of 1991 (Missile Defense Act of 1991, §§ 231–40). This legislative enactment put Congress on record as officially supporting a National Missile Defense program. It stated in part that (Missile Defense Act of 1991, § 232 (a) (1)):

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[1] Anti-Ballistic Missile Systems Treaty, U.S.- U.S.S.R., 26 May 1972, 23 U.S.T. 3435. Article XV of the ABM Treaty provides as follows:

"1. This Treaty shall be of unlimited duration.

2. Each Party shall, in exercising its national sovereignty, have the right to withdraw from this Treaty if it decides that extraordinary events related to the subject matter of this Treaty have jeopardized its supreme interests. It shall give notice of its decision to the other Party six months prior to withdrawal from the Treaty. Such notice shall include a statement of the extraordinary events the notifying Party regards as having jeopardized its supreme interests."

See also Maogoto and Freeland (2007b).

[2] ABM Treaty, Article V.

> [i]t is a goal of the United States to deploy an anti-ballistic missile system, including one or an adequate additional number of anti-ballistic missile sites and space-based sensors, that is capable of providing a highly effective defense of the United States against limited attacks of ballistic missiles.

Four years later, a bill was introduced in Congress entitled the Defend America Act (Defend America Act of 1995, § 1). Section four of that instrument provided that, within 1 year of its enactment, there should be at least one test of either an ABM interceptor based in space, a sensor in space capable of providing data directly to an ABM interceptor, or an existing air defense, theatre missile defense, or early warning system, so as to demonstrate the country's capability to counter strategic ballistic missiles or their elements in flight trajectory (Defend America Act of 1995, § 4).

In the same year, an almost identical provision was inserted into the Ballistic Missile Defense Act (National Defense Authorization Act For Fiscal Year 1996 1995). The legislation sought to allow deployment of multiple ground-based ABM sites to provide effective defense of the United States against a limited ballistic missile attack; unrestricted use of sensors based within the atmosphere and in space; and increased flexibility for the development, testing, and deployment of follow-on national missile defense systems. With the introduction of these initiatives, the future of the ABM Treaty was doomed, since it purported to restrain these emerging military and technological goals.

Since the 2001 decision to withdraw from the ABM Treaty, the United States has been actively pursuing innovative military technology that it considers as essential to its decision to not only establish a national ballistic missile defense system (BMD) but to also place important elements of it in strategic locations overseas. This strategy has led to a chorus of protests, particularly from the United States' principal military – and space – competitors, Russia and China. These protests intensified, specifically from the former, as a consequence of the decision by the United States in 2006 to locate parts of the system in Poland and the Czech Republic, following detailed bilateral talks with those two countries.

Although, following its election into power, the Obama administration initially halted the Eastern European part of the program, this has recently been revived in a new format, referred to as a "European Phased Adaptive Approach" (EPAA), involving a number of former communist bloc countries. While there had been some hope at the NATO summit in Lisbon in 2010 that the development of the BMD would proceed with Russia as a "partner," this now appears far less likely (Ischinger 2012).

In early May 2012, US Assistant Secretary of Defense Madelyn Creedon argued at a conference in Moscow that the EPAA was not a threat to Russia and that missile defense cooperation was "in the national security interest of all parties: the U.S., NATO, and Russia alike" (Creedon 2012). Yet, almost immediately thereafter, Russia's most senior military commander, General Nikolai Makarov, responded by warning NATO that it would consider preemptive military strikes in Poland and Romania if a missile defense radar system and interceptors are deployed in Eastern Europe (Kramer 2012). It is clear, therefore, that the development of such systems gives rise to considerable tensions and disagreements.[3]

At the same time, China has been rapidly consolidating its status as a space power, adding further to the tensions relating to space-related weapons technology. The first Gulf War had demonstrated to China's military leadership the importance of high-tech integrated warfare platforms and the ability of sophisticated space-based command, control, communications, and intelligence systems to link land, sea, and air forces. While one of the strongest immediate motivations for its space program appears to be political prestige, China's space efforts will almost certainly contribute to the development of improved military space systems.

Indeed, in January 2007, the Chinese military launched a KT-1 rocket that successfully destroyed a redundant Chinese Fengyun 1-C weather satellite, which it had launched in 1999, in low Earth orbit approximately 800 km above the Earth. This generated a great deal of alarm and unease in Washington and elsewhere, particularly as it indicated quite clearly the increasing technological capabilities of the Chinese military.[4] With China predicted by many to become the ascendant superpower in the twenty-first century, this space technology rivalry (particularly regarding its military utility) among the major space powers appears to be intensifying.

Each of these developments indicates a rapidly expanding perception among these major powers of the need for space-based systems in support of military operations. This perception is being translated into reality by the very significant resources now devoted by each of them to the development of evermore effective (and potent) space-related weaponry. It is important, therefore, to consider how the existing international legal framework governing the regulation of outer space may apply to such developments. This involves a consideration of both the general principles of international space law and an analysis of those specific provisions that are directed towards regulating the military uses of outer space.

## 6.3 The International Legal Regulation of Outer Space

### 6.3.1 General Principles of Space Law

The journey of Sputnik I immediately gave rise to difficult and controversial legal questions, involving previously undetermined concepts. Some earlier scholarship considered the nature and scope of laws that might apply to the exploration and use of outer space, but only at a hypothetical level.[5] However, history changed forever

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[3] Compare, for example, the views of Ivo Daalder (permanent representative of the United States to NATO) in "A new shield over Europe," *International Herald Tribune*, 7 June 2012, 6, with those of Nikolai Korchunov (acting permanent representative of Russia to NATO) published on the same page, "You say defense, we see threat," *International Herald Tribune*, 7 June 2012, 6.

[4] See, for example, Gordon and Cloud (2007), Spiegel (2007).

[5] For a summary of the main academic theories relating to "space law" in the period prior to the launch of Sputnik I, see, for example, Lyall and Larsen (2009).

on that day in 1957. Suddenly, the reality of humankind's aspirations and capabilities with respect to outer space became apparent. The world had to react, quickly, to an unprecedented event in an unregulated legal environment, particularly because it was clear that this was just the dawn of a quest to undertake a wide range of space activities.

Moreover, these embryonic space activities, and the rapid development of space technology that subsequently followed, were largely driven at the time by the geopolitical situation – predominantly the state of Cold War that prevailed between the two major (space) powers, the United States and the USSR. It is clear that the desire for ever-increasing technological prowess was as much motivated by military considerations as a wish to explore and use space for other (scientific) purposes, although no doubt these were also of relevance. It was in this context that the international community had to react, as it walked a fine balancing line between the wishes of these two superpowers on the one hand, and a general sense of uncertainty as to where exactly these military-driven achievements might ultimately lead on the other.

It was not a coincidence, therefore, that, shortly after the Sputnik I launch, the United Nations established a new committee to take primary responsibility for the development and codification of the fundamental rules relating to the use and exploration of outer space with the name of United Nations Committee on the *Peaceful* Uses of Outer Space (UNCOPUOS).[6] An ad hoc Committee on the Peaceful Uses of Outer Space, with 18 initial member states, was established in 1958 by the United Nations General Assembly,[7] which subsequently converted it into a permanent body in 1959.[8] UNCOPUOS is now the principal multilateral body involved in the development of international space law.

As to legal principles, first and foremost, Sputnik necessitated a clarification as to the legal categorization of outer space for the purposes of international law. As a preliminary matter, in order to be in a position to do this, one would naturally expect to require a legal definition of what constitutes outer space; i.e., where does outer space begin? Indeed, this was the first issue that the United Nations put to UNCOPUOS. While many theories have been proposed since then, quite remarkably (at least for those not involved in the diplomatic discussions), the question of

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[6] Emphasis added.

[7] See United Nations General Assembly Resolution 1348 (XIII) on Questions on the Peaceful Uses of Outer Space (13 December 1958). The 18 States were Argentina, Australia, Belgium, Brazil, Canada, Czechoslovakia, France, India, Iran, Italy, Japan, Mexico, Poland, Sweden, the Union of Soviet Socialist Republics, the United Arab Republic, the United Kingdom of Great Britain and Northern Ireland and the United States.

[8] See United Nations General Assembly Resolution 1472 (XIV) on International Cooperation in the Peaceful Uses of Outer Space (12 December 1959). In addition to the original 18 States, Albania, Austria, Bulgaria, Hungary, Lebanon, and Romania were included at that time as member states of this permanent body. UNCOPUOS currently has 71 members (the latest being Azerbaijan in early 2012), which, according to its website, means that it is "one of the largest Committees in the United Nations": http://www.unoosa.org/oosa/en/COPUOS/members.html (last accessed 8 June 2012). In addition to States, a number of international organizations, including both intergovernmental and nongovernmental organizations, have observer status with UNCOPUOS.

where air space "ends" and outer space "begins" has thus far remained unanswered from an international legal viewpoint.

Although the USSR had not sought the permission of other States to undertake the Sputnik mission, there were no significant protests that this artificial satellite had infringed on any country's sovereignty as it circled the Earth. This international (in)action confirmed that this new frontier of human activity did not possess the elements of sovereignty that had already been well established under the international law principles regulating land, sea, and air space on Earth. As was observed by Judge Manfred Lachs of the International Court of Justice (North Sea Continental Shelf Cases (Federal Republic of Germany v. Denmark and Federal Republic of Germany v. The Netherlands) 1969):

> [t]he first instruments that men sent into outer space traversed the air space of States and circled above them in outer space, yet the launching States sought no permission, nor did the other States protest. This is how the freedom of movement into outer space, and in it, came to be established and recognised as law within a remarkably short period of time.

However, notwithstanding the lack of a clear definition of outer space, a number of fundamental legal principles relating to the exploration and use of outer space emerged quickly, although the negotiations directed towards expressing these into a conventional form took more time. This was due to a number of causes, including the unique environment with which it would have to deal, the very significant political and strategic factors at play, and the rapid growth of space-related technology that followed almost immediately from the Sputnik success.

Thus, almost immediately after humankind began its quest to explore and use outer space, a number of foundational principles of the international law of outer space were born – in particular the so-called "common interest," "freedom," and "non-appropriation" principles. These principles were later incorporated into the terms of the United Nations Space Law Treaties,[9] with the result that they also constitute binding conventional rules, codifying what had already amounted to principles of customary international law. In essence, the community of States, including both of the major spacefaring States of the time, had accepted that outer space was to be regarded as being similar to a *res communis omnium* (Cassese 2005).

These three fundamental rules underpinning the international law of outer space represent a significant departure from the legal rules relating to air space, which is categorized as constituting part of the "territory" of the underlying State. The territorial nature of air space is reflected in the principal air law treaties. For example, reaffirming the principle already acknowledged as early as in 1919, (Convention on the Regulation of Aerial Navigation 11 L.N.T.S. 173) the 1944 Convention on International Civil Aviation

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[9] See, for example, Articles I and II of the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies.

(15 U.N.T.S. 295a) provides that "every State has complete and exclusive sovereignty over the air space above its territory."[10]

The International Court of Justice has confirmed that this characteristic of air space also represents customary international law.[11] As a consequence, civil and commercial aircrafts have only certain limited rights to enter the air space of another State (Articles 5 and 6, 15 U.N.T.S. 295b), in contrast to the freedom principle relating to outer space.[12] Even though, as noted above, a demarcation between air space and outer space has not yet definitively emerged – at least thus far – this has not in practice led to any significant confusion as to "which law" might apply in particular circumstances.[13]

By contrast to the position regarding airspace, Article II of the Outer Space Treaty encompasses the so-called "non-appropriation" principle, which is regarded as one of the most fundamental rules regulating the exploration and use of outer space.[14] The provision reads:

> Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.

In general terms, Article II confirms that outer space (which includes the Moon and other celestial bodies) is not subject to ownership rights and prohibits inter alia any sovereign or territorial claims to outer space. Outer space therefore is not to be regarded as "territorial," a principle that, by the time the treaty was concluded in 1967, was already well accepted in practice.

Indeed, by the time that the Outer Space Treaty was finalized, both the United States and the USSR had already been engaged in an extensive range of space activities; yet neither had made a claim to sovereignty over any part of outer space, including celestial bodies, notwithstanding the planting by the Apollo 11 astronauts

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[10] Chicago Convention, Article 1. For the purposes of the Chicago Convention, the territory of a State is regarded as "the land areas and territorial waters adjacent thereto under the sovereignty, suzerainty, protection or mandate of such State": Chicago Convention, Article 2.

[11] In *Case Concerning Military and Paramilitary Activities in and against Nicaragua (Nicaragua v. United States)* (Merits) (Judgment), the court noted that "[t]he principle of respect for territorial sovereignty is also directly infringed by the unauthorized overflight of a State's territory by aircraft belonging to or under the control of the government of another State": [1986] ICJ Rep 14, 128.

[12] Of course, any space activities requiring a launch from Earth and/or a return to Earth will also involve a "use" of air space. In this respect, the law of air space may be relevant to the legal position if, for example, the space object of one State travels through the air space of another State. See also Article II of the Liability Convention, which applies inter alia to "aircraft in flight" (i.e., in air space).

[13] However, as the range of activities in outer space becomes ever broader, the issue will become more important in relation not only to the broad principles of international space law but also on a practical level – for example, to the regulation of commercial suborbital space tourism activities, which, at least under current technological constraints, involve paying passengers being taken to an altitude slightly in excess of 100 kilometers above the Earth: see Freeland (2010b).

[14] For a detailed analysis of Article II of the Outer Space Treaty, see Freeland and Jakhu (2009).

of an American flag on the surface of the Moon.[15] As a result, although it was of great importance to formalize this principle of non-appropriation of outer space, the drafting process leading to the finalization of Article II of the Outer Space Treaty was relatively uncontroversial, particularly given its early acceptance as a fundamental concept by these two spacefaring States.

It is no coincidence that the non-appropriation principle is set out immediately following Article I of the Outer Space Treaty, which elaborates on the "common interest" and "freedom" principles and confirms that the exploration and use of outer space is to be undertaken "for the benefit and in the interests of all countries" and freely "by all States without discrimination of any kind, on a basis of equality and in accordance with international law." In general terms, the primary intent of Article II was to reinforce these important concepts by confirming that principles of territorial sovereignty do not apply to outer space. Not only does this reflect the practice of States from virtually the beginning of the space age,[16] but it also helps to protect outer space from the possibility of conflict driven by territorial or colonizing ambitions.

In this regard, the US delegate to UNCOPUOS, Mr. Herbert Reis, reiterated the specific object and purpose of Article II on 31 July 1969, just a matter of days after the Apollo 11 astronauts had landed on the Moon, as follows (Valters 1970):

> The negotiating history of the Treaty shows that the purpose of this provision (i.e. Article II) was to prohibit a repetition of the race for the acquisition of national sovereignty over overseas territories that developed in the sixteenth, seventeenth, eighteenth and nineteenth centuries. The Treaty makes clear that no user of space may lay claim to, or seek to establish, national sovereignty over outer space.

In this regard, the sentiments reflected in Article II of the Outer Space Treaty are fundamental to the regulation of outer space and its exploration and use for peaceful purposes. It is for these reasons that a binding principle of non-appropriation is an essential element of international space law, to be preserved and followed in the conduct of all activities in outer space.

Unlike the corresponding provision in United Nations Convention on the Law of the Sea (UNCLOS) dealing with the high seas, Article II does not

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[15] This is to be compared with the situation in Antarctica, which had seen a series of sovereign claims by several States in the period leading up to the finalization in 1959 of the Antarctic Treaty, 402 U.N.T.S. 71. Article IV of the Antarctic Treaty has the effect of suspending all claims to territorial sovereignty in Antarctica for the duration of that instrument, as well as prohibiting any "new claim, or enlargement of an existing claim." The Protocol on Environmental Protection to the Antarctic Treaty, 30 I.L.M. 1455, which came into force in 1998, augments the Antarctic Treaty by protecting Antarctica from commercial mining for a period of 50 years.

[16] There has, however, been one notable exception in this regard – the Bogota Declaration. In 1976, a number of equatorial States – including Brazil, Colombia, the Congo, Ecuador, Indonesia, Kenya, Uganda, and Zaire – issued the Bogota Declaration, in which they claimed sovereign rights over segments of geostationary synchronous orbit above their respective territories. They asserted their claims principally because of the lack of an accepted delimitation between airspace and outer space. Such assertions were strenuously opposed by other States and have not been successful.

expressly limit itself to the purported actions of States[17]; rather, the provision is drafted in more general terms, in that it seeks to prohibit specific actions that constitute a "national appropriation."[18] With the obvious exception of the reference to "by claim of sovereignty," there is no express limitation in Article II *only* to the actions of States. This has, over the years, given rise to frequent debate among commentators as to the precise scope of the prohibition and, more particularly, the extent (if at all) to which "private property rights" (Harris 2004) may exist in outer space, notwithstanding (or perhaps as a result of) the terms of Article II.

In other aspects, the degree to which international law governs outer space is not entirely clear. The Outer Space Treaty affirms that activities in space are to be carried on "in accordance with international law" (Article III, 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies), but the fact that most existing international law at the time was developed for "terrestrial" purposes meant that it was not readily or directly applicable in every respect to this new paradigm of human endeavor. Moreover, the non-sovereignty aspect of outer space meant that any then existent national law (which, in any event, did not at that time specifically address space-related issues) would not prima facie apply to this frontier and would not be the appropriate legal basis upon which to establish the initial framework for regulating the conduct of humankind's activities in outer space. It was clear, therefore, that, at the dawn of the development of "space law," specific international binding rules would be required to address the particular characteristics and legal categorization of outer space.

The law of outer space has developed as a body of law that is embedded within general public international law. Since the launch of Sputnik I, this process of evolution has been remarkably rapid, largely driven by the need to agree on rules to regulate activities in this new "frontier." There is now a substantial body of law dealing with many aspects of the use and exploration of outer space,

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[17] But note UNCLOS, Article 137(1), which provides that:

"No State shall claim or exercise sovereignty or sovereign rights over any part of the Area or its resources, nor shall any State or *natural or juridical person* appropriate any part thereof. No such claim or exercise of sovereignty or sovereign rights nor such appropriation shall be recognized" (emphasis added).

[18] One should note, however, that the Chinese version of the Outer Space Treaty differs in this respect from all other versions, in that it prohibits appropriation "through the state by asserting sovereignty, use, occupation or any other means." In accordance with Article XVII of the Outer Space Treaty, the Chinese version is "equally authentic" with all other versions. However, it has also been noted that the fact that the other four versions (English, Russian, French, and Spanish) all concur on the text of the provision is significant, "the more so if they include the languages which were mostly used in negotiations of the [Outer Space Treaty]": V. Kopal, "Comments on the issue of 'Adequacy of the Current Legal and Regulatory Framework Relating to the Extraction and Appropriation of Natural Resources of the Moon'" in Institute of Air and Space Law, McGill University, *Policy and Law Relating to Outer Space Resources: Examples of the Moon, Mars, and other Celestial Bodies*, Workshop Proceedings (28–30 June 2006) 227, 230.

mainly codified in and evidenced by treaties, United Nations General Assembly resolutions, national legislation, the decisions of national courts, bilateral arrangements, and determinations by intergovernmental organizations.

Five important multilateral treaties have been finalized through the auspices of UNCOPUOS.[19] These are:

(i) 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies (610 U.N.T.S. 205a)
(ii) 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (672 U.N.T.S. 119)
(iii) 1972 Convention on International Liability for Damage Caused by Space Objects (961 U.N.T.S. 187)
(iv) 1975 Convention on Registration of Objects Launched into Outer Space (1023 U.N.T.S. 15)
(v) 1979 Agreement Governing the Activities of States on the Moon and other Celestial Bodies (1363 U.N.T.S. 3)

Among other important principles, these United Nations Space Treaties confirm that the use and exploration of outer space is to be for "peaceful purposes," (Article IV, 610 U.N.T.S. 205b) although this principle has been highly controversial – arguments still persist as to whether this refers to "nonmilitary" or "nonaggressive" activities (see further below). The United Nations Space Treaties were formulated in an era when only a small number of countries had spacefaring capability. The international law of outer space thus, at least partially, reflects the political pressures imposed by the superpowers at that time.

The United Nations General Assembly has also adopted a number of space-related principles, which include:

(i) 1963 Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space (United Nations General Assembly Resolution 1962 (XVIII) on the Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space 1963a)
(ii) 1982 Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting (United Nations General Assembly Resolution No 37/92 on the Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting 1982)
(iii) 1986 Principles Relating to Remote Sensing of the Earth from Outer Space (United Nations General Assembly Resolution No 41/65 on the Principles relating to Remote Sensing of the Earth from Outer Space 1986)

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[19] UNCOPUOS was established by the United Nations General Assembly in 1959, shortly after the successful launch of Sputnik 1: see United Nations General Assembly Resolution 1472 (XIV) on International Cooperation in the Peaceful Uses of Outer Space (1959).

(iv) 1992 Principles Relevant to the Use of Nuclear Power Sources in Outer Space (United Nations General Assembly Resolution No 47/68 on the Principles relevant to the Use of Nuclear Power Sources in Outer Space 1992)

(v) 1996 Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries (United Nations General Assembly Resolution No 51/122 on the Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries 1996)

These sets of principles provide for the application of international law and the promotion of international cooperation and understanding in space activities, the dissemination and exchange of information through transnational direct television broadcasting via satellites and remote satellite observations of the Earth, and general standards regulating the safe use of nuclear power sources necessary for the exploration and use of outer space. More recent "guidelines" have also been agreed relating to various other issues, including the problem of space debris.[20]

It is generally agreed that Resolutions of the United Nations General Assembly are non-binding, at least within the traditional analysis of the "sources" of international law specified in Article 38(1) of the Statute of the International Court of Justice.[21] In the context of the regulation of the use and exploration of outer space, these five sets of principles have therefore largely been considered as constituting "soft law" (Freeland 2012), although a number of specific provisions may now represent customary international law.

Yet, despite all of these developments, it is clear that the existing legal and regulatory regime has not kept pace with the remarkable technological and commercial progress of space activities since 1957. This represents a major challenge in relation to the ongoing development of effective legal principles, all the more in view of the strategic and military potential of outer space in an era of globalization.

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[20] See, for example, UNCOPUOS (2007)

[21] 1 U.N.T.S. 16 (ICJ Statute). It is generally asserted by international law scholars that article 38(1) of the ICJ Statute lists the so-called sources of international law: see, for example, Schwarzenberger (1957), Cassese (2005). Article 38(1) of the ICJ Statute provides as follows:

"The Court, whose function is to decide in accordance with international law such disputes as are submitted to it, shall apply:

a. international conventions, whether general or particular, establishing rules expressly recognized by the contesting states;

b. international custom, as evidence of a general practice accepted as law;

c. the general principles of law recognized by civilized nations;

d. subject to the provisions of Article 59, judicial decisions and the teachings of the most highly qualified publicists of the various nations, as subsidiary means for the determination of rules of law."

### 6.3.2 Principles Regulating the "Military" Uses of Outer Space

As noted, the Outer Space Treaty provides a number of general principles that are intended to restrict the military uses of outer space, including the requirement that activities in the exploration and use of outer space shall be carried out "in accordance with international law, including the Charter of the United Nations."[22] One of the primary reasons for the inclusion of this provision was the concern among many States that outer space would become a new arena for international conflict. As a leading commentator, Bin Cheng, once aptly put it, "outer space brought with it a whole new ball game" (Cheng 1998).

Many of the fundamental principles that formed the basis of the Outer Space Treaty were concluded at a time when the world was in the midst of uncertainty and mistrust, largely as a result of the prevailing geopolitical environment of the Cold War. Almost as soon as Sputnik I was launched, the international community was concerned about the use of outer space for military purposes as well as the fear that it could perhaps ultimately become a theatre of war. In December 1958, the United Nations emphasized the need "to avoid the extension of present national rivalries into this new field" (United Nations General Assembly Resolution 1348 (XVIII) on the Question of the peaceful use of outer space 1958).

By 1961, the General Assembly had recommended that international law and the United Nations Charter should apply to "outer space and celestial bodies" (United Nations General Assembly Resolution 1721 (XVI) on International co-operation in the peaceful uses of outer space 1961). This was repeated in General Assembly Resolution 1962, which set out a number of important principles that were ultimately incorporated into the Outer Space Treaty (United Nations General Assembly Resolution 1962 (XVIII) on the Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space 1963b). The specific reference to the United Nations Charter was considered to be important, given that the maintenance of international peace and security is the underlying principle of the system established under that instrument.[23] The prohibition on the use of force contained in Article 2(4) of the United Nations Charter represents a crucial element in the regulation of international relations and is equally applicable to the use of outer space.[24]

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[22] Outer Space Treaty, article III. Article 2 of the Moon Agreement extends these sentiments by referring to "the Declaration on Principles of International Law concerning Friendly Relations and Co-operation among States in accordance with the Charter of the United Nations, adopted by the General Assembly on 25 October 1970."

[23] 1 U.N.T.S. xvi (892 U.N.T.S. 119). The first "Purpose" of the United Nations specified in article 1(1) of the United Nations Charter begins with the words: "To maintain international peace and security . . .

[24] Article 2(4) of the United Nations Charter provides: "All Members shall refrain in their international relations from the threat or use of force against the territorial integrity or political independence of any state, or in any other manner inconsistent with the Purposes of the United Nations."

The sentiments underlying the United Nations Charter were strengthened further by the restrictions imposed in relation to nuclear weapons and weapons of mass destruction by Article IV of the Outer Space Treaty, although, as has been well documented by leading commentators, this provision in and of itself does not represent a complete restriction on the placement of weapons in outer space, nor of their use.[25] Indeed, there have been, from time to time, proposals put forward to amend Article IV in order to enhance these restrictions, but this has not (yet) eventuated.[26]

The "peaceful purposes" provision set out in Article IV of the Outer Space Treaty has been the subject of much analytical discussion as to its scope and meaning. While there is general agreement – but not complete unanimity – among space law commentators that this is directed against "nonmilitary" rather than merely "nonaggressive" activities, the reality has, unfortunately, been different. As noted, it is undeniable that, in addition to the many commercial, civilian, and scientific uses, outer space has and continues to be used for an expanding array of military activities. Unless concrete steps are taken to arrest this trend – which will require a significant shift in political will, particularly among the major powers – it is likely that space will increasingly be utilized to further the military and strategic aims of specific countries, particularly as military and space technology continues to evolve and develop.

In this context, if one were to adopt a hard-line pragmatic view, it seems that the "nonmilitary vs. nonaggressive" debate relating to the peaceful purposes requirement is a redundant argument, even though it represents an extremely important issue of interpretation of the strict principles of international space law. In one sense, this assumes that the militarization of space is a given, as much as it pains international and space lawyers to admit this.

Moreover, Article 51 of the United Nations Charter – which confirms the "inherent right" of self-defense "if an armed attack occurs" – is also applicable to the legal regulation of outer space. Under the principles of public international law, this right remains subject to express legal limitations – the requirements of necessity and proportionality.[27] Even where the right of self-defense is lawfully exercised, the State so acting will remain subject to the laws of war. While this is, in theory, uncontroversial, the difficulty is to determine precisely whether (and how) these fundamental principles can be applied to the unique legal and technological context of outer space.

This is particularly relevant given that the use of satellite technology already represents an integral part of the military strategy and the conduct of many armed conflicts. As this technology continues to develop, the armed conflicts of the twenty-first century and beyond will increasingly involve the utilization of outer space.

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[25] For a detailed analysis of Article IV of the Outer Space Treaty, see Schrogl and Neumann (2009).

[26] See, for example, Bogomolov (1993), where the author refers to a failed Venezuelan proposal to amend Article IV.

[27] See *The Caroline Case* 29 B.F.S.P. 1137–1138; 30 B.F.S.P. 195–196, which also referred to a requirement of immediacy, although this was not mentioned in the more recent decision of the International Court of Justice in *Oil Platforms* (*Merits*) (*Iran v. United States*) [2003] ICJ Rep. 161.

In this regard, the United Nations is anxious to avoid a "weaponization" of outer space.[28] However, the current political momentum does, unfortunately, appear to be directed towards a greater incorporation of satellite technology in outer space as part of the course of warfare.

This is highly troubling and flies in the face of the principles of the Outer Space Treaty. Yet, it would be naive to ignore the realities – rather it is important both to understand what (and how) existing legal principles, including the rules of the laws of war, apply to any military activities involving outer space and to determine what needs to be done to provide, at least from a regulatory perspective, an appropriate framework to protect humankind in the future.

## 6.4 The Laws of War: General Principles

The principles of the laws of war (also known as international humanitarian law or the *jus in bello*) have emerged over time, as the international community has gradually agreed that there should be certain legal constraints applicable to the conduct of armed conflict. Wars have been with us since time immemorial and it has only been relatively recently that minimum international standards have been developed to regulate *how*, *with what*, and *against whom* they could be fought – in effect the rules that have developed are "intended to limit the terrible effects of war" (Legality of the Threat or Use of Nuclear Weapons 1996). Even though "war" as a concept was declared illegal by the 1928 Pact of Paris,[29] it is evident that armed conflict still continues and has become more complex, particularly given the increasing role of non-State actors. Moreover, the scope for cataclysmic destruction and loss of life has also increased due to the development of sophisticated weaponry, which includes the use of space technology.

The "laws and customs of war" had its origins in the customary practices of armies on the battlefield and has developed as an important branch of international law (Henckaerts and Doswald-Beck 2005, p. xxv). The application of these customary practices was not uniform, and it therefore became evident that more formalized standards were required. A major step forward in the development of the rules of war, which inter alia limit the method and means of conducting warfare and also provide for classes of protected persons and protected objects, came with the Brussels Conference of 1874 and, more significantly, the Hague Peace Conferences of 1899 and 1907, which gave rise to some important standard-setting treaties

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[28] Refer to the numerous United Nations General Assembly Resolutions, beginning with Resolution 36/97C (1981), which have all been directed towards the "Prevention of an arms race in outer space."

[29] Article I of the *General Treaty for the Renunciation of War* U.K.T.S. (1929) 29 provides:

"The High Contracting Parties solemnly declare in the names of their respective peoples that they condemn recourse to war for the solution of international controversies, and renounce it as an instrument of national policy in their relations with one another."

that are still applicable today. The 1899 Conference concluded that "[t]he right of belligerents to adopt means of injuring the enemy is not unlimited."[30]

Further treaties followed, specifying in greater detail the limits of what constituted (un)acceptable behavior in the context of armed conflict. As an example, those provisions of the Hague Conventions that applied the laws of war to restrict the use of poison or poisoned weapons and asphyxiating gases were further extended by the 1925 Geneva Protocol.[31]

The horrors of the Second World War demonstrated the inadequacy of the existing rules, particularly in relation to the treatment of civilians and noncombatants. The four 1949 Geneva Conventions were concluded to address these issues,[32] and these were strengthened by the Additional Protocols of 1977.[33] There have also been a growing number of other important treaties that have added to the corpus of international humanitarian law and the rules regulating armed conflict, particularly in relation to restrictions on specific weapons and means of warfare. Among these are several treaties that relate to the use of outer space, including those limiting the testing of nuclear and other weapons,[34] as well as the 1977 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), (16 I.L.M. 88) which was the first instrument that dealt with deliberate destruction of the environment during warfare, although it also applies in time of peace.

International humanitarian law is now a well-developed area of international law, covering many aspects of terrestrial warfare. The importance of the obligations arising under the fundamental principles, particularly those contained in the Hague Conventions and the Geneva Conventions and their Additional Protocols, has been reaffirmed by the United Nations Security Council.[35] In addition, the establishment of various national, regional, and international enforcement

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[30] 1899 Hague Convention II, [1907] Supp 1 *American Journal of International Law* 129.

[31] Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare, xciv L.N.T.S (1929) 65–74.

[32] Geneva Convention for the Amelioration of the Condition of the Wounded and Sick in Armed Forces in the Field 75 U.N.T.S. 31, Geneva Convention for the Amelioration of the Condition of the Wounded, Sick and Shipwrecked Members of Armed Forces at Sea 75 U.N.T.S. 85, Geneva Convention Relative to the Treatment of Prisoners of War 75 U.N.T.S. 135 and Geneva Convention Relative to the Protection of Civilian Persons in Time of War 75 U.N.T.S. 287.

[33] Protocol I Additional to the Geneva Conventions of August 12, 1949, and relating to the Protection of Victims of International Armed Conflicts (Additional Protocol I) 16 I.L.M. 1391 and Protocol II Additional to the Geneva Conventions of 12 August 1949 and relating to the Protection of Victims of Non-International Armed Conflicts 16 I.L.M. 1442.

[34] These include the 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water (480 U.N.T.S. 43), the 1996 Comprehensive Nuclear Test-Ban Treaty (not yet in force) and the 1972 Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction 1015 U.N.T.S. 163.

[35] See, for example, United Nations Security Council Resolution 1674 on the Protection of civilians in armed conflict (2006), paragraph 6.

mechanisms of justice – culminating in the International Criminal Court, the world's first permanent court of its kind – clearly indicates that the international community is determined that those senior officials (both military and political) who breach these norms are to be brought to account.[36]

While there are many principles that have arisen through the evolution of the *jus in bello*, it is perhaps pertinent to briefly mention three specific concerns that form the basis of any decision to undertake an act of military engagement. They are the principles of distinction, military objective, and proportionality. Each of these is relevant to a consideration of the applicability of the laws of war to the use of outer space[37]:

(a) The principle of distinction – deliberate attacks against civilians and noncombatants are prohibited.[38] In addition, those engaged in armed conflict must not use weapons that are incapable of distinguishing between combatants and noncombatants. These represent fundamental concepts in the conduct of military activities and illustrate the strong linkages between the scope of international humanitarian law and the development of formal legal principles for the human rights of the individual.[39]

(b) The principle of military objective – attacks not directed at a legitimate military target are prohibited. The important issue is the need to distinguish between civilian persons or objects and military objectives – comprising the elements of "effective contribution to military action" and "definite military advantage" specified in Article 52 of Additional Protocol I.[40]

(c) The principle of proportionality – even when attacking a legitimate military objective, the extent of military force used and any injury and damage to civilians and civilian property should not be disproportionate to any expected military advantage.

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[36] For a description of the powers and operation of the International Criminal Court see, Freeland S, "How Open Should the Door Be?: Declarations by non-States Parties under Article 12(3) of the Rome Statute of the International Criminal Court," (2006) 75:2 *Nordic Journal of International Law* 211.

[37] Many commentators combine issues of distinction and military objective into a broader principle known as "discrimination." This author prefers to differentiate between these two issues so as to emphasize the need to distinguish between civilians and combatants without reference to sometimes subjective considerations as to what constitutes a military target in the context of military advantage.

[38] Article 48 of Additional Protocol I provides inter alia that:

"[i]n order to ensure respect for and protection of the civilian population . . . the Parties to a conflict shall at all times distinguish between the civilian population and combatants."

[39] In his dissenting opinion in *Legality of the Threat or Use of Nuclear Weapons*[1996] 1 ICJ Rep. 245, Judge Koroma pointed out (at page 577) that:

"both human rights law and international humanitarian law have as their *raison d'être* the protection of the individual as well as the worth and dignity of the human person, both during peacetime or in an armed conflict."

[40] Article 52 of Additional Protocol I provides inter alia that:

"[i]n so far as objects are concerned, military objectives are limited to those objects which by their nature, location, purpose or use make an effective contribution to military action and whose total or partial destruction, capture or neutralization, in the circumstances ruling at the time, offers a definite military advantage."

> This demands an assessment of any potential "collateral damage" in the case of military action. However, it is often difficult to apply the proportionality principle in practice, given that different people ascribe differing relative "values" to military advantage vis-à-vis civilian injury and damage. One only need recall the advisory opinion in the *Legality of the Threat or Use of Nuclear Weapons*, where the International Court of Justice, while noting that the threat or use of a nuclear weapon should comply with the requirements of international law relating to armed conflict, in particular the principles of international humanitarian law, could not say categorically that the threat or use of nuclear weapons would in every circumstance constitute a violation of the international law.[41]

## 6.5 The Relevance of the Laws of War to Outer Space

As noted above, the existing principles of international humanitarian law, as an integral part of international law, are, in theory, applicable to the military use of outer space. There is no specific "territorial" limitation to the laws and customs of war, which apply both to the area where the hostilities actually take place and to other areas affected by those hostilities. If, for example, direct military action takes place in one area, but the effects of that action impact on civilians elsewhere, that represents a relevant consideration in determining whether such action is consistent with, for example, the principle of proportionality. As a consequence, any military activity that takes place in outer space will prima facie be subject to the *jus in bello* in relation not only to that direct action but also as to its effects elsewhere, including on Earth.

Having reached this conclusion, it is then necessary to determine whether this is just an issue of academic curiosity or, alternately, that the rules of war are "relevant" to activities in outer space. The answer, unfortunately, appears self-evident.

As noted above, it was during the Gulf War in 1990 that the military value of space assets for the conduct of warfare was first utilized to a significant degree. Indeed, "Operation Desert Storm" is regarded as "the first space war" (Maogoto and Freeland 2007a). It was recognized that the use of space technology would create an "integrated battle platform" to aid in the implementation of military strategy. Following the attacks of 11 September 2001, the US Administration embarked on a policy designed to dominate the space dimension of military operations. This necessitates having the ability to protect critical US infrastructure and assets in outer space. Although the Obama administration has more recently issued an updated space policy that emphasizes cooperation to a far greater degree, these sentiments still represent the approach of the US military.

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[41] On this issue the court was divided equally, with the casting vote of President Bedjaoui deciding the matter: see ICJ Statute, article 55(2).

Ballistic missiles play an increasingly important role in any sophisticated national security structure, and the development of defensive systems “is both a result of and additional factor driving” a global arms race (Hagen and Scheffran 2005). In 2001, prior to the attacks on September 11, a commission headed by former US Secretary of Defense, Donald Rumsfeld, suggested that an “attack on elements of U.S. space systems during a crisis or conflict should not be considered an improbable act” (Stoullig 2001). The report went on to (in)famously warn of the possibility of a “Space Pearl Harbor” – a surprise attack on the space assets of the United States.

The European Union has also identified outer space as “a key component for its European Defense and Security Policy” (Hagen and Scheffran 2005) and, as already noted, China and Russia also regard space as a vital part of their military infrastructure. Even for smaller countries such as Australia, the political landscape of national space policy highlights military and national security concerns (Freeland 2010a).

In this context, several commentators have gone even further and opined that space warfare is, in fact, inevitable and cannot be avoided.[42] If these assertions turn out to reflect reality, the principles of the laws of war should be applied. However, it is not clear how this will be done in practice and what consequences will follow.

One complicating factor in this analysis is the increasing prevalence of what are referred to as “dual-use” satellites. The concept of a dual-use facility or resource – typically a commercial facility or resource that is also utilized by the military for military purposes – has become a common feature of contemporary technological society. This presents particular difficulties for those conducting armed conflict, since an asset that could prima facie be regarded as a legitimate military target on the basis of military objectives (see further below) might also – even at the same time – be operating for civilian/commercial uses. It is sometimes very difficult, or indeed impossible, to “quarantine” what is the civilian/commercial aspect of a facility from the military component.

One terrestrial example is illustrative of the difficulties of engaging in a straightforward legal analysis of any attack against such a facility. During the 1999 NATO bombing campaign directed towards forcing the Serbian military to leave Kosovo (known as “Operation Allied Force”), one deliberate target was the RTS Serbian TV and Radio Station in Belgrade. NATO missiles destroyed the station on 23 April 1999, with significant – and only civilian – loss of life. The bombing of the TV studio was part of a planned attack aimed at disrupting and degrading the C3 (command, control, and communications) network of the Government of the former Yugoslavia.

At a press conference on 27 April 1999, NATO officials justified this attack in terms of the dual military and civilian use to which the communication system was routinely put, describing it as a[43] (Final report to the prosecutor by the commitee

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[42] See, for example, De Angelis (2002).

[43] For a detailed analysis of the NATO Report, see Freeland (2002).

established to review the NATO bombing campaign against the Federal Republic of Yugoslavia, 13 June 2000 2000a):

> very hardened and redundant command and control communications system [which . . .] uses commercial telephone, [. . .] military cable, [. . .] fibre optic cable, [. . .] high frequency radio communication, [. . .] microwave communication and everything can be interconnected. There are literally dozens, more than 100 radio relay sites around the country, and [. . .] everything is wired in through dual use. Most of the commercial system serves the military and the military system can be put to use for the commercial system.

In essence, NATO stressed the dual usage to which such communications systems were put, emphasizing the fact that "military traffic is . . . routed through the civilian system." (Final report to the prosecutor by the commitee established to review the NATO bombing campaign against the Federal Republic of Yugoslavia, 13 June 2000 2000b).

This concept is, as noted above, also a common feature of space technology. A combination of factors – the increasing dependence by military and strategic forces within (the major) powers on the use of satellite technology; the inability of governments to satisfy such demands for reasons associated either with costs or the lack of technological expertise (or both); and the advent of commercial satellite infrastructure and services that are responsive, technologically advanced, available, and appropriate to meet these demands – means that military "customers" are now regularly utilizing commercial satellites to undertake military activities. Given that such an increasingly important group of space assets used for military purposes are these dual-use satellites, one is also drawn to the question of whether, and in what circumstances, such a satellite can (ever) be regarded as a legitimate target of war.

The answer will depend upon a number of fundamental principles of international law. Clearly, the physical destruction of a satellite constitutes a use of force. Apart from a consideration of the principles in the United Nations Space Treaties, one would have to determine whether such an action represents a legitimate (at law) use of force, with the only possible justification being Article 51 of the United Nations Charter.

Assume, for example, that a combatant regards a dual-use satellite – for example, a GPS or remote-sensing satellite – as representing a legitimate military objective in accordance with the principles of distinction and military advantage. Even if this were a correct assessment, the principle of proportionality would also apply. Moreover, one could argue that implicit in the principle of distinction is the obligation on the parties to a conflict to take "all feasible precautions" to protect civilians from the effects of an attack[44] (Henckaerts and Doswald-Beck 2005, p. 70).

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[44] There would also be adverse environmental consequences (including significant space debris) resulting from the destruction of a satellite, and various international environmental law principles would therefore also be applicable in these circumstances.

One can certainly envisage that the deliberate destruction of such a satellite could, even if it does not result in any immediate civilian casualties, have a devastating impact on communities, countries, or even regions of the world. Millions of lives and livelihoods could, potentially, be affected, economies destroyed, and essential services incapacitated. Obviously, some of the consequences of such an attack may be difficult to foresee, but it would, one could argue, be regarded at the least as reckless. However, there is likely to be some uncertainty as to whether and how a "recklessness" test is to be applied in such a situation.[45]

Overall, given the unique nature of outer space, the fundamental principles of the laws of war – developed to regulate *terrestrial* warfare and armed conflict – are probably neither sufficiently specific nor entirely appropriate for military action in outer space. Even though every effort should be made to apply the existing principles as directly as possible, the largely unprecedented nature of such circumstances means that more specific rules will almost certainly be required, if they are to provide a comprehensive framework to properly protect humanity from the otherwise disastrous consequences of outer space (potentially) becoming another theatre of warfare.

## 6.6 Regulating the Threat of Space Warfare: Some Recent Initiatives

### 6.6.1 Draft Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects (PPWT)

As noted above, since the early 1980s, there have been a series of United Nations General Assembly (UNGA) Resolutions on the specific issue of preventing an arms race in outer space. For example, in December 2007, the UNGA adopted another of these resolutions (United Nations General Assembly Resolution 62/20, 22 December 2007 on the "Prevention of an arms race in outer space"), having earlier repeated its invitation to member states to (United Nations General Assembly Resolution 62/43, 5 December 2007 on "Transparency and confidence-building measures in outer space activities"):

> continue to submit … concrete proposals on international outer space transparency and confidence-building measures in the interest of maintaining international peace and security and promoting international cooperation and the prevention of an arms race in outer space

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[45] For a discussion of the difficulties of applying the proportionality principle in the case of the "high-altitude bombing" during the NATO military action in Serbia and Kosovo in 1999, see Freeland (2002).

Such measures focused even further the attention of the broader international community on the need to respond to various military initiatives taken by major space powers in their use of outer space. Moreover, the UNGA had, at the same time, also emphasized the importance of international cooperation in the peaceful uses of outer space, an important element of which is that (United Nations General Assembly Resolution 62/217, 22 December 2007 on "international cooperation in the peaceful uses of outer space"):

> all States, in particular those with major space capabilities . . . contribute actively to the goal of preventing an arms race in outer space

Ostensibly responding to these calls, in February 2008, the then Minister of Foreign Affairs of the Russian Federation, Sergey Lavrov, presented a draft document headed "Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects" to the 65 members attending the plenary meeting of the United Nations Conference on Disarmament (CD) in Geneva.[46] The PPWT had been developed by Russia and China, two of the major space superpowers in the world. An earlier draft had been informally circulated the previous June, resulting in comments from a number of other countries.[47]

The formal submission of the PPWT to the CD followed several years of diplomatic discussion, directed towards agreeing the terms of legally binding rules addressing the dangers of an arms race in space. In presenting the PPWT, Minister Lavrov noted that the terms of the document were supported by a majority of the member states of the CD. He warned that[48]:

> [w]eapons deployment in space by one state will inevitably result in a chain reaction. And this in turn, is fraught with a new spiral in the arms race in space and on the earth.

In his supporting comments, the Foreign Minister of the People's Republic of China, Yang Jiechi, added that (Message from Foreign Minister Yang Jiechi of The People's Republic of China to the Cnference of Disarmament, 12 February 2008):

> [a] peaceful and tranquil outer space free from weaponization and [an] arms race serves the common interests of all countries. It is therefore necessary for the international community to formulate new legal instruments to strengthen the current legal regime on outer space.

In general terms, the PPWT focused on three primary obligations of state parties, each of which are specified in Article II:

(a) Not to place in orbit around the Earth, install on celestial bodies, or station in outer space in any other manner "any objects carrying any kind of weapons"

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[46] The United Nations Conference on Disarmament was established in 1979 as the single multilateral disarmament negotiating forum of the international community, following the first Special Session on Disarmament (SSOD I) of the United Nations General Assembly held in 1978.

[47] For example, Canada submitted "detailed comments" to Russia in relation to an earlier draft: Comments by Ambassador Grinius of Canada, Geneva, 12 February 2008, page 1.

[48] Statement by H.E. Sergey Lavrov, Minister of Foreign Affairs of the Russian Federation at the Plenary Meeting of the Conference of Disarmament (unofficial translation), Geneva, 12 February 2008, page 6.

(b) Not to "resort to the threat or use of force against any outer space objects"
(c) Not to encourage another State(s) or intergovernmental organization to "participate in activities prohibited" by the PPWT

As well as applying to a broader range of weapons (see further below), the prohibitions in Article II, specifically Article II(b), rectify another major shortcoming of Article IV of the Outer Space Treaty, in that they appear to cover the *use* of such weapons as well as their placement.

In addition, the PPWT includes a definition of "outer space" as "space beyond the elevation of approximately 100 km above ocean level of the Earth" (Article I(a)). Apart from the curious use of the word "approximately" – in what circumstances would it *not* be 100 km? – this represents a rather revolutionary suggestion by two major superpowers, which, along with the United States, have historically tended to stifle attempts to designate a formal demarcation, primarily for strategic and political reasons.

As noted, one of the most important definitions in the PPWT is that of "weapons in outer space" (Article I(c)).[49] While it is a relatively broad description – including "any device" – it still leaves some room for doubt, particularly as to assets that may initially be "peaceful" but are subsequently utilized to "damage or disrupt normal functions of objects in outer space," such as through the generation of various electromagnetic pulses. Moreover, if an object is deliberately allowed to become debris, and then affects the space assets of other States, query whether this falls within the requirement of "produced or converted."

From a broader public international law perspective, the definitions of "use of force" and "threat of force" (Article I(d))[50] are of interest. Of course, as noted above, the concept of "force" is a fundamental principle of international law under both the United Nations Charter and by way of a customary norm (Military and Paramilitary Activities in and against Nicaragua (Nicaragua v. United States of America) 1986), underpinning the conduct of international relations. Under traditional international law principles, "force" is regarded as an act of "violence," so that, for example, economic sanctions were not to be regarded as such, despite arguments to the contrary raised by developing countries at the time that the United Nations Charter was being negotiated.

The definition in the PPWT appears to be considerably broader than these traditional views of what constitutes force, and was presumably drafted in this way to encompass (nonviolent) actions such as "jamming" and the use of

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[49] Article 1(c) of the PPWT provides that:

"the term 'weapons in outer space' means any device placed in outer space, based on any physical principle, specially produced or converted to eliminate, damage or disrupt normal function of objects in outer space, on the Earth or in its air, as well as to eliminate population, components of biosphere critical to human existence or inflict damage to them."

[50] Article 1(d) of the PPWT provides that:

"the 'use of force' or 'threat of force' mean any hostile actions against outer space objects including, inter alia, those aimed at their destruction, damage, temporarily or permanently injuring normal functioning, deliberate alteration of the parameters of their orbit, or the threat of these actions."

electromagnetic interference, as long as they constituted a "hostile" act. Should this new approach to force become more widely accepted, it may also raise interesting questions about the legal nature of actions such as "cyber-attacks."

In responding to the PPWT, the US Administration has continually reiterated that it opposes any treaty that seeks "to prohibit or limit access to or use of space," adding that, in any event, such a treaty would be impossible to enforce (Cumming-Bruce 2008). Indeed, verification measures in relation to the obligations of state parties under the PPWT would undoubtedly prove to be difficult and complex – though perhaps not impossible – to implement. Instead, the United States has indicated that it prefers "discussions aimed at promoting transparency and confidence building measures" (known colloquially as TCBMs) (Cumming-Bruce 2008).

Overall, and despite its shortcomings, the PPWT has raised issues of crucial importance to the future use and exploration of outer space, indeed to the very *nature* of space activities. It was therefore unfortunate that the document was so quickly rejected out of hand by the United States. Indeed, in February 2008, barely a week after Russia and China submitted the PPWT to the CD, the United States fired an SM-3 missile from USS Lake Erie that destroyed a failed satellite approximately 150 km above the Pacific Ocean. Although the United States argued that this action was necessary to prevent the fuel tank of the satellite – containing hydrazine – from breaking up and polluting the atmosphere, others have suggested that this was simply a "test" by the United States of its antisatellite capability.

At the time, the Chinese Communist Party newspaper, *The People's Daily*, reported that (Randerson and Tran 2008):

> [t]he United States, the world's top space power, has often accused other countries of vigorously developing military space technology . . . But faced with the Chinese-Russian proposal to restrict space armaments, it runs in fear from what it claimed to love.

Yet, despite these setbacks, the formal submission of the PPWT by two of the world's space superpowers has had the effect of generating further momentum in relation to other initiatives to address the impending perils associated with the possible weaponization of space. This has, in part, led to the development, primarily at the instigation of the European Union, of what is now known as the draft "International Code of Conduct for Outer Space Activities."[51]

### 6.6.2 Draft International Code of Conduct for Outer Space Activities (CoC)

While it was not openly admitted, the rejection of the PPWT by the United States gave rise to added impetus for ways to find other avenues to progress discussions regarding the issues of space weaponization and space warfare. In late 2008, the

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[51] The CoC had initially been referred to in discussions as the "European Union Code of Conduct for Outer Space Activities."

Council of the European Union (EU) published a draft voluntary Code of Conduct for Outer Space Activities. This had been prepared by an EU Working Party on Global Disarmament and Arms Control, endorsed by the EU Political and Security Committee and submitted to the EU Council in December 2008. A revised draft of the CoC was adopted by the EU Council in September 2010. The document was intended to form the basis for consultations with third countries.

In adopting the draft CoC, the EU Council expressed its desire to (Council of the European Union 2010a):

> strengthen [. . .] the security of activities in outer space in the context of expanding space activities that contribute to the development and security of states.

The draft CoC seeks to find a balance between a number of relevant (and sometimes competing) issues related to activities in outer space, particularly as they relate to a country's (real and perceived) national security interests. It is expressed to be guided by three underlying principles (Council of the European Union 2010b):

(i) Freedom of access to space for peaceful purposes
(ii) Preservation of the security and integrity of space objects in orbit
(iii) Due consideration for the legitimate defense interests of States

It takes into account that (Council of the European Union 2010c):

> space debris constitutes a threat to outer space activities and potentially limits the effective deployment and exploitation of associated space capabilities

Related to the issue of space debris is, of course, the issue of maintaining the integrity of space assets, both in terms of adhering to measures on space debris control and mitigation (specifically referred to in Article 5 of the CoC) and also by minimizing the possibility that a State would "destroy" another State's satellite (and in the process almost certainly create additional space debris). These are, of course, delicate issues related to the heart of space-related security, involving the need for close cooperation and agreement. In this regard, the CoC provides that the Subscribing States would (albeit on a voluntary basis) (Council of the European Union 2010d):

> refrain from any action which intends to bring about, directly or indirectly, damage, or destruction, of outer space objects unless such action is conducted to reduce the creation of outer space debris and/or is justified by the inherent right of individual or collective self-defence in accordance with the United Nations Charter or imperative safety considerations

There has been some confusion and a series of mixed signals from the United States as to its approach to the CoC.[52] On the one hand, from its perspective it is, in principle, a far more palpable "type" of instrument than the PPWT – a voluntary code as opposed to a binding treaty. Yet, to the extent that it is perceived

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[52] See, for example, Listner (2012)

as impinging upon America's "sovereignty," even this document has met with considerable and vehement opposition.[53]

At a United Nations Institute for Disarmament Research (UNIDIR) conference in Geneva in April 2011, US Deputy Assistant Secretary, Bureau of Arms Control, Verification and Compliance in the Department of State, Frank Rose, indicated that (US Department of State 2011):

> . . . the United States is continuing to consult with the European Union on its initiative to develop a comprehensive set of multilateral TCBMs, also known as the international "Code of Conduct for Outer Space Activities." We hope to make a decision in the near term as to whether the United States can sign on to this Code, including what, if any, modifications would be necessary.

In early January 2012, Ellen Tauscher, Undersecretary of State for Arms Control and International Security, stated that the US Government would not sign the CoC because it was "too restrictive" (Weisgerber 2012). Yet, only a few days later, Secretary of State Hillary Clinton indicated that (US Department of State 2012):

> the United States has decided to join with the European Union and other nations to develop an International Code of Conduct for Outer Space Activities. A Code of Conduct will help maintain the long-term sustainability, safety, stability, and security of space by establishing guidelines for the responsible use of space . . .. [but] we will not enter into a code of conduct that in any way constrains our national security-related activities in space or our ability to protect the United States and our allies.

It is as yet still unclear as to whether and how this collaboration will be effected, let alone the end product, if any. It is not unreasonable to assume that the draft CoC as currently exists may form the basis of a starting point for further discussions, notwithstanding the objections of the American administration to its "restrictive" nature. However, there are clearly many unknowns in this respect, and it is by no means certain as to what specific terms would be included in any final document, let alone whether any agreement will be reached at all.

## 6.7 Conclusions: Perspectives on the Way Forward

This brief discussion gives rise to several conclusions: first, present indications suggest that there is an increasing likelihood that outer space will not only be used to facilitate armed conflict (as it already is) but may ultimately become a theatre of war. The tendency of the major powers to increasingly rely on space technology may spiral a space weapons race, despite the efforts of the international community. Even though the United States may currently claim space superiority, it can only be a matter of time before other spacefaring countries – including China and Russia – will have access to equally sophisticated (and potentially devastating) space weapons technology, if we have not already reached that point.

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[53] See, for example, Bolton and Yoo (2012)

Secondly, the development of such technology and the increasing range of military uses of outer space heighten the dangers of a space war, as frightening as that prospect is. The proliferation of crucial military space assets means that, from a military and strategic viewpoint, the disabling or destruction of satellites used by another country may be perceived as giving rise to very significant advantages. The fact that it has not happened in the past is no reason to assume that we will never see a space conflict.

Thirdly, all countries in the world are highly dependent on space technology to maintain and improve their livelihood and standard of living. The nonmilitary uses of space have become vital aspects of any community's survival. At the same time, however, many of the satellites providing these commercial and civilian services are dual use, in that they are also utilized for military and strategic purposes. This raises difficult questions about the "status" of such assets under the rules of war – particularly as to whether they may, under certain circumstances, be regarded as legitimate military objectives.

Fourthly, the Outer Space Treaty, which also reflects customary international law, specifies that the rules of international law apply to the use and exploration of outer space. These include not only the *jus ad bellum* principles regulating the use of force but also the principles of the laws of war. Respect for these rules is absolutely vital for the safety and security of humankind, as well as the interests of future generations. However, with the exception of those treaties that seek to ban the use and testing of certain types of weapons, there are many uncertainties that arise when one seeks to apply, in particular, the laws of war to a (at this stage hypothetical) space conflict. The consequences of a space war are potentially so enormous and unknown that one cannot be sure as to exactly how these existing rules are to apply.

Fifthly, if we are to avoid "grey areas" in the law, it is therefore necessary to develop specific and clear rules and standards that categorically prohibit the weaponization of outer space as well as any form of conflict in the region of outer space and against space assets. The Outer Space Treaty, as well as the other United Nations Space Treaties, does not currently provide stringent rules or incentives to prevent an arms race in outer space, let alone a conflict involving (and perhaps "in") space. This may, therefore, require additional specific legal regulation of outer space that is directly applicable to armed conflict involving the use of space technology. The position is, of course, further complicated by the applicability of the right of self-defense, a right that States will never abandon.

As part of these new rules, clear definitions must be developed for concepts such as "space weapons," "peaceful purposes," and "military uses." Moreover, the fundamental issue of "where space begins" should be definitively resolved, so as to counter any arguments that outer space is, in fact, an area akin to the territory of a State for the purposes of national security.

Sixthly, at the same time, careful consideration must be given to the application of the principles of the laws of war to this new paradigm of potential conflict. While, of course, there already exist very well-established fundamental rules regulating terrestrial warfare, it is not clear whether these are entirely appropriate, relevant, and sufficient to protect humanity from the exigencies and consequences of any future "space wars." Ideally, binding treaty norms should be negotiated, to be adhered to in good faith by all relevant States.

Having said this, to the extent that additional regulation may ultimately be concluded that (further) relates military/weapons-related activities in outer space, this is almost certainly not likely to take the form of binding treaty obligations that supplement the existing laws of war (as they may apply to such activities) in the short-medium term, but rather will be on a voluntary non-binding basis. This illustrates the sensitivities related to (further) regulating outer space activities that (are perceived to) relate to issues of national security interests, particularly those of the major space powers.

It seems that a "softly, softly" approach involving the development of TCBMs is the preferred strategy, particularly of the United States, but this brings with it much more uncertainty, a lack of formal enforcement capability and enforcement mechanisms, and the possibility of undue flexibility of approach by the main stakeholders. Whether this outcome alone would be adequate to meet the complex issues remains a difficult question.

Finally and most significantly, in undertaking any future discussions and (possibly) developing new rules and norms, we must at all times adhere to the fundamental sentiment of "humanity" that underpins both space law and international humanitarian law, in order to avoid the possibility of alternate scenarios that are too frightening to contemplate.

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# The Role of Space in Deterrence

# 7

Roger Harrison

## Contents

**Abstract**

Whether or not weapons are actually deployed in space, the era in which satellites could operate without potential threat is over. The question therefore arises: what actions can be taken and what trends encouraged to reduce the possibility of space becoming a theater, or a catalyst, for hostilities? The answer may lie not in the actions of nation states, but in the nature of the space environment on the one hand and the leadership of commercial space operators on the other.

> *Thus far the chief purpose of our military establishment has been to win wars. From now on its chief purpose must be to avert them. It can have almost no other useful purpose.*
> *(Bernard Brodie)*

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## 7.1 Introduction

The strategic situation in space is changing. Deterrence theory is changing, too, if only in becoming more self-referential and less relevant to the problems at hand. It may be that we are headed into dangerous era in space, in which mutual suspicions, nationalist pretensions, and an entirely illusory striving for the "high ground" leave our species unable to address what are clearly foreseeable problems, including not only the problems of debris and orbital crowding but also the problem of war. In this case, the role of space may be to incite violence between nations rather than deter it. But there are also hopeful signs of an emerging order in space. These come not so much from governments but from commercial space operators who recognize that, however abused the concept, space is undeniably a "commons" in which the actions of each affect the interests of all. Both of these trends, the militarily threatening and the necessarily cooperative, must and will be accounted for in policy of nations. The question is one of emphasis. Shall war fighting be our concentration, with deterrence a by-product which – in a world of "inevitable war" – we see as temporary and expedient or shall we concentrate on avoidance of hostilities and the creation of a stable and predictable space environment, recognizing that this will require a demonstrated capability to fight if our effort fails. The difference this makes for policy – and for the possibility of order based on mutual restraint – is considerable.

## 7.2 Background

The body of strategic analysis that structured Cold War deterrence provides a foundation as well for a study of preventing hostilities in space; but factors unique to space make the conclusions reached in that earlier era suggestive rather than determinative. Among those unique factors are some that make the task of deterrence easier and some that make it more problematic. There was scope in the Cold War for exploitation of various defense strategies including hardening, mobility, and eventually ballistic missile defense. Defensive options also exist in space, but are more limited and may compromise capability. Cold War deterrence assumed a rough equality of capability and risk between the superpowers. This is no longer true. The United States is a uniquely capable space, but also uniquely vulnerable there. There is also a new vector of attack which Cold War planners could not have imagined, i.e., an attack on the computers that control satellites and process the information they provide. It may well be that the key danger to space capabilities in the future will come not from adversarial hardware but from a corruption of software. There are defenses against this sort of attack as well, but they seem to be lagging offensive capability. The failure of deterrence in space might be a catalyst for conflict within the atmosphere between major powers. But is would not in itself be an existential threat to our species. There is no analogy in space to mutual assured destruction. Hence, decision makers concerned with space deterrence have more latitude to adopt a variety of approaches than did their Cold War counterparts.

## 7.3 Space and Deterrence

Deterrence is the process of convincing an opponent that the costs of attack will outweigh the benefits. This can be done by holding at risk things of value to the adversary (threats of retaliation), by convincing him that he will not achieve the goals of his attack (denial of benefit), and by increasing his level of uncertainty – or some combination of these. In space there are unique issues and several obstacles to deterrence strategies. These might be summarized in three categories:

- The vulnerability gap in space
- The difficulty of defending satellites
- The weakness of space situational awareness/attribution of attack

## 7.4 Vulnerability Gap

That a vulnerability gap exists is not disputed. The United States has created a military structure which is heavily satellite dependent, without making corresponding improvements in the survivability of those satellites in a hostile environment. The result is a classic opportunity for asymmetric, preemptive attack. Because of the vulnerability gap, an adversary might assume that even if the origin of an attack in space were known and the United States retaliated in kind by destroying (even disproportionately) the enemy's space assets, he would nonetheless gain by the exchange since overall US military capability – more dependent than his on space – would be disproportionately degraded.

Some believe that this gap will narrow of itself as the militaries of potential adversaries modernized and become more dependent on satellites. But other space-faring nations may be alert to the distinction between reliance and overreliance on space and less certain of the value-added space provided in the sort of wars they are likely to fight. They may take advantage of emerging technologies to deploy space assets in inherently more defensible modes – rather than committing to large, single point of failure satellites. US reliance on space is fueled in part by the country's desire for global reach. Likely competitors are – at least for the moment – geographically less ambitious, although in the case of China, that may be changing. Even if potential adversaries mirror the US military space strategies, they are unlikely to become as dependent on space, and the vulnerability gap is therefore unlikely to narrow significantly.

The effect of the vulnerability gap on strategic stability and deterrence may not, however, be as great as this analysis would indicate. Classic nuclear deterrence theory demands holding at risk things of value. Nations less dependent on satellites than the United States may nonetheless value them – as potential economic growth multipliers, as symbols of national progress, as tools of political control, or as tokens of status given to the military in return for military obedience. This may be true in particular of the PRC, but cannot be discounted in the case of other emerging space-faring nations. In short, although our military vulnerability in space is greater, the value gap may not be so great. The threat of retaliation in kind, even in a situation where the United States is asymmetrically vulnerable, may therefore have some deterrent value.

## 7.5 Difficulties of Defense in Space

The categories of direct, offensive threats to satellites have been very well understood for at least four decades. These are divided, generally speaking, into physical threats – impact (kinetic kill) or proximity explosion – and electromagnetic threats, EMP, laser, high power microwaves, and neutron beam. Both types of attack can in theory be delivered by either terrestrially based or space-based weapons. The options for defense of satellites have also been understood: hardening, maneuver, and various guardian or self-defense satellite schemes. Given limitations on mass, satellite designers are faced with trade-offs between capability, service life, and defense. Generally speaking, they have made the choice of maximizing capability. Even if designers had assumed a more hostile environment, it is not certain they would have altered fundamentally the trade-off between capability and defense. Some space capabilities, especially reconnaissance and communication, required large structures in fixed orbits which are inherently easier to target and therefore more difficult to defend. They can be hardened against EMP and equipped to counter laser dazzling. They can maneuver to avoid attack. But they cannot be hardened to withstand KE attack; maneuver is limited by onboard fuel supplies (which are also needed for station keeping and against the contingency of maneuver to avoid space debris). Finally, defense against jamming and laser attack may require, in effect, shutting down operations temporarily – which is all a potential adversary may require.

Advances in technology may offer an inherently more defensible means of deploying capability in space. Many argue that mini-satellites hold the promise of basing mode which is much more difficult for a possible adversary to target. Constellations of these satellites might provide some or even most of the same functions of the existing satellite constellation. They could be designed to degrade incrementally, in essence reconfiguring to account for losses of some of their element to hostile action. Finally (and again, in theory), mini-satellites would be cheaper to develop than existing, large multifunction satellites. More redundancy would therefore be possible within existing budgets. All these characteristics of mini-satellite constellations would enhance deterrence. Indeed, adoption of this technology by all major spacefaring nations might create the defense dominant atmosphere in space which is not only favorable for deterrence but for a stable and predictable space environment.

There are, however, reasons for skepticism, not least that no one has so far succeeded in deploying and utilizing constellations of mini-satellites, which might also be used, if finally deployed, as hunter killers, on the model of the so-called “brilliant pebbles” ABM concept. Whether the advantage in this technology lies with the offense or defense, with war fighting or deterrence, therefore remains to be seen.

## 7.6 Attribution of Attack

An abiding issue for space deterrence is the difficulty in attributing attack and distinguishing between intentional interference and the consequences of operating in an electromagnetically active and physically harsh environment. If a satellite ceases to operate, or operate effectively, the fact will be immediately apparent, but the cause may remain unknown. The problem of attribution is not entirely unique to space; it exists as well in other theaters of military operation, particularly the war on terror and cyber warfare. The contestants in the Cold War often used surrogates and "spoofing" to disguise the real origins of conventional attacks. Still, attribution in space poses particular problems.

In general, operators will only become aware of an attack in space because of its effects. Direct ascent KE weapons, such as the one tested by the PRC in 2007, are an exception to this rule; the origin of the attack of such weapons would be detected. But for a variety of other attacks – either from space-based interceptors or, more likely, ground-based dazzling or jamming – origin may be difficult to determine and the identity of the attacker even more so. For example, a hostile entity might mount a jamming or dazzling attack from a third country, as the Iranians apparently did from Cuba in 2003. The culprits in that case were eventually determined, but only after a lapse of some months. It is conceivable, though not likely, that a similar operation could be conducted from neutral countries or even countries allied with the United States without the knowledge of the government. It is also possible that we might attribute the failure of a space system in a crisis to the action of an adversary, when in fact, it results from the natural effects of the space environment itself, such as severe space weather.

The most difficult scenario arises if a key satellite simply ceases to function. In that case, we may not know – or be able to discover – the cause of the malfunction.

These difficulties, however, may be more apparent than real. The likelihood of a random attack unconnected to some strategic or tactical purpose within the atmosphere is remote. The greater likelihood is that attacks will take place in the context of the failure of deterrence within the atmosphere and therefore as a result of, or in preparation for, terrestrial hostilities. In context, the source of the attack will be difficult for an adversary to disguise. Moreover, gaining military advantage would necessarily involve a coordinated attack on a number of satellites; an adversary could hardly expect such an attack to be mistaken for anything else or the origin of the attack to remain a long secret. The number of countries that might be expected to have both motive and capability to launch such an attack is small and not likely to grow appreciably in the twenty-year time frame of this study. Finally, experience in the Cold War and the war on terror indicates that we will often discover the origin of attack not from detecting the attacker at the time, nor from direct evidence available at the point of attack, but from intelligence sources with access to the information either directly from the attacking country or through third parties – not, that is, exclusively from ELINT, but also from HUMINT sources. Such detection might even occur before the fact.

Finally, the question from the point of view of deterrence theory is: will a potential adversary believe that the origin of his attack can be disguised? Will he make the key decision based on this assumption? If so, deterrence is weakened. But – for the reasons listed above – a prudent decision maker would have to assume that the origin of such an attack could not be disguised, especially if the attack were connected with hostilities on the surface. He would have to have a plan not just for the initial attack, but for a strategy if the origin of the attack were discovered; and if that plan were not credible, deterrence would be strengthened. In short, he would have to act as if the attack would be discovered. In short, the advantages of secrecy could not be assumed in advance, and this has a deterrent effect.

## 7.7 A Brief History of Space and Deterrence

Space as in issue of strategic interest has gone through four phases and is now entering the fifth (Moltz 2011; Hays 2002). Only in the last of these has deterrence become a focus of policy.

In the first phase, the two Superpowers struggled to establish themselves in orbit. In the second, each began exploiting space for military and intelligence purposes, and each deployed – and then abandoned – antisatellite weapons. The third phase witnessed the demise of the Soviet Union and the emergence of US space dominance, proclaimed with assertive policies of space control, freedom of action, and denial of access (Fig. 7.1).

**Fig. 7.1** Earth viewed from space (Image courtesy of [chrisroll]/FreeDigitalPhotos.net)

During this period and up to the present, space remained generally a benign environment. Weapons in orbit, although imagined and sometimes developed, were not deployed. Rather, the emphasis through the Eisenhower, Johnson, and Kennedy administrations was on the "nonaggressive militarization of space" (Kalic 2012) and was marked by the strong opposition of these presidents to placing weapons in orbit. This period was exemplified in the Outer Space Treaty of 1967, which banned nuclear (but not conventional) weapons in orbit or on heavily bodies and mandated notification for any space activities that might disturb the satellites of another of the signatory parties. The conventional ASAT systems that were briefly in service for both the Soviet Union and the United States during this period were conceived as potential instruments of war rather than means of deterrence, and more potent systems that would have posed a challenge for nuclear deterrence (such as orbiting nuclear weapon platforms) did not become reality. The Soviets did test a fractional orbiting bombardment system (FOBS) that would have allowed nuclear warheads to achieve temporary orbit, approaching the United States from the southern hemisphere to avoid defense oriented to the north. FOBs gave impetus to various US ASAT programs, but these were all ground launch rather than space based and were phased out in the 1980s.

In short, there was no threat *from* space to be deterred and no means *in* space to deter possible challenges to the terrestrial status quo. There were a plethora of space-based ASAT programs in these years with acronyms like SAINT, BAMBI, and SPAD; but none of these became operational because of technical obstacles, cost escalation, and civilian concern about the implications of placing weapons in orbit. Even at the height of the Cold War, space remained in effect a sanctuary, characterized by a culture that ranged from mutual suspicion to grudging cooperation to active collaboration – depending on the overall tensions in the relationship of the two Superpowers. From the beginning, though, the United States refrained from interfering with Soviet satellites, and the Soviets reciprocated – a practice that was later codified in nuclear arms control agreements in provisions for noninterference with national technical means of verification. In Clay Moltz' apt description, each of the Super Powers decided that it valued "stability over superiority" (Moltz 2011). In part because of this culture, and because space was still peripheral to the overall military balance between the Super Powers, space could be made the starting point of President Nixon's policy of détente with the Soviets. It could be the symbol of détente because, if détente failed, the resulting damage to national power would be limited.

The period from about 1990 to the first year so of the new millennium was one of the uncontested American ascendance in space and of a degree of triumphalism in the statements of the US strategic space policy. From this era stem pronouncements of the US space control, freedom of action, and denial of access to adversaries. Ironically, these pronouncements became more assertive just as the objective situation was changing in ways that made them more problematic. The growing dependence of the US forces on satellite services, and the perceived vulnerability of these sophisticated systems to relatively primitive means of disruption, seemed to create a classic opportunity for asymmetric – and perhaps preemptive – attack.

This brought the overall system of deterrence into question. The situation was analogous to that which arose in the Cold War when increased warhead accuracies made extremely capable land-based nuclear delivery systems potentially vulnerable. The result in that case – at least the result perceived by decision makers – was to incentivize a disarming nuclear first strike, destabilize the nuclear balance, and undermine deterrence. Similarly, if an adversary decided to disrupt the overall status quo by force, targets on the other side which were simultaneously vital and vulnerable would be the most inviting. As US exploitation of, and dependence on, satellites increased through 1990s, the sense of vulnerability also increased.

The policy implications of these changes can be discerned in the Rumsfeld Commission report of 2001 and its warning of a potential “space pearl harbor,” i.e., a disarming first strike on satellites which would disable satellite-dependent US forces (Andrews et al. 2001). New players were emerging to challenge US predominance in space, particularly China and a revitalized Russian Republic. The realization was also dawning that the US strategic satellite constellation (and therefore a key advantage of the US land, sea, and air forces) was dependent on a limited number of large, “single point of failure” satellites that would be difficult to defend against a determined and technically competent opponent.

Two aspects of the Commission report are worth emphasizing for the influence they were to have on future consideration of space deterrence. One of these is the hoary and reductionist doctrine of “inevitable war.” In the words of the report, “We know from history that every medium – air, land, and sea – has seen conflict. Reality indicates that space will be no different. Given this virtual certainty, the United States must develop the means both to deter and to defend against hostile acts in and from space.” One can sense in the phrases “virtual certainty” and “reality indicates” the efforts of the drafters, by torturing language, to reconcile the relative doves with the majority hawks on this bipartisan committee.

The other and parallel theme is an emphasis on the limits of our knowledge about threats in space and the consequent likelihood of unpleasant “surprises” in orbit. Space had traditionally been spared this sort of strategic calculus simply because the weapons to implement it were imaginary rather than real. But, as the Commission report pointed out, the growing dependence of the United States on space had not been matched by an increased ability to defend satellites should the environment turn hostile. The report doubtless exaggerated the magnitude of the threat existing at the time of its release; but since it was a call to action, and since space programs have gestation periods measured in decades, this exaggeration is perhaps explicable. In any case, the trend lines were clear enough.

The Commission’s conclusion was a call for maintenance of superiority in all aspects of space operations. Such superiority would allow the United States to “project power through and from space in response to events anywhere in the world” and give the United States “a much stronger deterrent and, in a conflict, an extraordinary military advantage.” But, in keeping with its bipartisan character, the Commission also emphasized the need for coalition building with allies and for the development of internationally agreed “rules of the road” to establish norms of peaceful behavior and bring political pressure to bear on possible outliers. The question remained: how most effectively to respond?

Much of the Rumsfeld report would eventually be incorporated in the US national policy but that would be delayed by bureaucratic wrangling until the release of the Bush Space Policy document of 2006. Indeed, the Bush Space Policy document of 2006 represented a considerably less nuanced, *fin de siècle* version of the arguments for space control and denial of access first advanced in the Rumsfeld report. Deterrence as a strategy of conflict avoidance had meanwhile fallen out of favor as too passive. Whereas the Rumsfeld Commission had supported both cooperation with allies and the creation of norms for operating in space, the Bush Space Policy rejected any international agreements that would limit US freedom action in space, including those like the Outer Space Treaty to which the United States was already party. Several weapon programs were begun to give substance to new direction in policy. These proved for the most part overly ambitious or ruinously expensive or both, although the failure of hardware programs was not immediately reflected in policy statements.

This brings us to the fifth period in strategic space history which has emerged in the last decade. This is the era of what the commander of the US Space Command has called congested, competitive, and contested space. To these three C's might be added a forth budgetary constraint. For convenience sake we might date the beginning of this fifth era to January, 2007, when the Chinese staged a successful, direct assent ASAT weapon test against a defunct Chinese weather satellite in low earth orbit. The impact of this event was not so much strategic as symbolic; there was no evidence (or, at least, any made public) that the Chinese were embarked on the sort of capital-intensive deployment program that would pose a kinetic ASAT threat to a substantial portion of the US satellite constellation. Kinetic attack is far from the best and most efficient way to disable satellites. The United States and the Soviet Union had both abandoned that approach in the 1980s in part because of the persistence in orbit of the resulting debris. The Chinese ASAT test produced the largest debris field of any event in history, with consequences for all space operators including the Chinese themselves. It also had a political cost in the form of international condemnation, no small thing for a nation as image conscious as the Chinese. For all these reasons, the test seemed to other space actors an irrational move, and the motives behind it remain a question for speculation. It might have what General Kehler has called a "blue bear," i.e., a conspicuous display to distract attention from other and more ominous Chinese counter satellite programs. The great advantage of the "blue bear" argument (and others like it) is that the absence of evidence seems to make the threatening phenomenon more rather than less likely. But the Chinese test did puncture the doctrine of "denial of access" and put paid to the notion of "compellence" as a practical option for the United States. Hence forward, competent space actors like China could not be compelled; their access to orbit could not be denied. They might still be denied the military advantage which satellites provide and would certainly seek the means to deny those benefits to others. But now persuasion and cooperation, not coercion, would have to play a greater role in space security.

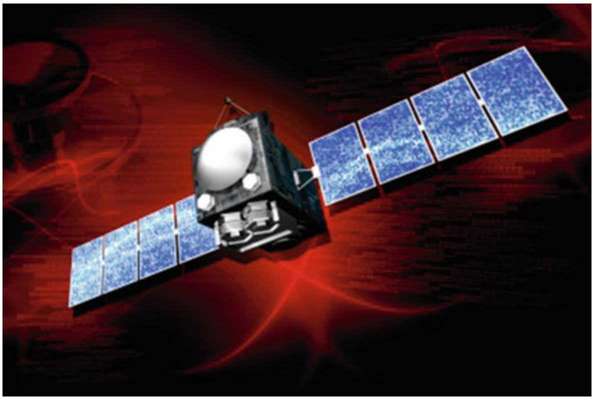

**Fig. 7.2** Artistic depiction of a satellite (Image courtesy of [dream designs]/ FreeDigitalPhotos.net)

The changes of circumstance were reflected in the Obama Space Policy of 2010, which differs markedly from the Bush Policy issued four years before. The vision shifted abruptly from hegemonic control of space to cooperation (the word is found 13 times in the introduction alone). Deterrence, which in the old policy had emerged as a function of dominance and the active assertion of power, is portrayed in the new policy in a more traditional sense as one of a "variety of measures" to help assure the use of space "for all responsible parties" and as an inherent function of the right of self-defense. The assertion of the right to deny access to enemies is gone, as is the claim to freedom of action regardless of international agreements. Space control is relegated to an addendum as one of the responsibilities of the Secretary of Defense. Some of this change is doubtless attributable to the eclipse of the neoconservatives. But many commentators have noted how the Bush Space Policy had already changed, in substance if not in rhetoric, as the second term progressed. It is more accurate to say that the 2006 Bush Policy was the last hurrah of the vision of the United States as a stern but benevolent space hegemon, a vision which the facts would no longer support.

The more the United States asserted its supremacy in space during this period, the more European allies disassociated themselves from US leadership, proposing their own solution to the problem of conflict in space. This was manifest in the EU decision to go forward (against strong US opposition) with an independent GPS constellation (Galileo), but also with the adoption of the EU Code of Conduct for Outer Space Activities. The EU Code of Conduct for space, a collection of voluntary and heavily caveated bromides for space operators, has faced indifference or active opposition. Codes of conduct and/or international treaties tend to be possible only when major actors are more or less satisfied that an equilibrium point has been reached, that is, when an acceptable balance of power exists (Fig. 7.2).

This is not true in space, partly because the situation there is a function of the changing balance of power within the atmosphere and partly because of the persistence of fantasies about breakout weapon systems – like orbiting weapon platforms, new and more powerful surface-based lasers, or clouds of autonomous hunter-killer satellites – that would bestow a long-term advantage. History has shown that the advantage achieved by technological breakthrough tends to be short lived and the resulting balance less stable than the one preceding. This was true of nuclear and thermonuclear weapons of SLBM's, of terminal guidance, and of MIRV's warheads, of satellite surveillance, and lately of cyber. It will be true of space as well if national leaders are impudent, and improvident, enough to test the idea there.

Another aspect of this new era should be mentioned, since it plays a crucial role in whatever form of deterrence and verification emerges to cope with contested, congested, and competitive space. I mean the emergence of essentially stateless commercial satellite companies as a force not only in civil but also in strategic space. These companies, like Intelsat and SES, both headquartered in Luxembourg, operate satellites that are crucial to US military capability, and are important for others. Virtually all activities by the US remotely piloted vehicles are dependent on commercial satellites. That dependence will grow. Moreover, in our globalized world, the spread of technology from the public to the private sector means that geographic survey companies can now scan the earth with resolutions not much inferior to that available from the national security network. Since this is a cheap alternative, it is likely to be used more often. In the short term, technology transfer controls can slow the development of these technologies by potential US adversaries, but in the medium term, we will likely see a democratization of capabilities in orbit that will be available, in essence, to the highest bidder.

The problem for deterrence now, and particularly for extended deterrence, is twofold: on the other hand, commercial, increasingly necessary for national security, is not hardened against attack, as national security satellites are. It could be, as orbits fill and disputes over spectrum multiply, that nations will stand by as observers of commercial hostilities in orbit with – thanks to the increasing use of commercial satellites for military purposes – real national security consequences for them.

## 7.8 Survey of Recent Literature

Space deterrence is a relatively recent subdivision of the general subject of deterrence, and in this context almost exclusively a US and Chinese preoccupation. The most extensive treatment of the subject is Harrison, Jackson, and Shackelford *Space Deterrence* (Harrison et al. 2009), which proposes a system of "layered deterrence" including deterrence by international norms, increased transparency, threat of retaliation, and denial of benefit. My fellow authors and I concluded that, among these measures, the most effective means of deterrence was deterrence by denial of benefit, i.e., by lessening US vulnerability by ensuring the US forces are trained, equipped, and prepared to fight without space.

Gompert and Saunders, considering the overall question of deterrence in the context of emerging US-China strategic cooperation, argue that deterring Chinese attacks in cyber or space may require the capability of "severe retaliation" to cripple the Chinese economy and cyber networks, although the possibility that the Chinese would have similar capability raises the problem of “decoupling” the United States from its allies on China’s periphery (Gompert and Saunders 2011). They point out that the United States possesses an escalatory advantage, since it can attack the Chinese mainland in response to cyber or space attacks, viz., retaliation against Chinese launchers against direct, kinetic ASAT attacks. They argue that if the Chinese become more dependent on space and cyber, a decisive US cyber and ASAT advantage might create an atmosphere of “mutual restraint” which (given even greater US dependence and vulnerability) would be a “major American success” (Gompert and Saunders 2011). The problem with this approach is geographic: in any conflict between China and the United States, the Chinese will likely be operating close to the homeland, well within the range of traditional means of ISR and command and control; the United States, on the other hand, will be heavily dependent on satellite-enabled means of projecting power. Even if the Chinese become more dependent on satellites, it is difficult to see how this underlying imbalance of dependence/vulnerability can be redressed. The United States might, as Gompert and Saunders argue, couple space and cyber, threatening a cross-domain cyber-attack to disable the Chinese economy as a way of fostering a general atmosphere of mutual restraint. But the threat of cross-domain deterrence depends on a clear superiority in that domain in which retaliation would be carried out. The United States is probably superior overall in cyber, but this cannot be known for sure. It may have superior hardware and software and still be defeated – as the Shamoon virus illustrates – by a trusted agent with a thumb drive. And the United States is probably more vulnerable than China to disruptions in cyber as well as space, making a cyber for space cross-domain threat less credible.

A Rand Corporation Study, “Deterrence and First Strike Stability in Space,” argues for different thresholds of deterrence in space. According to the Rand study, the threshold may be quite low for reversible-effect attacks on ISR satellites, particularly those for reconnaissance of the ocean surveillance, but much higher on commercial satellites carrying military communication and higher still on GPS and early warning satellites. The Rand study describes the US security constellation as robust and urges a declaratory policy combined with the promotion of norms on aggression in space (Morgan 2010). This is in keeping with an earlier Rand study which suggested that Defense Department pronouncements may be “unwittingly producing a security dilemma where its own efforts to protect its systems may be driving other to develop systems to counter U.S. efforts” (Gompert and Saunders 2011).

Chinese literature on space deterrence offers a variety of views. Some echo US military thinking on issues like “space control” (Mulvenon and Finkelstein 2005), the Rumsfeld Commission report on the relevance of cyber-attack as means of disabling satellites, and the US Air Force views that space control is the key to prevailing in the air, sea, and electromagnetic domains and therefore to prevailing in war (Mulvenon and Finkelstein 2005). Although Chinese military writing contains many references to the advisability of building an offensive as well as a defensive capability in space, there is also recognition of the technical difficulties and high cost of such systems. The Chinese ASAT test 2007 demonstrated some direct ascent kinetic kill capability, but there is no evidence in open sources to indicate ongoing deployments of either ground-based kinetic systems or orbital weapons sufficient to pose a threat to the US satellites. It is to be assumed, on the other hand, that the PRC, the United States, and perhaps other countries are devoting significant resources to ground-based EW ASAT capability, as well as cyber means of disrupting satellite command and control. Gompert and Saunders argue that, because commercial satellites are integral to civilian economies as well as military forces, there are no convenient "firebreaks" between military and civilian attacks. By this they seem to mean there is the absence of a clear threshold, or trigger, for what might safely be considered a military attack subject to appropriate retaliation. Commercial satellite companies exist in an ambiguous relationship with governments. On the one hand, many have moved offshore to avoid regulation and weaken possible identification with any likely space adversaries, with all of whom they hope to do business. On the other hand, they depend for business on the major national space operators and for vital location and conjunction avoidance information on the United States. Gompert and Saunders conclude that a nation wishing to disrupt the status quo in space might play on this ambiguity by disrupting commercial satellites. But the opposite may also be true that the commercial companies have grown so important that they provide a stabilizing influence on the policies of various possible space adversaries. Without doubt, the commercial companies have been forcing the pace toward a more regulated and transparent space environment, and governments – including the United States – have found it in their interests to cooperate. As order builds, the costs of disrupting that order increase and deterrence is correspondingly strengthened.

Beyond this, however, there is another and vitally important "firebreak" in space that has been recognized from the dawn of the space age. Sean N. Kalic has provided a useful history of the US militarization of space under presidents Truman, Eisenhower, Kennedy, and Johnson and the combination of ideals, bureaucratic jostling, and Cold War tensions that formed the foundations of the US space policy (Kalic 2012). His theme is the continuity through the administrations of these three presidents of a space policy built around the "nonaggressive military uses of space," a policy which effectively ruled out weapons in orbit. There were, of course, many in the military and scientific community with a different view on weaponization. As early as 1948, the future father of Saturn, Werner Van Braun, had championed orbiting nuclear weapon platforms to ensure "world domination," before concluding (on advice of friends) that this sort of thing was perhaps more appropriate to his previous employer than the one to whom he and his team had bartered their services in 1945. He wisely moved on to the moon, but space policy has vacillated between an altruistic Ying and atavistic Yang ever since. The fact that the bulk of resources were devoted in these early years to peaceful striving rather than weaponization (to Apollo rather than a Fractional Orbital Bombardment Vehicle) was due, Kalic convincingly argues, to decisions made by the three Presidents whose administrations he describes. Thanks to them, prudence, the desire for the world's admiration, and scientific curiosity carried the day.

## 7.9 Deterrence in the Era of Competition, Congested, and Competitive Space

To speak of deterrence at all, of course, presumes the existence of some offensive capability on the part of potential adversaries. This is a safe assumption with regard to space. The Chinese, for one, have made no secret of their determination to prevent satellite-dependent military operations around their periphery nor of their drive for "parity" in space, presumably including military parity. Cold War deterrence between the Super Powers was based a rough balance of capability and risk. This proved stabilizing and created the possibility of arms control. The same situation does not exist in space. The United States is uniquely capable in space, but also uniquely vulnerable there, and it would be imprudent to assume that others will not seek to exploit that vulnerability. The means of doing so are also multiplying to include relatively inexpensive micro-satellites as well as cyber-attacks. In short, there is an inherent instability in the present circumstance that makes the task of preventing hostilities more difficult. The question is what steps might be taken to mitigate that danger.

The good news is this: that now, as in the past, there is no threat *from* space to be deterred and no means *in* space to attack other objects in orbit. Maintaining that as a baseline is the first and necessary step in any deterrence structure. This is not as improbable as it once seemed, even given the prospect of "inevitable war." Means are emerging to disrupt satellites without ever going into space. These are potentially far cheaper and more effective than clouds of orbiting hunter killers. They also open the possibility of spoofing an opponent by manipulating the data he sees. In short, the software has proven more permeable at lower cost than the hardware. This may be cold comfort to those hoping that space will be an eternal sanctuary; but it is probably unavoidable on the one hand and a far more stable alternative to weaponization in orbit on the other.

## 7.10 Deterrence as a Function of Transparency and Regulation

One such step is increase transparency. We face a future in which a spontaneous tendency toward order and predictability is in tension with the atavistic impulse for military advantage. Dreams of hegemonic rule supported by responsible actors and enforced against outliers seem no longer realistic. In this circumstance, "deterrence" will be dependent on the self-restraint and good sense of policy makers.

On the side of order, there is the emergence of a comprehensive web of space regulations with broad, international consensus. It is true that neither the ITU (which allocates orbital positions and communication spectra) nor the ISO (which sets standards for communication and other purely technical requirements for operators) nor the US-backed debris mitigation guidelines are backed by an effective enforcement power other than international opinion and the practical necessities of operating effectively and safely in space. But these are in themselves not insignificant inducements. There is also an international treaty, the Outer Space Treaty of 1967, to which all major space actors are party which bans nuclear weapons in orbit and requires prior notification for activities in space that are likely to disturb the satellite operations of other operators. All of these regulatory activities have been in place for decades. A new regulatory presence is the Space Data Association, a contractual arrangement between major commercial satellite operators that facilitates exchange of situational awareness data between the companies and includes an enforcement mechanism with penalties of up to twenty million dollars. The effect of this has been to accelerate the third development of the last decade tending toward enhancing "deterrence," and that is the vastly increased transparency of the space environment. Another key factor in transparency is the Internet. It has allowed the networking of smaller space observation telescopes to the point that objects no bigger than 10 cm can now be imaged in low earth orbit. It has also vastly increased the potential of the private observers, those mavens with stop watches and binoculars who watch the skies by night, and can now post their finding instantly on international websites were they can be confirmed, or not, by other observers. This process was successful, in one notable instance, in observing close proximity satellite maneuvers by the PRC in 2011. Finally there is increased information sharing, especially by the United States, which has by far the best ability to gather information about what is taking place in orbit and has shown increasingly willingness to share that information with other space operators. Indeed, the issue is not whether such information should be shared, but how much information sharing is consistent with other security considerations. Still, the tendency has been toward more information rather than less.

Of course, transparency does not directly deter anything in space. Nor do regulations which are not backed by enforcement power. Still, what we are seeing is privately moved toward a more regulated and transparent space environment in which clandestine activities are more difficult to hide and potentially have a higher political cost. This movement is led by the private sector and is coming just in time, as easier and cheaper access to space raises the specter of jostling for orbital space and spectrum, "cowboy" operators, and problems with space debris. But the tendency of these events is toward greater order and predictability in space and therefore toward "deterrence" in the broad sense we are using the term. Transparency is also an aid to the maintenance of norms, since it allows the observance of those norms to be verified. Given the long development times of space systems, transparency increases warning time and mitigates the possibility of a "bolt from the blue" disarming first strike akin to the overused "space pearl harbor" analogy raised by the Rumsfeld Commission.

## 7.11 Conclusions

The future is indeed an undiscovered country, but of the thousands of alternative futures that might be imagined for space, two stand out. One is a rough extrapolation from the history of space in the last fifty years. That would mean an intensification of the commercial exploitation of orbit for communications, military intelligence, and geographic survey and perhaps human tourism. Although space would continue to be exploited for military purposes like ISR and command and control, the emphasis would be on stability and predictability. Less expensive launch, which seems now to be a reality, means more potential for overcrowding of "golden" orbits and of communication spectra, and this might become an increasing source of conflict. It is difficult to see, however, how such conflicts can be settled by *force majeure*, and since the major difficulties will be largely between commercial companies rather than governments, the atavistic drives of nationalism might well yield to the profit motive in pushing actors toward some system of allocation, perhaps administered by the ITU, or the ITU in league with some encompassing commercial organization along the lines of the Space Data Association. It could also be that tourism and science will sustain a persistent human presence in space, perhaps in a chain of inflatable habitats like the one envisioned by Bigelow Corporation. The persistent presence of humans in orbit would also increase incentives for regulatory measures like debris mitigation.

The other scenario is more ominous. Whether or not weapons are deployed in space, the era in which satellites could operate without potential threat is over. Among other things, as long as satellites are crucial to ISR and targeting, military commanders will insist on some way to disrupt them, if only temporarily. Research will continue on methods to disable satellites temporarily (reversible effects) or permanently, either by direct kinetic attack, ground-based EW attack, or cyber penetration of the adversaries command and control. Perhaps such weapons already exist. The US national security constellation has been built in anticipation of the EW and hardened against it. Effectiveness of defense, or "cloaking," cannot be assessed from outside the system, but the key components of the national security constellation have been updated in the recent past, so their defenses are, as the Rand study asserts, "robust." Cyber-attack is another matter. It can be safely assumed that strategic satellite command and control is done in a "closed loop," i.e., without connection to the Internet. But this is not true of many commercial operators. Indeed, one of the issues raised by closer information sharing between government and commercial operators is that the relatively more open commercial systems will be exploited as a vector for cyber-attack against government satellite control networks. Even if this problem can be overcome, the recent Iran-sourced "Shamoon" attack against the Saudi Oil company Aramco points to another vulnerability. The Shamoon bug was reportedly introduced into Aramco systems by a "lone perpetrator," i.e., an insider with access to Aramco's systems. Such agents are hardly unknown in the most sensitive areas of the US national security system. Needless to say, commercial satellites, which carry a great deal of military communication, are vulnerable to both outside and inside attacks, so might be disabled or potentially held hostage in crisis. This threat is mitigated to a degree by the fact of "entanglement," i.e., the mutual dependence of major players in the world economy in the health and well-being of the satellite constellation. In the event of all-out war, of course, this would not be a decisive inhibition; but in the far greatly likelihood of skirmishes, brush fire, or surrogate wars, it would have a significant deterrent effect.

There are some obvious things that might be done, but they depend on a measure of self-restraint on the part of leading actors. The most important step is to refrain, on a basis of reciprocity, from the deployment of weapons in orbit. Generally speaking, these would be cumbersome, short-lived, crushingly expensive, unpredictable in operation, and (particular space to earth weapons) strategically destabilizing and impossible to defend. There are the inevitable and tedious arguments about what constitutes a weapon, but that will surely remain, as it has always been, in the eye of the beholder. The device which is perceived as a threat – and provokes imitation and/or counter deployments – is a "weapon" for purposes of the deterrence narrative. This will not stop development or deployment of surface-based means of disrupting satellites. That process will be anything but transparent, although the testing of such devices could be visible. The second is abstain from interfering by either physical or electronic means with the satellites of other nations or those of commercial operators, i.e., to extend and generalize the principle of "noninterference with national technical means of verification" that was crucial to the avoidance of space weaponization in the Cold War. Noninterference should be the first topic of discussion if and when the Chinese agree to engage with the United States on practical issues of space security.

Greater use of space for military purposes is not necessarily at odds with the economic exploitation of the cosmos, as long as space-to-space weapons are not actually deployed. If that occurs, the tendency will be for the combatants to individually exploit the relatively easy gains to be made in offensive systems and, therefore, an offensive arms race in space, perhaps involving hunter-killer satellites (on the model of Brilliant Pebbles), co-orbiting space mines, or space planes developed from the prototype X37B capable of popping into orbit as weapon platforms and then returning into the atmosphere. There may also be orbiting EW platforms. These would have the potential advantage of disabling rather than destroying satellites in orbit, thereby limiting debris harmful to the attacker as well as the attacked. But such weapons in orbit have the inherent disadvantage of cost, complexity, limited onboard energy supplies, and (because of their size) defense against more primitive but also potentially more effective KE interceptors. In this scenario, deterrence will remain a goal always just beyond reach – until (as in the Cold War) budgetary constraints or simple exhaustion produces a de facto status quo. Also, in this circumstance, the contestant who puts aside scruples about debris in favor of the cheap, kinetic hit to kill vehicles will have an offensive advantage.

Finally, and most speculatively, the general cause of preventing hostilities in space may be aided as the relative importance of space in modern war declines. This may already be happening. Space is becoming more transparent. Many of the ISR functions which could only have been provided by dedicated national security satellites can now be duplicated by a profusion of sources of information, not just from a variety of air-breathing, high-altitude, long-persistence, lighter-than-air vehicles as well as remotely control miniature crawlers.

Commercially operated satellites can provide services, like photo reconnaissance, down to resolutions of a third of a meter. Google Street View provides anyone on earth with a more detailed image of much of the world than was available to the most powerful leaders a generation ago. Almost every individual with a cell phone has become an intelligence source. An opponent hoping to blind the US forces in theater would now have to reckon with a variety of systems like the Broad Area Maritime Surveillance (BAMS) sensor operating from the Navy MQ-4C equivalent of the Global Hawk RPA or the Army's lighter-than-air Long-Endurance Multi-intelligence Vehicle (LEMV), as well as high-altitude, long-endurance vehicles like the Boeing Phantom Eye. Systems like these are more flexible and vastly cheaper than satellites; they can adapt to changing technology much more quickly becoming cheaper, smaller, and more effective. All this, plus the ever increasing costs of satellites, may well erode over time the comparative advantage which, in an earlier era, satellites possessed, decreasing satellite dependence and making attacks in space less inviting.

As well, in future, the problem will not be producing more information from more satellites, but processing the information we already possess from a virtually infinite numbers of sources. Militaries will have to assume transparency; the only sure defense will be in mobility or disguise; and nations may again come to believe – as the Cold War combatants did – that maintaining a degree of order in space is more important to them than any military advantage in the cosmos could be. If that occurs, a space war will have been deterred in the only way the term now has meaning.

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# Responsive Space

# 8

Nina-Louisa Remuss

## Contents

### Abstract

The European Space Policy, while being currently largely driven by civilian considerations, faces growing security-related demands for European security and safety missions ranging from external security actions to maritime surveillance and emergency response to natural disasters. Several EU and think tank initiatives have examined how space assets can support internal and external security missions. The resulting insights into existing capabilities identified a need for instruments supporting a variety of European security and safety missions as well as more flexible and more affordable space applications. Time- and cost-related considerations form the basis of the concept "responsive space" (RS). The most well-known approach to RS is the one under development by the

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US Department of Defense, but countries such as Canada have also looked into developing RS. On the basis of their experience, this chapter aims to look into a European approach to RS.

## 8.1 Introduction: The Setting for a European Approach to Responsive Space

Europe has adopted a broad understanding of the concept of security comprising internal security threats such as terrorism and organized crime; environmental threats such as deforestation and climate change; natural disasters such as landslides, earthquakes, and tsunamis; and external security threats including military aggression in the near abroad. The two key elements defining Europe's approach to security are the European Security Strategy (ESS) of 2003 which is complemented by the report on its implementation of 2008 (Council of the European Union 2008) and the European Internal Security Strategy of 2010. The ESS mentions terrorism, proliferation of weapons of mass destruction, regional conflicts, state failure, and organized crime as the key threats for Europe (Council of the European Union 2003). The European Internal Security Strategy adds cybercrime, cross-border crime, violence itself, and natural and man-made disasters to this list (Council of the European Union 2010, pp. 5–6). Given the broad range of potential threats Europe could face, it has to meet a variety of user requirements for the prevention of and response to any of these threats. Europe needs operational, responsive, and flexible instruments with which to act.

Several EU research initiatives have looked into how space as an instrument can support security policy and missions both internally and externally: the EU's Framework Programme (FP) for Research and Technological Development, the Space and Security Panel of Experts (SPASEC) and its subsequent SPASEC Report, the Group of Personalities (GoP) for Security Research, the European Security Research Advisory Board (ESRAB), and the European Security Research and Innovation Forum (ESRIF). They have given insights into existing capabilities and the improvements needed. Additionally, several think tanks have looked into European approaches to security. These include the Belgian Royal Institute for International Relations initiative which proposed a European security concept for the twenty-first century (cf. Belgian Royal Institute for International Relations 2004) and the EU Institute for Security Studies (EUISS) that put forward suggestions for Europe's ambitions for European defense in 2020 (cf. de Vasconcelos 2009). While not directly dealing with the use of space applications in the provision of security, these attempts have aimed to answer questions which are also raised in the context of responsive space, such as the EU's relationship with NATO and the question of parliamentary oversight over the EU Common Security and Defence Policy. Additionally, the European Space Policy Institute (ESPI) has researched the use of space applications for internal security threats (Remuss 2009) as well as their contribution to the fight against piracy (Remuss 2010b).

In this setting, the European Space Agency (ESA) has looked at new potential concepts in the realm of space and security consistent with its Convention, the European Space Policy (ESP), and the recent Resolutions adopted by the Space Council and by the ESA Council at Ministerial level. One of these attempts was GIANUS (Global Integrated Architecture for iNnovative Utilisation of space for Security), a concept which aimed at meeting user needs particularly with an eye to the increased dependence of the EU on space assets, the need for tools in the operational theaters, and the increased opportunities arising from the FP 7 projects in particular. GIANUS was designed to contain a responsive element and envisaged as a unified, holistic, and integrated approach. It has been discontinued in favor of a fragmented approach since March 2011. This is due to the fact that ESA, as a technology development agency, is directly steered by the Member States, which were not supporting the idea of GIANUS. ESA currently neither is mandated to develop security-related technologies without Member States consensus nor is mandated to operate security-related technologies.

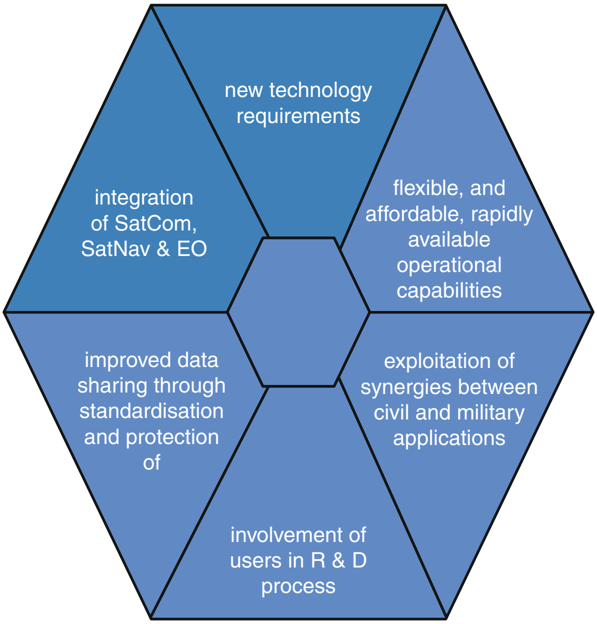
This chapter has three objectives. Firstly, it aims to define the concept of responsive space, thereby shedding light on the motivations and objectives of this concept. Secondly, it intends to show the reasons for Europe to develop responsive space applications. Thirdly, it outlines the approach and degree of involvement in responsive space of the main spacefaring nations, thereby shedding light on their motivations, objectives, and definitions for responsive space. Finally, it concludes by proposing several elements of a roadmap for Europe in the context of responsive space.

## 8.2 Responsive Space for Europe?

Considering the topics that are currently under discussion in the context of Europe and space policy, e.g., workshop and conference topics, as well as study, article, and presentation requests, the following recurring issues for Europe can be identified:

- Emerging new technology requirements
- The need for operational capabilities, i.e., how to address the transition from demonstration to operation
- The need to exploit synergies between military and civil applications
- The need to involve users in the research and development process
- Issues related to data policy
  - Standardization and regulation, i.e., counteracting the EU's islands of data by establishing standardization of data to improve data sharing
  - Protection of sensitive data while at the same time not hindering data sharing for, for example, emergency response, i.e., across borders and user communities
- The need for a more integrated approach in terms of
  - Integrating European and national assets, capabilities, and services
  - Integrating SatCom, SatNav, and EO
  - Integrating space applications with other terrestrial applications

**Fig. 8.1** Responsive space – a holistic approach to the issues currently at stake



Responsive space (RS) is a concept that addresses all these issue areas in a holistic manner (see Fig. 8.1). Its main objective is to provide more flexible and more affordable space applications in a timely manner to users. RS could take up user requirements that are formulated and successfully demonstrated in FP projects and put them into practice. In this way it would address the transition from demonstration to operation and enhance user involvement in the research and development process. Given that user needs are diverse, RS draws upon an integrated approach and combines Satellite Communications (SatCom), Satellite Navigation (SatNav), and Earth Observation (EO) assets and applications as well as incorporating space applications into comprehensive concepts with terrestrial applications. Since RS relies on all existing assets, it will also need to establish a data policy thereby addressing the issue of standardization and protection of sensitive data with an eye to increased data sharing while at the same time trying not to pose trade barriers.

## 8.3 Conceptual Considerations: Defining "Responsiveness"

Responsive space neither is a simple armament approach nor is a futuristic technology-push model. It is a concept whose time for more detailed investigation has come and for which appropriate policy perspectives must be developed. Its benefits for European civilian- and security-related issue areas are abundant and should be given detailed and thorough consideration.

Space applications have typically been depending on large and expensive satellites, which, for the most part, are designed for long life and high reliability and cannot be reconstituted quickly if compromised (Dal Bello 2006). The life and reliability requirements are due in part to the high cost and limited availability of space launch (Brown 2004). In the context of increasing dependence on space assets for both military and civil applications, space applications are increasingly considered as critical infrastructures. Different threat scenarios thus lead to the need for careful consideration of rapid replacement possibilities, requiring both on-demand capabilities and rapid launches.

Current space systems require years to develop due to the complicated specialized design and manufacturing processes (Brown 2004). Additionally, space systems do not adapt well to change (Doggrell 2006).

With customers' needs being dynamic, as they "emerge in time and evolve stochastically, prompted by unfolding environmental (political, economic, or technological) uncertainties and network externalities" (Saleh and Dubos 2009), the resulting discrepancy between "the time associated with the emergence and change of customers' needs and the response time of the industry in delivering solutions to address these needs" (Saleh and Dubos 2009) increasingly leads to the criticism of space assets as being too rigid and incapable of modernization. Such needs can consist of completely new capabilities for different customers such as military or commercial users but can also translate to a modification or repositioning of an existing on-orbit asset. Typically, several years pass from the moment that a need is identified to the time when the asset becomes operational. Disadvantages resulting from these time delays range from the commercial competitive aspects, i.e., opportunity loss or failure to secure the first-mover advantage, to the military context, i.e., loss of lives or failure to save lives. Other industry branches have faced similar problems in terms of the discrepancy between the rate of change of customers' needs and the ability of the industry to deliver timely solutions. These issues came to be known as the "just-in-time" concept. "Responsiveness" can be taken as the space industry's close analogy to the just-in-time concept in other industries (Saleh and Dubos 2009, p. 377).

Apart from the delivery time problem, current space mission planning is also extremely costly. Thus, launching smaller spacecraft with less costly launch vehicles, reducing the cost of individual missions, or other less costly alternatives are increasingly being considered. One side-effect in finding a solution to the costliness of space missions will be the impact on the availability of space access to organizations and countries previously lacking adequate funding (Rao et al. 2006).

While the need for space responsiveness is unambiguously felt, clear and agreed upon definitions of space responsiveness are lacking. In recent years the word "responsiveness" has become increasingly popular. In 2003 an annual Responsive Space Conference was established in the United States with the objective of bringing together various stakeholders in an effort to address problems associated with the lack of responsiveness in the space industry. Three years later, the conference chair James Wertz still had to acknowledge that "there seemed to be more definitions of responsiveness than participants" (Saleh and Dubos 2009, p. 377). Similarly, the term has often been depicted as "fuzzy" with different meanings depending on the particular business section talked to, e.g., developer, operator, or customer of those systems.

"Responsiveness" can be understood as "the ability of an industry to address (. . .) changing customers' needs in a timely and cost-effective way" (Saleh and Dubos 2009, p. 376). A system in turn is commonly referred to as "responsive" if it can "rapidly react to stimulations and exogenous inputs or events" (Saleh and Dubos 2009, p. 178) or if it is "in effect coping efficiently with changes and uncertainty in its environment" (Saleh and Dubos 2009). Based on the above analysis of the underlying problem, timely development, flexibility (i.e., the ability to modernize), low costs, and rapid launches and rapid orbit deployments can be identified as the main elements of today's understanding of "responsiveness."

"Time" is thus one of the main elements of "responsiveness." The response time of a system is defined as "the time elapsed between the onset of the input or stimulation and the time when the system's response gets 'close enough to the steady-state level'" (Saleh and Dubos 2009, p. 377). Applied to space this means that the time dimension starts when the need for a new on-orbit capability is identified and formalized (i.e., when the request for proposal as a Request for Proposal (RFP) is issued). In response to a request, the industry will undertake a series of events and design activities and reviews until the space asset is developed and ready to address the new identified need (Saleh and Dubos 2009). The time element also refers to the time after the element is being developed, i.e., launching and deployment.

Hence, in order to improve responsiveness in the development of a new space asset or in modifying an on-orbit capability, there is a need to understand the various activities within the space industry (e.g., design, production, reviews, integration, testing) and how much time each activity contributes to the total time. This, however, requires a thorough understanding of the temporal breakdown of each activity including temporal overlaps enabling parallel tasking. It is important to acknowledge that these are not solely of a technical nature but can be legal, organizational, or procedural activities. This is referred to as the "schedule structure" of a space program. Understanding this schedule structure proves to be a prerequisite for identifying bottlenecks and time inefficiencies (Saleh and Dubos 2009).

Given that not all activities related to the schedule structure are technical in nature, it is important to identify legal, organizational, and managerial aspects and related obstacles to responsiveness as well. This consideration already shows that satellite manufacturers are not the only players influencing the schedule structure. Government agencies (military and civilian), satellite operators, end users, banks, investors, insurance companies, and regulatory agencies all contribute and influence responsiveness in varying degrees (Saleh and Dubos 2009, p. 381).

Summarizing the abovementioned considerations, it is critical that several points be identified and understood prior to defining an approach for responsive space. These are compiled in Table 8.1. The answers to these questions might vary for

**Table 8.1** Time-related considerations: summary of points for departure

| Time-related considerations: summary of points for departure |
|---|
| What are all the activities (technical, legal, organizational or managerial in the space industry following the issuance of an RFP for a new or modified on-orbit capability?) |
| How much time does each activity contribute to the total time? |
| How do all these activities contribute to the overall development and readiness of the system? |
| What determines the duration of each activity? |
| What is the degree of overlap between these activities? |
| Where are the bottlenecks? |
| What are the reasons for the bottlenecks and how can they be eliminated? |
| Who are the main stakeholders in this schedule structure? |
| To what extent does each stakeholder influence or hinder responsiveness? |
| How can bottlenecks related to specific players be eliminated? |

**Table 8.2** Cost-related considerations: summary of points for departure (Based on Saleh and Dubos 2009)

| Cost-related considerations: summary of points for departure |
|---|
| What are the elements of the total-life-cycle cost (LCC)? |
| How much does each element contribute to the LCC? |
| What determines the cost of each element? |
| What problems raise costs and how can they be eliminated? |
| Who are the main stakeholders? |

different satellite applications such as Earth Observation, SatCom, and SatNav. They will also be different for new on-orbit capabilities and modifying existing on-orbit capabilities.

Another way of considering responsiveness is from the costs perspective by conducting a cost analysis, which entails analyzing the total-life-cycle costs, including acquisition cost, the costs to operate and maintain the specific system, as well as other nonobvious and indirect costs incurred during the service life of the system. “Cost” is thus the second main element of “responsiveness.”

There is a need to develop payloads that are both affordable and capable of performing their mission in only minutes after launch. As indicated earlier, the challenge is not only to make access rapid but also to make it affordable (Worden and Correll 2004). Research into microsatellites (i.e., smaller satellites that can be built faster, are cheaper, and can be launched together with other satellites) is a first step in this direction. Cost-related considerations critical to a responsive approach are summarized in Table 8.2.

Another complementary aspect of responsiveness is to look at it from the level of different stakeholders, the so-called levels of responsiveness, of which it is possible to identify three: (1) global industry-wide responsiveness, which looks at responsiveness from the end-user perspective; (2) local stakeholder responsiveness, which looks at responsiveness from the perspective of the local customer in comparison to seeing it from the perspective of the end customer; or (3) inter-stakeholder perspective, which considers how well or

**Table 8.3** Levels of responsiveness considering different stakeholders' perspectives (Based on Saleh and Dubos 2009)

| Levels of responsiveness | Identified actions |
|---|---|
| 1. **Global industry-wide responsiveness**: responsiveness taken from the end-users' perspectives | Eliminating bottlenecks in the value-chain |
| | Minimising waiting periods |
| | Maximising overlap to the degree possible between different streams of activities at the level of different suppliers |
| | Compressing the "response time" of each single supplier |
| 2. **Local stakeholder responsiveness**: responsiveness as perceived by the local customer | Reducing or compressing delivery time for single action |
| 3. **Inter-stakeholder perspective**: responsiveness as being dependent on the interaction between customer and supplier | Improving efficiency where necessary in the interaction of customer and supplier |
| | Reducing the complexity of a system leading to involvement by fewer stakeholders' thus easing management tasks |

efficiently the customer interacts and works with its suppliers (Saleh and Dubos 2009). Table 8.3 summarizes the levels of responsiveness and the identified actions.

Additionally, responsiveness depends on different levers:

1. **Design and architectural choices of a system**, determined by the complexity of a system, the degree of use of identical units and repetitive tasks ("learning curve"), modularity, plug-and-play, and standardization of interfaces
2. **Launch vehicles and range**
3. **Soft levers** such as the selection process, design reviews, and acquisition policies

A decrease in system complexity reduces the number of subsystems and payload instruments to be developed as well as their connections and interfaces and, in doing so, results in reduced complexity which in turn results in shorter design and development times for the different sections of a spacecraft. A decrease in system complexity also leads to a reduction in the time needed to assemble and test. Additionally, reduced complexity will lead to less involvement of stakeholders and suppliers. With fewer suppliers and stakeholders to manage and take into account, interactive responsiveness can be improved. Another possibility is to reduce the time spent on system design and architecture by making use of repetitive tasks and production of multiple identical units whenever possible. This should result in time compression. The "plug-and-play" approach relying on modular design and standardization of interfaces is another possibility to improve responsiveness in the design and architecture phase. A thinking outside the box in line with the "commercial of the shelf principle" could help.

Another step to tackle in the schedule structure is the launch stage. It can be divided into launch vehicles and launch ranges, which together constitute the launch levers of responsiveness. Literature on responsive launch advocates moving away from a "pull production system" to a Build-To-Inventory (BTI) or "push production system." Lately one can observe a trend towards relying on BTI concepts. In the BTI concept, products are manufactured not in response to a confirmed order but on the assumption that through "pushing" these products onto the market, they will eventually be purchased. Apart from finding a responsive approach to launch vehicles, it will be important to improve the existing launch ranges. Currently most ranges are government owned and function under certain restrictions that often result in delays in the order process.

Engineers and scientists will also have to explore how smaller payloads can be deployed rapidly to achieve useful effects and how these can augment and reconstitute existing capabilities or enable new ones (Worden and Correll 2004). Currently, it is dependent upon a launch-on-schedule concept. In order for launches to be responsive, a launch on-demand approach must be prepared (Doggrell 2006).

As indicated above, responsiveness not only depends on technical and operational characteristics but also on legal, organizational, and managerial aspects, which are referred to as the "soft levers of responsiveness." The most prominent components of these are the selection process, design reviews, and acquisition policies.

Turning to the first, the selection process is composed of the time from when the need is identified and formalized to the program initiation. So far no research has been conducted to benchmark the selection process between competing proposals for on-orbit capabilities in a military acquisition context, in a government civilian context, and in a commercial context. A reduction in the time of the selection process would constitute a major improvement in space responsiveness.

Multiple design reviews also add to the total amount of time spent in the development process. Given that they provide for progress visibility for all stakeholders, allow for the early identification of design errors and other problems, and allow for multidisciplinary assessment of the level of quality and maturity of the project, they can well be said to be justified. While some research suggests that intense customer involvement in the development process can stretch the development schedule by over 50 %, other sources indicate that a "handshake and trust" policy with suppliers is certainly practical (cf. research conducted by Saleh and Dubos, pp. 393–394). This however requires a delicate balance between trust between customers and suppliers in the space industry as well as trust between senior management and technical lead personnel.

Policies for the acquisition of space systems can also be an obstacle to responsiveness. Experience has shown that requirements for space systems are often not adequately defined at the start of the program or that they change significantly after the program has started, resulting in significant schedule delays. Conflicting demands for changing system requirements after a program has started should be carefully balanced with the need for responsiveness. Furthermore, given the often large number of officials and organizations involved in requirement definitions and system acquisition, program managers have to have the authority to make necessary trade-offs between requirements, changes in requirements/requirements growth, and maintaining the program on schedule and within budget. Thus, effective program management skills and team empowerment can also be taken to constitute a lever of responsiveness.

## 8.4 The United States

The United States is currently the spacefaring nation most prominently developing an RS capability. The US Operationally Responsive Space (ORS) concept originates from the military. Already in January 2001 the Rumsfeld Commission identified problems in developing new space capabilities (Worden ad Correll 2004, p. 7) and the Department of Defense (DoD) started considering satellites as potentially vulnerable critical infrastructures (Doggrell 2006). The Space Transportation Policy Directive of 6 January 2005 of the Bush Administration identified the need to demonstrate an initial capability for operationally responsive access to and use of space – providing capacity to respond to unexpected loss or degradation of selected capabilities and/or to provide timely availability of tailored or new capabilities – to support national security requirements (Doggrell 2008).

ORS initially meant different things to different people, thus a redefinition and common understanding had to be established. Initial definitions ranked from a new business model, to a low-cost launch vehicle, a program to develop near space platforms, a small-satellite program, global strike weapons to part of an "unblinking eye offering persistent surveillance over the battle-space" (Berube 2007). While the exact definition of ORS may remain in transition, its origins and intents are relatively straightforward: "ORS recognizes that space systems and technologies are essential to the U.S. war fighter and primarily are responsible for conferring the 'information dominance' on which the U.S. and allied troops currently rely" (Dal Bello 2006). When Congress in 2007 mandated DoD to formulate a plan to establish ORS and authorizing it to establish an ORS Office, ORS was defined as "[a]ssured space power focused on timely satisfaction of Joint Force Commanders' needs" (JFC) (Berube 2007). Specifically, ORS was to "provide an affordable capability to promptly, accurately, and decisively position and operate national and military assets in and through space and near space" (Doggrell 2006).

The development of the US ORS was mainly motivated by the changing space environment and the different user requirements in post-Cold War times. Increasing reliance on space applications and emerging global challenges have placed new demands on US space capabilities, which were designed during the Cold War to counter Cold War security threats. As an increasing number of nations have developed space programs, the space environment is increasingly perceived as nontransparent and contested. While the JFC continues to be one of the main users of US space capabilities, in contrast to the Cold War era, the military is no longer the sole user of space applications. With the changed threat environment, the JFC is facing new requirements. Additionally, commercial satellites are increasingly offering vital space applications such as in the provision of security, emergency management, and climate change. Commercial satellites are thus also being used by military users.

The main objectives of the US ORS concept are to satisfy the needs of the JFC and to develop the enablers to allow for rapid development, deployment, and operation of space assets to support JFC needs. The US ORS follows a three-tiered strategy: (1) rapid exploitation of existing capabilities; (2) use of existing technologies and capabilities to replenish, augment, and reconstitute; and (3) development of new technologies and capabilities to replenish, augment, and reconstitute. As such ORS aims at addressing issues anywhere from minutes to hours to months (Wegner 2008). In order to do so, it aims at bringing together operational, acquisition, industry partners, and science and technology communities to rapidly exploit emergent capabilities to fill operational gaps (Wegner 2008). It also aims at actively engaging with all stakeholders in the space community (defense, civil, industry, and academia) at the international level to define and promulgate spacecraft modular open standards.

The DoD inaugurated the ORS Office in 2007, which has been tasked to coordinate the development of hardware as well as the development of the concept across the agencies involved. This capability is supposed to be in place by 2015.

The ORS Office is implementing a rapid innovation process using a Modular Open Systems Architecture (MOSA) to facilitate rapid assembly, integration, and test (AI & T), deployment, and operations of space assets into the current space architecture. Thereby, the focus lies on material (spacecraft, launch, range payloads) and nonmaterial solutions (business model, acquisition, policy, industrial base, training, command and control, tasking, exploitation, processing, dissemination, concept of operations), and collaboration with national and international agencies to leverage existing investments and develop long-term relationships (Operationally Responsive Space Office 2012).

According to the ORS' Implementation Plan, the so-called I-Plan, the ORS Office is to accomplish its objectives in a "crawl, walk, and run" approach (United States Government Accountability Office 2008, p. 11). During the crawl phase the war fighter was getting involved with the concept and the focus was on demonstrating building blocks for later efforts, conducting experiments, and determining what can be accomplished with current assets. The US Government Accountability Office described "walking" as "the evolution of the ORS concept into a war fighter-driven concept with selected capabilities tied to gaps and integrated within the existing architecture" (United States Government Accountability Office 2008, p. 11). "Run" involves the ability to provide and end-to-end ORS structure, i.e., a full range of space effects delivered when and where needed. The plan foresees this for 2015. While the walking phase was according to the "I-Plan" only expected to start by 2010, the demonstrations of single elements of end-to-end demonstrations which have been demonstrated until 2009 can be said to have "propel[led] the ORS concept to somewhere between a walk and a run" (The former Deputy Commander of US Strategic Command in United States Government Accountability Office 2008, p. 11).

In addition to the ORS' activities, the United States follows several programs for the development of responsive launch, e.g., Responsive Access, Small Cargo, Affordable Launch (RASCAL), Force Application and Launch from CONUS (FALCON), Evolved Expendable Launch Vehicle Program (EELV), United Launch Initiative, and the Affordable Responsive Spacelift (ARES). Research has also investigated the choice of possible launch sites. The United States is researching responsive payloads and buses as part of its TacSat Program, an Air Force initiative that uses small spacecraft known as TacSats.

Interestingly, the Air Force has also looked at a cooperative approach to responsive space referred to as Coalition Operationally Responsive Space (C-ORS) (cf. Doyne 2007a). Taking NATO's space heritage as a case study, an international constellation of like-minded nations participating in security operations around the world was proposed (Doyne 2007b). Given that all nations face similar challenges such as shrinking budgets, aging equipment, and the need to transform the military, the idea was to intensify the level of cooperation and coordination to adapt to the shared challenges and constrains (Doyne 2007b). The idea of a C-ORS was also based on the Disaster Management Constellation (DMC), where involved partners agreed to buy and operate a satellite while sharing the data with the constellation partners. Accordingly, if each member of NATO agreed to buy and operate a single small satellite, then 26 small satellites would be available for use in NATO operations. As with the Disaster Management Constellation, individual NATO members would get the benefits of a constellation for the price of a single satellite (Doyne 2007b). Apart from NATO, a cooperation in the framework of the European space policy was also considered (Doyne 2007a).

From the beginning the ORS Office and AFRL have had the goal of collaborating with US allies. Under the heading "Globalize and Internationalize ORS Standards and Technology" (GIST), it is sought to establish the processes and procedures required to authorize DoD and nondefense entities (e.g., industry) to collaborate with allied countries in developing and codifying Space Plug-and-Play Avionics (SPA) and other ORS standards (=Internationalize) and to publish publicly releasable or "open" standards (=Globalize) and to establish a worldwide community to evaluate and extend the concept of responsive space standards (Pugh et al. 2009, p. 1). The collaboration with a foreign partner is organized through a Memorandum of Understanding (MoU) prepared by DoD, which is currently being negotiated and expected to be ready for signatures in summer 2013. The nature of the activities and the ability to share the results of the projects are determined by the terms of the MoU. Specific joint projects require Project Agreements (PA) under the auspices of the MoU. A PA defines an even more restricted scope of activities as well as the objectives, responsibilities, and expected outcomes of the project (Pugh et al. 2009, p. 5). Basically, the MoU will serve as an umbrella for more specific agreements from government to government agreements on specific joint projects.

The future of the US ORS program was largely unclear during 2012. While being originally directly funded through the US Department of Defense planning, programming, and budget cycle, with the funding being allocated to the ORS Office through the US Air Force, the White House's fiscal year 2013 budget request marked the termination of ORS for 2013 (Clark 2012) by not including any funding for the ORS Office (Ledbetter 2012c). The Strategic Forces Subcommittee of the US House Armed Services Committee in contrast recommended continuing the funding of ORS (Ledbetter 2012a). In its request the Air Force proposed closing the ORS Office and allocation of US$10 million to integrate the ORS concepts and results into other military space programs (Ledbetter 2012a). Proponents of such a move claimed that it was necessary as part of the Air Force contribution to the US$487 billion in planned reductions in defense spending over the next decade mandated by the Budget Control Act of 2011 (Ledbetter 2012c). Accordingly, the risk in cancelling the Space Test Program (STM) was acceptable as the AFRL would still spend US$370 million on space-related research, and concepts developed by the ORS Office would find their way into other programs (Ledbetter 2012c). It was however not explicitly specified how much, if any, of the money saved by closing this account will find its way into other space-related programs (Space News Editor 2012). The proposal to terminate the program stood in sharp contrast to the US$110 million which the Congress appropriated for the ORS Office in fiscal year 2012 (Clark 2012). While recommending rejecting the Air Force proposal, lawmakers proposed funding ORS activities at US$25 million, thereby recommending no funding for any integration activity.

Currently, ORS funding is spread across five space budget accounts in the Air Force budget request. The committee was not convinced that the Air Force plan "will fully address joint military operational requirements for on-demand space support and reconstitution." Critics also said "it does not make sense to try and lower costs by cancelling the programs that were specifically established to find ways to save money" (Rep. Martin Heinrich in Ledbetter 2012c). The Air Force was asked to submit a plan on the future of ORS to the committee by November 2012 (Ledbetter 2012a). Congress has subsequently appropriated US$105 million for the ORS Office in fiscal year 2013. Despite this unclear situation, the ORS Office is continuing its plans to launch two more demonstration missions scheduled for 2013 and 2015 (Ledbetter 2012b).

## 8.5 Canada

While traditionally Canada has been pursuing a civilian space policy, there have been military cooperations in the field of space at least since 1998, when the Canadian Department of National Defence signed a Memorandum of Understanding (MoU) with the United Kingdom and the United States concerning trilateral technology research and development projects (TTRDP MoU). Pursuant to the TTRDP MoU Canada, the United Kingdom and the United States have been cooperating in a small-satellite military utility project since 1998. Both the MoU and the subsequent small-satellite military utility project are an example of the cooperation under the GIST-Project Agreement (Pugh et al. 2009, p. 5).

The Canadian Department of National Defense (DND) was prompted by the advent of increasingly capable microsatellites to propose the establishment of a responsive space program (Bédard and Spaans 2007, p. 1). The motivation behind was research into microsatellites which showed that they offer low-cost solutions and accelerated development schedules. Since 2001 the Defence Research and Development Canada (DRDC) in collaboration with the Directorate of Joint Capability Production (formerly known as the Directorate of Space Development) has established a responsive space research and development effort with the objective to evaluate the military utility of microsatellite and to foster innovative ways of accelerating their introduction into the range of capability areas available to Canadian Forces (CF) planners (Bédard and Spaans 2007, p. 2).

Proponents of the Canadian RS effort were initially hesitant to define the term "responsive." On the one hand, the framework for such a definition was lacking as the Canadian defense space strategy was not formally approved, and on the other hand, confusion with the US ORS concept was to be avoided (Bédard and Spaans 2007, p. 2). DRDC thus defined its initiative on the basis of the four attributes: multi-mission micro-/small bus, cost, timelines, and scope (Bédard and Spaans 2007, p. 2). First, the responsive space effort was heavily based on the multi-mission microsatellite bus (MMMB) program which was proposed by the Canadian Space Agency (CSA) and designed to create a generic microsatellite but to provide low-cost access for science and technology demonstration missions. Second, if space assets were to become viable options to support CF operations, then the cost of providing an end-to-end system was to come down drastically. Third, the period from concept identification to operational status was to be reduced to 2–5 years. Fourth, the responsive space mission is believed to be focused on a specific user community and not intended to satisfy a broad range of user needs (Bédard and Spaans 2007, pp. 2–3). The objective is not to develop a satellite but to deliver a capability, from space, on a small platform, where is makes most sense to do so (Bédard and Spaans 2007, p. 7).

Canada initially identified a need for assured access to surveillance of space information (orbital data and space debris) as well as for maritime surveillance. In two joint efforts the DRDC and the CSA have launched two missions regarding these operational requirements. In June 2003 the CSA launched the Microvariability and Oscillations of Stars (MOST) autonomy mission demonstrating that microsatellites could be very useful to the defense community. This was followed by the DRDC-CSA joint microsatellite mission NEOSSat (the Near-Earth Object Surveillance Satellite)[1]. The second joint DRDC-CSA mission was a maritime surveillance mission (M3MSat) collecting and reporting AIS signals for integration into a RMP (Bédard and Spaans 2007, pp. 4–7).

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[1] For more information on the current status of NEOSSat cf. Canada's Space Agency (CSA) (2011).

The Canadian Space Commerce Association has recently submitted a report to the Canadian Federal Aerospace Review 2012[2], which recommends that the federal government commit to specific steps towards the development of an indigenous small-satellite launch capability (Canadian Space Commerce Association 2012). Additionally, Canada hosted its first Nanosatellite Workshop in 2012, which among other things concluded that "Nanosatellites and microsatellites have demonstrated a capability to serve operational needs in a cost-effective and responsive manner" (Report from the 1st Canadian Nanosatellite Workshop 2012, iii).

Since 1 January 1979 Canada has been one of ESA's Cooperating States. As such Canada participates in ESA's bodies and decision-making and takes part in ESA's programs and activities. Canadian firms can bid for and receive contracts to work on programs of interest to them. Since the new agreement was signed in 2000, ESA can also take part in Canadian programs. Canada's involvement in responsive space is thus also interesting in the light of ESA's research in responsive technologies.

## 8.6 China

China is currently focusing on the development of three new launcher configurations, which shall be finalized by 2016. They are relying on more efficient engines and an entirely new upper stage. This includes Long March 5, with a LEO lift capacity of 14 t; Long March 6, with a LEO lift capacity of 1 t; and Long March 7, with a LEO lift capacity of 5.5 t. Of particular interest in the context of RS is Long March 6, which is described as a "high-speed response launch vehicle." Being particularly light, it is said to provide China with a responsive launch capability, with obvious national security and commercial applications (Al-Ekabi 2012, pp. 82–83). China's interest in RS has however already been recognized since 2001, when it formulated its commitment to developing mobile, quick response launch vehicles and satellites to be put into operation within the first few orbits (Cooper 2003, p. 3; Cosyn 2001).

## 8.7 Japan

Japan too has been increasingly looking into the development of small satellites in the last years (Matsuda et al. 2008, p. 1). In this context Japan has also been looking into the development of affordable microsatellite launchers, with the MV small/medium launch vehicle program being discontinued in 2006. Initiated in 2009 the Ministry of Economy, Trade, and Industry (METI) has been working on a research

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[2] The Aerospace Review has been mandated by the Government of Canada to produce concrete, fiscally neutral recommendations on how federal policies and programs can help maximize the competitiveness of Canada's aerospace and space sectors.

and development project known as ALSET – Air Launch System Enabling Technology. The project is carried out jointly by USEF, IHI Aerospace, CSP Japan, Kawasaki Heavy Industries, and Fujitsu and aims to build up an air launch concept to provide higher flexibility and responsiveness to meet the launch needs from the emerging small-satellite market as well as to demonstrate key technologies of the new launch system to validate its feasibility for future commercialization (Arime et al. 2012, p. 2).

## 8.8 Russia

There is no explicit information on a Russian involvement in the development of a responsive capacity. However, it is highly unlikely that a spacefaring nation is not looking into the development of microsatellites from a military and civilian perspective, their launches as well as rapid launches in general.

## 8.9 European States

The United States has recently opened up its ORS initiative and invited several States to work together on developing common standards under the heading of responsive space capabilities (RSC) research. It has thus asked the following countries to join by signing a Memorandum of Understanding (MoU). Apart from Canada, Australia, and New Zealand, the European countries involved (through their respective Ministry of Defence) are France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, and the United Kingdom. The objective is to reach interoperability through the development of common standards and technologies.

## 8.10 . . .and NATO?

NATO has been looking into RS through a project on "emerging space system concepts" of its Research and Technology Organization (RTO) since 2009. The RTO is missioned to conduct and promote cooperative research and information exchange within NATO and with its partners (Sembenini 2009). In the context of emerging space systems concepts, the project aimed to assess the military utility of new space system concepts, to develop space system concepts significant to NATO, and to explore NATO interoperability for space systems (Sembenini 2009). The results of the projects are however classified. In this context it is important to recognize that neither NATO has own space assets[3] nor does it have

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[3] "NATO's space capabilities" are really national space capabilities used in a NATO context (Verroco 2012a).

**Table 8.4** Five proposed guiding principles for a NATO space policy (JAPCC 2012, p. 14)

| Proposed guiding principles |
|---|
| Alliance collective defence and security is applicable to space capabilities supporting NATO operations |
| International standards and norm contribute to the preservation of space capabilities for all |
| The coordination of Nationally owned and controlled space capabilities will result in improved operational effectiveness and efficiency for the Alliance and Nations |
| Space capabilities, along with technology in general, are rapidly improving resulting in the levelling of previously stark disparities |
| Coordination and collective defence of space capabilities employed on behalf of NATO is an active and continuously evolving process |

a space policy yet. This however does not differ from other fields. NATO relies on NATO Member States' assets in its operation, generally. NATO has no centralized coordination or command and control structure for space (Meacci 2011). Thus, the question about NATO's involvement in responsive space is actually a general question about NATO and space. Since the creation of the Joint Air Power Competence Centre (JAPCC) in January 2005, an extensive effort has been made to underline the role of space and its link to air power in the contemporary world (Meacci 2011). The JAPCC, which can be understood as some kind of think tank for airpower-related issues for NATO, has recently proposed a framework for a NATO space policy entitled "Filling the Vacuum" (JAPCC 2012), which proposes a policy framework for NATO in space. It starts by proposing five guiding principles for a NATO space policy, which are enumerated in Table 8.4 below. It continues by laying down some basic definitions before formulating seven tenets recommended for NATO's approach to space.

NATO has further explored combined space operations within a NATO construct during the Schriever Wargame 2012 International, the world's premier space and cyberspace wargame conducted by the US Air Force Space Command and hosted by the US Air Force Warfare Center. The game hints that coordinating military space operations across NATO at the Joint Force Operational level improved mission effectiveness (Verroco 2012b).

## 8.11 Conclusions

The first responsibility of any government is to protect its citizens from harm and to provide them with an environment that induces confidence in the future. Europe as an ever-closer Union shares this responsibility with its Member States (Belgian Royal Institute for International Relations 2004, p. 5).

In order to do so, the EU must have the necessary means and instruments. The European Union Institute for Security Studies (EUISS) has in this context identified ten priorities for the next 10 years (de Vasconcelos 2009), which can be used as guiding themes and background information relating to the requirements and the changing context that calls for a European concept for responsive space. They have been listed in Table 8.5 below.

While none of these ten priorities explicitly mentions or refers to space applications, services, or satellites, they give some important insights on European values and perspectives in security policy and thus also for space policy.

The EU ISS highlights (Priority 2) Europe's respect for human rights and the rule of law in the international system. Accordingly, Europe's human security doctrine may require undertaking the full range of military operations. RS will support both of these. On the one hand flexible, capable, and affordable space capabilities will provide objective tools clarifying human rights and international justice issues; on the other hand, they will prove to be irreplaceable support instruments in any military operation.

In contrast to the United States' approach to ORS, the European Space Policy (ESP) is currently largely driven by civilian considerations. As has been said, given Europe's broad understanding of the concept of security, there is a need for instruments to support a wide variety of European security and safety missions. A European concept for RS would provide these instruments. Thus, in contrast to the US ORS, which deals solely with the military national security requirements, Europe will need to develop a RS concept, which takes both civil and military requirements into account. Given that the United States and Europe differ in terms of the objectives of their space policies, their threat perceptions and, consequently, their understanding of the concept of security, the US ORS can only serve as an example and not as a "prototype" for Europe to simply take over. Therefore, the institutional architecture supporting RS in Europe will need to look different from the one the United States has chosen. Similarly the European Navigation System Galileo in contrast to the US' GPS is civilian but can be used by the military while GPS is an Air Force/military program. Security as a policy area has always been difficult to integrate. The most prominent example showcasing this difficulty is the attempt to found a European Defence Community (EDC) in the 1950s, which failed to pass the French Parliament in 1954. The collapse of the EDC gave room to the founding of the Western European Union (WEU), a defense organization residing outside the European Coal and Steel Community (ECSC) (cf. Dinan 1999, 24 ff). To empower one institutional actor to steer the RS seems to be necessary in order to ensure oversight and comprehensiveness, avoid duplication of efforts, and guarantee that all stakeholders share the same understanding of RS.

The development of a European approach to RS will also require Europe to develop a perspective on the role of NATO (EU ISS Priority 6). The issue about the role of the EU and NATO and their division of labor is a reoccurring one in many different contexts, e.g., transatlantic relations and the fight against piracy. The main objective for Europe should be to avoid duplications and to find a solution for both sides to gain. NATO should be informed about any attempt to develop

**Table 8.5** EUISS' ten priorities for the next 10 years

| |
|---|
| **1. Crisis management today – common defence beyond 2020** |
| The EU should continue to do what it already does and should concentrate on doing it better: managing conflicts of a variety of types, in most cases internal wars in non-European States, as well as combating banditry, piracy, trans-national criminality including terrorism and cyber terrorism |
| **2. A human security doctrine may require the use of force** |
| Respect for human rights and international justice at all levels of military operations is an essential component of its legitimacy and effectiveness. There is no contradiction between the notion of human security and undertaking the full range of military operations |
| **3. Civilian and military 'force-generation' goals must be met** |
| National military and civilian commitments should be adequately publicised in order to increase transparency and an improved monitoring system of fixed benchmarks set in place to facilitate scrutiny. The EU is seeking to develop adequate capabilities to set up a number of civilian-military missions simultaneously, part of which will need a strong military component. The development of EU capabilities should build on 'Europeanising' existing national capabilities. A common budget should be established, to pay for the common structures and to finance a significant part of ESDP military missions. At-the-ready capabilities for civilian crisis management must be improved, with the goal to develop into an EU-crisis management package suited to different types and stages of civil and civilian military missions |
| **4. The case for a single European defence market and joint procurement** |
| The success of the EU single market has yet to be extended to defence |
| **5. Prioritising the European military and civilian command** |
| Need for a number of permanent structure such as a formal Council of Defence Ministers, chaired by the EU "Foreign Minister" |
| **6. Developing a European perspective on the role of NATO** |
| The distinctive identities of NATO, a military alliance, and European defence, a security and crisis management component of the Union, should make the question of the role of each in international security quite easy. This should be the point of departure for the definition of an EU perspective on NATO |
| **7. Creating a European Parliamentary Council for Security and Defence** |
| Democratic control of ESDP is becoming an issue, as European public opinion is demanding greater accountability and transparency with regard to the full spectrum of EU decisions. This requires the engagement of national parliaments and of the EP. More extensive parliamentary debates on ESDP will led to increased public scrutiny and awareness of ESDP missions, thus enhancing their legitimacy, both at the European and national level |
| **8. Building an 'open' ESDP** |
| There is no reason for the EU not to open ESDP to strategic partners and develop with them common training and interoperability necessary to the effectiveness of the missions |
| **9. Overcoming the political deficit: putting coherence first** |
| A clear priority is to make the necessary reforms to ensure the coherence and the consistency of the EU's international action |
| **10. Inclusiveness is a prerequisite for legitimacy** |
| The ambition of the Union for 2020 should not be a European mini – defence project, spearheaded by the most militarily capable Member States but a powerful foreign, security and defence policy, able to pull together in a coherent and consistent way, the weight of all Member States and of all the EU institutions |

a European RS, as to ensure that NATO, as a security stakeholder, is familiar with the European understanding of RS and NATO's concerns can be considered right from the start. Similarly, the United States should be informed about the European attempts – especially with an eye to the United States opening of the ORS program through the GIST and C-ORS initiatives.

The introduction of a European approach to RS further leads to assessing the roles of other existing European bodies. The EU ISS called for the creation of a European Parliamentary Council for Security and Defence (Priority 7). The European Security and Defence Assembly (ESDA)/Assembly of the Western European Union (WEU), which existed in the framework of the Western European Union (WEU), was dissolved in June 2011, following the termination of the Modified Brussels Treaty of 1954 establishing the Western European Union (WEU). Both, the European Union Satellite Centre (EUSC) and the EU ISS had been transferred to the community framework before. According to Article 10 of Protocol 1 on the Role of National Parliaments in the European Union of the Treaty of Lisbon, the Conference of Parliamentary Committees for Union Affair (COSAC – *Conférence des Organes Parlementaires Spécialisés dans les Affaires de l'Union des Parlements de l'Union Européenne*) "may also organise inter-parliamentary conferences on specific topics, in particular to debate matters of common foreign and security policy, including common security and defence policy." As a consequence ESDA became void. ESDA was debating space- and security-related topics. In the course of establishing a European approach to RS, a call for more parliamentary oversight might evolve. It remains to be seen whether the recently founded Inter-Parliamentary Conference for the Common Foreign and Security Policy (CFSP) and the Common Security and Defence Policy (CSDP) will tackle this task.

As can be seen RS perfectly fits into both the EU's research as well as the think tanks' initiatives. Consequently, RS should not be considered as an isolated concept but rather as part of a larger attempt to resolve many issues requiring a more integrated approach. Hence, while it is important to consider existing capabilities such as Galileo and GMES for RS, it is also important to consider RS in the context of the general policy of the EU with regard to topics such as data harmonization, standardization, and integration of European and national capabilities.

The current degree of readiness of the European industry to become involved in RS is hard to assess. The European industry has been involved in many demonstrations as part of the FP projects. Their feedback shows that they are ready to provide many of the requested technological requirements and are sometimes even far ahead of the outcomes of EU research projects. What has been lacking so far is the political will to encourage the industry to take the necessary future steps towards more integrated, flexible, and affordable space applications for Europe. Specifically, it is the lack of political direction for European, rather than national, solutions.

Based on the abovementioned conceptual considerations and the US ORS experience, elements of a roadmap for RS in Europe can be identified. Basic problems that have to be tackled and answered before being able to formulate a European approach to RS are (1) institutional and architectural questions; (2) legal, organizational, and managerial challenges; (3) time; (4) cost; (5) secure data policy and governance; and (6) the time frame for the establishment of a European RS.

1. One possibility to start creating RS is to conduct a thorough assessment of current space assets both at European and national levels. This status report should enumerate existing capabilities and include a thorough gap analysis. The Joint Research Centre (JRC) has already conducted some first studies in the context of space applications for maritime security. It conducted benchmarking activities as part of the FP 5 DECLIMS project, and, as part of the Commission's call for an integrated maritime policy, it evaluated existing maritime surveillance systems at national level and compiled a comprehensive report in a document entitled "Integrated Maritime Policy for the EU: Working Document III – On Maritime Surveillance Systems." A gap analysis should answer the following questions: Who are the users? What do they need? What do we have? In particular, how would Tactical Imagery Exploitation System (TIES), Multinational Space-based Imaging System (MUSIS), Galileo, and Global Monitoring for Environment and Security (GMES) contribute to RS? What is missing? The gap analysis could draw on FP and national research. The resulting needs matrix should be subdivided into short-, mid-, and long-term requirements in line with the three-tiered approach (technically the best option). Alternatively, one could start by identifying European aims and requirements and match these with the existing capabilities, resulting in gap analysis. This way Member States' suspicion when asking about their capabilities can be avoided (politically best enforceable solution).
2. In addition to a status report on existing space capabilities, lessons learned and demonstration results of research and development projects at both European and national level should be taken as building blocks for Tier-2 and Tier-3 developments.
3. By compiling both of these, the stakeholders involved could be identified. From the very start, these should be included in the development process of a European Responsive Space as to agree on the definition for RS.
4. Once users have been identified, a requirements matrix should be established. The matrix should be used to identify a way to feed-in the different user requirements for the RS architecture and development process.
5. Moreover, there is a need to develop the political will to use the capabilities that are available. Outreach activities showing users what is possible and presenting the case in all possible forums could help in fostering the necessary political will.
6. In the future, military requirements can be compiled by the European Defence Agency (EDA) and civilian ones by the European Commission (EC) supported by the Council.
7. Engagement and dialog with users should be increased. The establishment of a user-exchange mechanism would be a step in this direction.

8. Access to systems in the event of a crisis is of utmost importance. In this context, ownership is crucial. However, guaranteeing that systems remain on the European side can also be achieved through the use of multinational missions or by signing treaties and agreements to cover these cases.
9. The US experience has shown that it is particularly important to establish an understanding of responsive space with all these stakeholders. In the United States, the ORS Office is responsible for this. As space competencies within Europe are distributed between EU, ESA, and the Member States, it seems difficult to entrust an existing actor with this task.
10. Responsive space is expected to create a whole new paradigm in the space field that, from a developer's perspective, requires specific technologies and new development and implementation approaches. As many new enabling technologies need to be investigated, a system for long-term R&D efforts to foresee future requirements needs to be found. Both academia and think tanks can be involved in this effort. Industry and satellite operators should also provide their input. RS will require adaptation of field operations, decision-making processes, and of activation or allocation procedures. This would go hand-in-hand with adaptation of the industry value chain.

The above-indicated recommendations are to be understood as elements towards the development of a comprehensive approach for Europe to RS. The idea to conduct an assessment of existing European capabilities, the gap analysis, as well as the proposed supportive institutional architecture should thus be seen as elements of such an approach. The order of the elements is not necessarily mandatory but should be adapted flexibly as to make room for political hesitations.

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## Further Reading

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# Space and Cyber Security

# 9

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**Abstract**

This chapter will describe how space is strongly connected and interacting with cyber security. The latter, even though there is no wide consensus about any formal definition, will be described and defined, for the sake of the argument, using concepts borrowed from both the civilian and military context.

It will be shown that space system and cyber security challenges are to be faced through systems engineering concepts and methodologies and that such an approach paves the way to undertake effectively challenges in both these fields at the same time, achieving cyber secure space systems. Specialized technical issues will be mentioned when necessary but not dealt with in detail; on the other hand, specific information will be provided about tackling space system conception, development, detailed design, production, deployment, management of operations and maintenance, and exploitation from the standpoint of a correct cyber security approach.

## 9.1 Introduction

Space, in this chapter, will be described examining its interdisciplinary relations with cyber security. Firstly, it is necessary to define what we intend by the terms space and cyber security.

The expression space is meant to encompass space systems in all their phases: conception, detailed design, production, deployment, management of operations and maintenance, utilization, and disposal; in other words, we are concerned with the space system life cycle. It is well known that such a field, as described in Wertz and Larson (1999), Gerosa and Somma (2011), Spagnulo (2011), NASA (2007) and ECSS Standards, is the realm of advanced systems engineering, and related standards, and entails the absolute necessity of sophisticated project management techniques, as detailed in Gerosa and Somma (2011) and Spagnulo (2011). Differently put, and the reason will be clear shortly, we will be dealing with high-level technical and management issues and concepts, aimed at the final goal of satisfying user and stakeholder requirements while achieving the best trade-off between performance, schedule, and financial resources.

It is interesting to quote the following definition of systems engineering: "Systems engineering" is an interdisciplinary field of engineering focusing on how complex engineering projects should be designed and managed over their life cycles. Issues such as logistics, the coordination of different teams, and automatic control of machinery become more difficult when dealing with large, complex projects. Systems engineering deals with work processes and tools to manage risks on such projects, and it overlaps with both technical and human-centered disciplines such as control engineering, industrial engineering, organizational studies, and project management. Such a definition is sufficient to give an idea of the systems engineering process and is coherent with the references (Wertz and Larson 1999; Gerosa and Somma 2011; Spagnulo 2011; NASA 2007; Defence Acquisition 2001; System Engineering).

Coming to cyber security, we need to note that there is not any commonly accepted definition of cyber security and of the correlated concepts. It is undisputed, however, that cyber security and the correlated issues stem from information technology (IT), IT systems complexity, and their worldwide pervasiveness, dependability, strategic importance, and role, hence, the bond with information security and information assurance. Moreover, emphasizing furthermore the modern IT systems complexity, it is more and more common to undertake their implementation and life cycle management through systems engineering methodologies, consequently creating, with reference to security, a sort of hybrid between information assurance and systems engineering applied to security, which we may call information assurance security engineering. This approach has been proposed by Ross Anderson and Stuart Jacobs in (2008) and (2011).

It is useful to quote some definitions for cyber security, security engineering, information security, and information assurance:

1. Cyber security is the body of technologies, processes, and practices designed to protect networks, computers, programs, and data from attack, damage, or unauthorized access. In a computing context, the term security implies cyber security, as defined in Cyber Security.
2. Security engineering is a specialized field of engineering that focuses on the security aspects in the design of systems that need to be able to deal robustly with possible sources of disruption, ranging from natural disasters to malicious acts. It is similar to other systems engineering activities in that its primary motivation is to support the delivery of engineering solutions that satisfy predefined functional and user requirements, but with the added dimension of preventing misuse and malicious behavior. These constraints and restrictions are often asserted as a security policy, as reported in Security Engineering.
3. Information security means protecting information and information systems from unauthorized access, use, disclosure, disruption, modification, perusal, inspection, recording, or destruction, as defined in Information Security.
4. Information assurance (IA) is the practice of assuring information and managing risks related to the use, processing, storage, and transmission of information or data and the systems and processes used for those purposes. While focused dominantly on information in digital form, the full range of IA encompasses not only digital but also analog or physical form. Information assurance as a field has grown from the practice of information security, as mentioned in Information Assurance.

It is simple to realize that cyber security as defined in def. (1) is a subset of def. (3) and def. (4). Def. (4) stems from def. (3) modified adding the risk management issues; this is true from a historical point of view as well, and information assurance is to be considered a more effective approach, which supersedes information security. In other words, based on these widespread definitions and considering the reference made in def. (2) to systems engineering and user requirements, it seems logical, possible, and consistent to tackle cyber security issues through information assurance and systems engineering.

The definitions above have been developed in an unclassified context, i.e., in the private sector and in the government when not operating with classified information. It must be emphasized, though, that not only classified information has to be protected; that is obviously due to privacy, safety, and/or business reasons, and the level of effort may be extremely high.

When we deal with security and classified information, as it is common in the military and in specific government sectors, the general definitions are similar; however, there are minor differences and peculiarities, summarized as follows:

(a) The term cyber security is often meant as the strategic context where national and coalition, like NATO, cyberspace – the electronic medium of computer networks, in which online communication takes place – and interests are protected through cyber defense. This definition is extremely abstract and high level but certainly contains def. (1); moreover, it has to be mentioned that sometimes, especially in a technical context, the expression cyber security is used to refer to the specialized security measures that are implemented.

(b) The expression cyber defense is widely used; it is usually defined as cyber security in the sense of def. (1) above, so being a subset of cyber security as defined in (a) above. However, it is not correct to infer that cyber defense is the name given to cyber security, meant in def. (1) above, in the military and security-sensitive government sectors. Cyber defense, in fact, applies the information assurance concept and the multidisciplinary DOTMLFPI approach; the acronym DOTMLFPI means Doctrine, Organization, Training, Material, Leadership Development, Personnel, Facilities, and Interoperability. It is immediate to understand the huge complexity of such an approach, which confirms the necessity of systems engineering methodologies.

(c) Government and military approach is highly structured, complex, and ruled by many laws and regulations, both technical and procedural, some of which are often classified and may be very demanding. In other words, government and military requirements are usually more stringent and more difficult to meet.

(d) Finally, it is important to mention that the information assurance approach has superseded the information security in the military and classified government sectors as well. However, due to historical reasons, the following terms are still very common, identifying as many security areas:
    1. INFOSEC for information security, often used meaning IA and not to be confused with def. (3) above; as a matter of fact, as it will be shown, INFOSEC and IA are quite different.
    2. OPSEC for operational security; it refers to physical, organizational, and procedural security issues.
    3. COMPUSEC for computer security; technical computer-related security issues.
    4. COMSEC for communications security; technical communication-related security issues, which comprise the following areas: CRYPTOSEC for cryptographic security, EMSEC or TEMPEST for emission security which is related to unintentionally emitted information, including all the possible physical phenomena and therefore not limited to electromagnetic waves, and

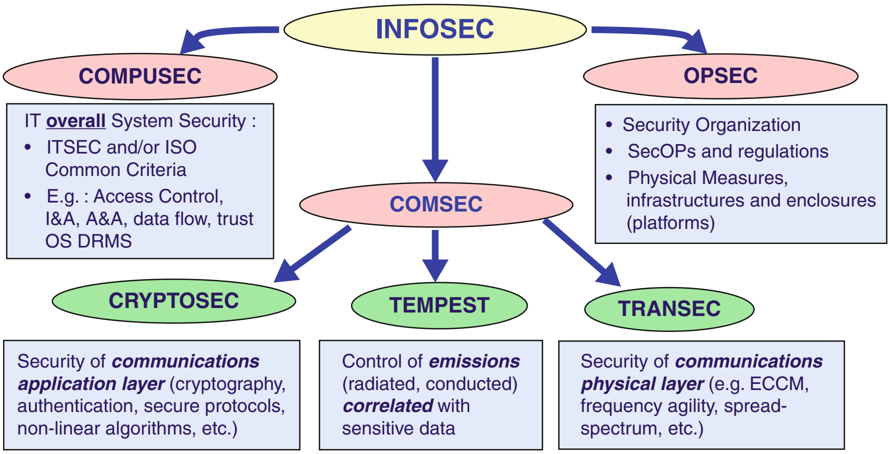

**Fig. 9.1** INFOSEC taxonomy

TRANSEC for transmission security which is related to the ability of transmitting information without being intercepted.

The INFOSEC terms are clear in their general meaning; nonetheless, they may entail highly complex and difficult technical issues and challenges; related technical standards, publications, and regulations are almost always classified (an INFOSEC Taxonomy is shown in Fig. 9.1).

The information presented about cyber security allow us to deduce that such an issue is perceived in a similar way both from the military, the private sector, and the government in all its various capacities. Stakeholders dealing with classified information will have to face more demanding requirements and the procedures to manage classified information, but the general approach will stay the same. Specifically, it is necessary, given the complexity level involved, to achieve cyber security through the methodologies of both information assurance and systems engineering.

We can now try to understand the connection of cyber security with space systems.

Firstly, it is evident that a generic space system may be considered as composed by several information technology systems or subsystems that interact among them, generating, processing, and exchanging information; subsequently, part of the exchanged information is disseminated and/or exploited through further information exchanges with external systems not belonging in the space system.

The above mentioned space IT subsystems are the control ground system (CGS), the user ground system (UGS), and the space segment (SS), in single or in constellation configuration. The external systems are whatsoever information technology systems that may exploit the information delivered by the space system.

This conceptual decomposition of a space system may be applied to:

1. Communication satellite(s); the CGS controls and manages the satellite(s) while inside the UGS, composed by satellite communication terminals; links are established and information is exchanged. A proper gateway may connect the UGS with other external communication systems.

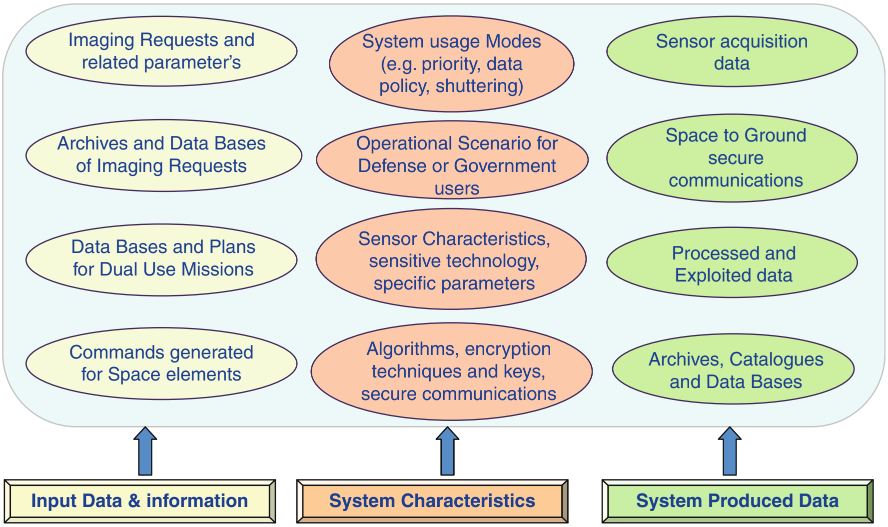

**Fig. 9.2** Typical data assets

2. Earth observation satellite and scientific missions; the CGS controls and manages the SS satellite(s)/spacecraft while the UGS, composed usually by specialized receivers, exploits the information collected and transmitted by the satellite(s) payload(s); a proper gateway may connect the UGS with other external systems able to exploit the images and scientific data.
3. Navigation systems; the CGS controls and manages the satellite(s) while the UGS in composed by specialized receivers able to exploit the navigation waveforms and messages; in this case as well a proper gateway may connect the UGS with other external systems usually to exploit the extremely precise time and frequency references delivered by navigation systems.

So we covered virtually every possible space systems, showing that they are, even if not only that, information technology systems; in addition, they need to be connected to other systems in order to be exploited at the maximum level.

Examples of typical data assets in observation, communications, and navigation space systems are presented in Fig. 9.2.

It may be then argued that space systems have to comprise the necessary tools to deal with cyber security issues; in other words they need to integrate the methodologies of both information assurance and systems engineering. The results of this integration may be called information assurance systems engineering.

In the following two paragraphs, we will try to illustrate the most significant aspects of information assurance systems engineering and the integration with the space industry, i.e., space-related systems engineering methodologies and project management techniques.

## 9.2 Information Assurance Systems Engineering (IASE) Essential Features

Information assurance systems engineering essence has been defined as the integration of IA and systems engineering; in order to understand what it means, we need to better define both IA and, from an IA perspective, systems engineering.

Based on the definitions previously given, IA may be regarded as the protection, over the time, of information assets – i.e., systems, software, hardware, networks, and data – fully respecting relevant laws and regulations, managing the related risk, and achieving the following security services that are also called security/protection attributes or goals: confidentiality, integrity, availability, authentication, and non-repudiation.

In addition, IA has to be achieved in several environments and organizations, both private and governmental, at national and international levels; the approach and the level of ambition will be a direct consequence of the organization security policy and security requirements.

Security services may be described as follows:

1. Confidentiality consists of preventing the disclosure of information assets to unauthorized individuals or systems.
2. Integrity means that information assets, and data in particular, cannot be modified undetectably.
3. Availability mandates that the information assets must be available when needed, assuring business continuity. This means that the computing systems used to store and process the information, the security controls used to protect it, and the communication channels used to access it must be functioning correctly. High-availability systems aim to remain available at all times, preventing service disruptions due to power outages, hardware failures, and system upgrades. Ensuring availability also involves preventing denial-of-service attacks.
4. Authentication is necessary to ensure that the data, transactions, communications, or electronic or physical documents are genuine. It is also important for authenticity to validate that both parties involved are who they claim they are.
5. Non-repudiation implies that one party of a transaction cannot deny having received a transaction nor can the other party deny having sent a transaction.

It is useful to observe that, from a historical perspective, the first security services to be defined were confidentiality, integrity, and availability, sometimes called CIA with some humorous puns as a logical consequence (see Stamp (2011)); authentication and non-repudiation were added later, due to the new requirements stemming from the development of IT systems and their growing pervasiveness. The term INFOSEC still refers to CIA, not including authentication and non-repudiation. However, many works and books about information assurance and information security focus essentially on the CIA attributes; this explains the confusion between IA and INFOSEC and why those terms are often mistaken.

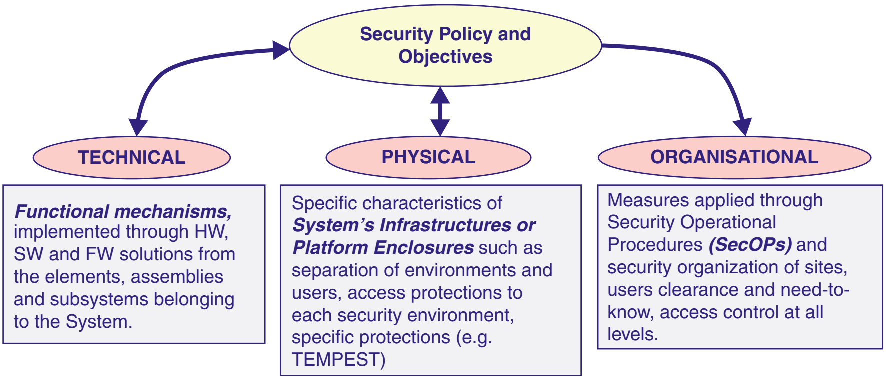

**Fig. 9.3** Security measures taxonomy

Security services are implemented through technical, physical, and organizational/procedural security measures, often called controls or countermeasures, and good engineering practice; see Fig. 9.3.

Technical measures are essentially the result of computer, network, and communications engineering; they consist of functional mechanisms implemented through hardware, software, and firmware solutions. Applied cryptography is essential in achieving all the security objectives, with the exception of availability that, essentially, is related to robustness and dependability.

Physical measures are related to the infrastructures that host and physically protect the information assets; there are technical aspects, but they are not information technology related, being rather architectural, building, and plant engineering challenges and requirements. Typical issues are environment separation, security environment access, and specific protections related to EMI/EMC, TEMPEST, NBC, etc.

Organizational/procedural measures are implemented through security operational procedures, easier called “SecOPs” and site security organization.

It is immediate to identify the analogy with the concepts of OPSEC, COMPUSEC, COMSEC, CRYPTOSEC, EMSEC/TEMPEST, and TRANSEC.

Further IT related technical details are beyond the scope of this work and may be found in Jacobs (2011), Stamp (2011), Schneier (1996), Anderson (2008) and Menezes et al. (1996); physical and procedural technicalities are too organization specific and will not be treated.

IA may be seen as a continuous process that involves both the information assets to protect and the organization responsible for them, managing the related risk through the abovementioned security objectives, which are achieved implementing the proper security measures in accordance with the approved security policy and requirements.

Such a process, extremely complex, requires, in accordance with consolidated systems engineering methodologies, an overall management system, which is generally called information security management system (ISMS).

Let us review the most important elements of an information security management system.

There are several standards and guidelines about the elements of a proper security management system; we may quote as examples:

- OECD's nine principles, as reported in OECD principles
- The ISO 27000 family of standards, with specific reference to ISO/IEC 27001 and 27002
- The "Standard of Good Practice" of the Information Security Forum

All these directives present several common parts that we can summarize as follows:

- Awareness; all the elements of a company must be aware of the need to protect their resources starting from the top management to the whole organization in all the different roles. A proper training level is needed to reach the target.
- Rules and organization; it is necessary to define an organization model aimed to security by defying tasks and responsibilities. Security rules will be effective only if maintained at high level, including, among their tasks, the search of the best strategy, particular society targets, and their performance assessment systems.
- Risk analysis and management; as it appears clearly as a consequence of the concepts already introduced, the risk analysis and management is crucial to know threats and problems of the organization as well as efforts and resources that are limited by definition needed to protect the most threatened areas.
- Policy and procedures; once explained the risk analysis, it is important to define policies and their procedures. They are characterized by three levels: general, describing the organization, the government system, and its goals and principles; users, i.e., the daily user behavior with respect to technologies; and technical, by which the ICT staff learns how to manage the stages of technology implementation and maintenance.
- Continuous monitoring and tuning of the protection system; the security management system must be designed in order to guarantee the best monitoring, both operational and technical, allowing the organization to react and adapt to the changes of the risk domain.

Risk analysis and management is of paramount importance and will be thoroughly analyzed.

There are two more aspects to be considered about ISMSs, IT products/systems, and the professionally involved people: security certification and security accreditation.

These two terms are often mistaken, and the concept of security accreditation may have different shades of meaning according to the context.

Certification is the confirmation of certain characteristics of an information asset, person, or organization usually provided by some form of external review or assessment. The primary forms of certification impacting IA are product certification and process certification that address the processes and mechanisms used to determine if a product, service, or operation meets minimum standards. From an integration perspective, security certification is the process of assessing the security measures/controls in the information system to determine whether they are implemented correctly, are operating as intended, and are meeting the system's security requirements. The certification process itself is conformal to specific standards.

Certification, usually, is widely understood in the same way, in both the private and public sectors; differences may arise as a consequence of the selected certification standard.

Accreditation is the act or process of examining the competency, authority, or credibility of organizations that issue credentials or that are accredited by standard/ government bodies, thus also known as "accredited certification bodies," to certify other enterprises are compliant with official standards. The accreditation process focuses on verifying that these accredited certification bodies are competent to test and certify third parties, behave ethically, and employ suitable quality assurance processes. An example is the accreditation of testing laboratories and certification specialists who are permitted to issue official certificates of compliance with established standards.

The description above applies to both the private and government sectors.

It is important to point out that while certification may be performed by several different bodies, accreditation is necessarily centralized and controlled; usually we talk of accreditation authority. Accreditation authorities are defined at national and international level; in the first case it is a government or government-controlled entity, while in the second it is an "ad hoc" committee or agency, usually composed by representatives of the nations involved.

It should be noted that, depending on the context and the laws and regulations, the accreditation authority may retain the certification authority; in this case, there are still several bodies performing certification activities but not able to issue any formal certification.

There are cases, very common in military and military industry sector, when classified information assets have to be protected, but there is no need to accredit the bodies in charge of it in terms of the capability of issuing credentials or certifying third parties; in such a situation the accreditation is a slightly different process and becomes the formal assessment of how an information asset is protected against its information assurance requirements, including certification requirements and resulting in the acceptance of residual risks in the context of the business and operations requirements; this type of accreditation here is easier called government accreditation.

Based on how we defined accreditation, we may rephrase the security certification definition of an IT system as follows: security certification is the process/ technical evaluation of an IT system's security features, made as part, and in support, of the approval/accreditation process, that establishes the extent to which a particular IT system's design and implementation meet a set of specified security requirements.

In addition, considering government accreditation, we may consider certification and accreditation as a sort of overall unique standard process to insure that systems meet their documented security requirements and maintain the security-accredited structure throughout their system life cycles. Still we have to distinguish between

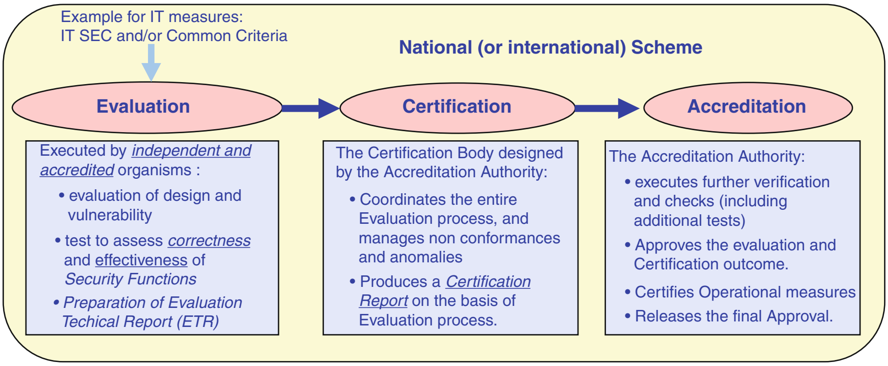

**Fig. 9.4** Government accreditation

certification and accreditation. Certification is the technical evaluation of the security components and their compliance for the purpose of accreditation: a certifier, usually an independent third party, audits a system for compliance with an established set of security requirements, while the accreditation is the formal acceptance of the adequacy of the system's overall security by the management.

The accreditation of system/products by the security authority, according to applicable international and/or national schemes and standards, is the final goal of the process. An example of a possible IT measure government accreditation process is shown in Fig. 9.4.

The most important impact of IASE on space systems is, in the authors' opinion, given by risk analysis and management, certification, and accreditation, which we tried to describe in their essence.

In the following we will be giving more details about the first two; the latter is too influenced by national laws and regulation to be tractable in this work; anyway, in general terms, the impact of the accreditation issues will be described.

## 9.3 IASE: Risk Analysis and Management

Now we want to identify all the components of a general model of risk analysis and management. Our goal is to identify a clear map of all the elements of a generic model, in order to better understand the schemes and the related processes of the different models today available.

### 9.3.1 Risk Analysis

Nowadays, economic and social life cannot be separated by the corresponding information resources and communication networks. Unlike the physical world, information and networks are vulnerable to risks of wide nature, often hidden and constantly evolving.

Furthermore it can be observed that:

- IT systems are more and more sophisticated and their changes create new risks.
- A complete protection leads to a limited and slowed down usage of network and computing resources.
- The protection technique strictly depends on the considered risk.
- The costs of a high security system that go far beyond the needs or extended to the lower impact elements are often too high.

Hence it is important to carry out a risk analysis in order to:

- Define information threats against the organization.
- Assess their impact in case of occurrence.
- Define and implement countermeasures in order to mitigate the risk with a commiserate effort to the potential impacts.

The risk analysis is then crucial in order to choose the best countermeasures without guessing them, balancing these countermeasures with respect to their costs and risks.

The risk analysis is one of the most important elements of the security management system. It is furthermore required directly or indirectly by EU and national laws and by the main reference standards such as:

- The ISO 27000 family of standards, with specific reference to ISO/IEC 27005
- ISF Standard of Good Practice
- CobIT, which is for ISACA "Control Objectives of IT Governance"

The risk analysis assumes even more importance in wider context of corporate risk analysis and management.

The growing importance of the information risk analysis with respect to the more general context of the corporate risk management is based on the growing support that information technologies provide to the business and the corresponding corporate process.

So, the information risk, that is, the risk related to the lack of information system protection, influences and conditions more and more the other risks categories like financial, market, and operational risks.

The risk analysis must be carried out a priori, periodically and in a continuous/dynamical way, in order to update the protection system to the effective and real identified need, allowing at the same time the best use of available resources.

### 9.3.2 General Notes About the Different Risk Analysis Methodologies

There are several risk analysis methodologies, with different targets and features, but most of them share some common concepts, elements, and procedures.

There is no best methodology: it is important to understand which approach could be the best considering the type of analysis to perform and the risk measurement system to apply.

In addition, the available methodologies have many elements in common.

The type of analysis may be conceptual, i.e., related to the management and addressed to the organization and its processes, and/or operational, i.e., related to the person in charge of the information systems and addressed to technologies and the operative context.

The conceptual high-level risk analysis and assessment allow:

- To define the risk profile at a strategic and organizing level
- To define the organization threats and the critical macro areas or the risk context to address over time
- To define a plan of immediate enterprise interventions
- To define the general security policy

Such an evaluation attains the perception and awareness of the corporate top management about the importance of the security management plan definition and implementation.

It achieves also the commitment to the security plan and above all allows addressing the effort towards the most critical areas.

The operational risk analysis is targeted to a detailed and in-depth security assessment of the single technologies, systems, and specific network environment and pursues the following macro objectives:

- Comprehension of vulnerabilities, threats, and risk to which the single technologies, such as the application platform and networks, and the processed information are exposed.
- Define security architectures and technological standards.
- Check policies and system management procedures.
- Propose operational measures for the identified weakness corresponding to necessary security controls.
- Achieve the compliance to the security technologies' best practices.

### 9.3.3 Risk Measurement System

In order to choose the best methodology, it is important to consider the metric system used by the methodology itself for the different model elements with respect to the defined targets.

A quantitative measurement system, based on statistics and monetary elements, allows the definition of an investment budget in a more immediate way, but it could be too complex to elaborate and could not entirely avoid subjective evaluations. In order to use this approach, all risk factors must be quantified with respect to elements as assets and resources recovery cost and reputation and material damages for the organization. To achieve this it is necessary to have access to high-quality information not easily available. There are two variants inside this approach that could be defined: the truth and the appearance. The first includes cases in which numbers that represent real quantities are used. This is the case of the damage directly estimable with the monetary unit. The second case, which has been defined as apparent quantitative, i.e., semiquantitative, has been created to address the cases where there is a need, related to a computer use, to convert qualitative measures into numerical values. For example, a criticality value, initially expressed with qualitative terms as high, medium, low, and void, can be expressed with a correspondent set of numeric values – i.e., 3, 2, 1, and 0 – in order to allow a logic product with another measure like the exposure risk level. The pure-quantitative approach, certainly more precise than the qualitative one, is not easy to apply, mainly for two reasons. The first is that the needed values are often not available (for example, it is extremely difficult to estimate quantitatively the impact of a lemished reputation). The second is that, considering the lack of information, it is easy to make wrong estimates, assigning numeric values to something we can evaluate only qualitatively.

Qualitative methodologies do not require statistical data, expressing values in terms such as low, medium, high, crucial, and critical. Such approaches may seem superficial and less precise, but as a matter of fact, they turn out to be better, and less misleading, than wrongly or poorly applied quantitative methods.

The main aspect the designer has to deal with is the metric balance, in terms of excursion, of the possible values for the different concepts and for the different metric systems used, being qualitative-based or quantitative-based systems.

As a matter of fact, it is clear that choices implying measurement concepts characterized by different scales that are not congruent could lead to inconsistent results.

The identification of a verification system for the consistency assessment of the different metric systems is still an open issue.

The conclusion could be that the quantitative system is more indicated to the conceptual business context analysis, while the qualitative one targets the operative analysis where the countermeasure efficiency dominates the cost justification.

Common Elements Among the Main Methodologies

There are many elements and stages of risk analysis common to all the methodologies. As a matter of fact, a risk assessment, independently from the used methodology, must allow to:

- Define the analysis context and specifically what has to be defended against the risk.
- Locate and evaluate hostile agents, threats, attacks, and vulnerability.
- Define the threats to face.
- Calculate the final risk, evaluating the acceptable levels, and define the countermeasures to keep the risk within them.

Most of today’s analysis methodologies include all the elements listed above, but they have different concepts and terms, often not well defined and far from the prevailing meaning, which is defined by the reference standards. This is the case of terms and concepts of protection, danger, threat, attack, damage, and, hence, risk.

It is important to pinpoint the prevailing meaning of the following concepts and their definitions:

- Boundary of intervention and information resources, i.e., census and classification
- Protection attributes or security services

- Threat census
- Vulnerability census
- Occurrence probability, i.e., threat exposure
- Impacts evaluation
- Countermeasures' definition, i.e., measures or controls
- Risk reduction after the countermeasures' implementation

### 9.3.4 Boundary of Intervention and Information Resources

First of all we have to define the boundary of intervention and hence the interested organizations and the managed information. Afterwards, we must proceed to an analytic census of information included into the border of intervention. The details of the census depend on goals and types, conceptual or operative, of the risk analysis to carry out.

In order to create a conceptual analysis, it is enough to take a census of the process data, billing, payments and staff, and/or the application software, while the operative analysis needs to consider even reference technologies like communication networks and hardware/software used for the process.

Anyway, we must compare the single elements that make up the information, such as data, software, technologies, and all the processes needed to locate the proper methods for information access. All these elements must be classified for homogeneous categories in order to evaluate threats and vulnerability. Information networks characterize the communication and processing systems (input, output, and updating) of all the information, and hence it may be noted that they could be protected apart from information they process. This could be true in some circumstances (for instance, the backbones of a telecommunication society). Anyway, we must be aware of what it has to be protected and how many resources are needed to protect all the elements of the information asset, according to their criticality.

### 9.3.5 Goals and Protection Attributes

It is important to define the goals of protection systems. It influences all the activities since business goals of a profit society cannot be compared to the missions of no-profit or government organizations and thus the protection goals.

According to these goals there are some other features to define and evaluate one by one. These influence the process of risk assessment and the corresponding protection technique choiceness.

As underlined before, the current best practice is characterized by five security attributes: confidentiality, availability, integrity, authentication, and non-repudiation. It is advisable to evaluate one by one these attributes, since they present different risk scenarios.

### 9.3.6 Threat Census

The risk strictly depends on the concept of threat, which constitutes an equivalent concept without the two features of probability and consequential damage. Furthermore, the risk can be considered as a negative event that causes damage to someone or something. Threat is as a matter of fact such event.

A threat can be thus defined as anything that causes the loss of security attributes/services. The threat is often an undesired event that can be a priori potentially identified. It could be classified as an internal or external event. A threat is actualized by attacks of different actuation. There is a tendency to protect the boundary of intervention mainly against external threats, maybe because of their exposure, with respect to the internal ones. The reality is that internal risks are the most frequent, so they cannot be underestimated.

Internal threats and the corresponding countermeasures strictly depend on the organization and the nature of the process of the information, while external threats can be influenced by the technologies used, apart from people or processes. The determination of internal threats must consider the specific organization environment, while the external ones can be treated by more standardized solutions belonging to the mainly adopted technologies.

### 9.3.7 Vulnerability Census

The vulnerability is an organizational or technological condition that allows the threat actuation. Threats are present anyway but vanish, ideally, in absence of vulnerabilities. On the contrary, threats have a greater chance to actuate in the presence of numerous and important vulnerabilities.

Vulnerabilities can be organizational or procedural, for instance, due to a lack of a vital corporate function, i.e., monitoring, or technological like technical weakness of BIOS, operating system, and database.

Technical vulnerabilities can be located by means of special scanners, i.e., automated products for the continuous scanning of technical weaknesses, or by the activities of attack and penetration. Table 9.1 summarizes the most common vulnerability categories as classified by a security survey carried out, in the year 2003, by PricewaterhouseCoopers and CIO Magazine.

The main factors leading to vulnerability proliferations are:

- Faulty components
- Geographical distribution
- Dimensions and complexity
- Technological evolution
- Limited security problem know-how

The level of vulnerability can be reduced through the implementation of proper security countermeasures, studied and described in detail in Jacobs (2011) and Anderson (2008).

**Table 9.1** The most common vulnerability categories taken from “Information Security: A Strategic Guide for Business” © PricewaterhouseCoopers 2003

| Vulnerability | Probability of occurrence (%) |
|---|---|
| Exploited a known operating system vulnerability | 39 |
| Abused valid user account/permissions | 30 |
| Exploited known application vulnerability | 30 |
| Misconfiguration/human error | 28 |
| Exploited unknown operating system vulnerability | 22 |
| External denial of service | 22 |
| Exploited poor access control | 22 |
| Guessed passwords | 19 |
| Exploited unknown application vulnerability | 18 |
| Social engineering | 11 |
| Internal denial of service | 7 |

The vulnerability cannot ever be totally eliminated, because even the countermeasures present weakness.

### 9.3.8 Occurrence Probability

As indicated somewhere else in the document, the risk can be identified as the product logical or arithmetical of the impact, caused damage, and the occurrence probability of a particular threat. The determination of this probability can be expressed by a judgment or considering, when available, the statistics of accidents and attacks or both of them.

All the elements that contributes to the risk and, hence, threats, attacks, and vulnerabilities have to be analyzed in this phase. Table 9.2 relates some examples of threats with the corresponding attacks and vulnerabilities.

### 9.3.9 Impact Evaluation

One of the most important aspects of the risk analysis process is the determination of the impact, or caused damage, upon the resources to be protected and upon the enterprise as a whole when a threat is successfully actuated.

The impact, as described in the following, is the second component of the risk after the threat probability occurrence. The condition for which a metric system, i.e., conceived to measure, could be applied to a concept is that such concept can be measured.

That leads us to discussion about quantitative and qualitative approaches, previously described.

Measurement and Risk Reduction

**Table 9.2** Relation among threats, attacks, and vulnerabilities taken from "Information Security: A Strategic Guide for Business" © PricewaterhouseCoopers 2003

| Threat | Attack | Vulnerability |
|---|---|---|
| An outsider accesses the private network of the organization | The outsider accesses the system through a backdoor using a wireless local area network (WLAN) | Network service set identifier (SSID) has not been properly masked |
| | | The unauthorized access point has been installed by an internal employee |
| | | Wired equivalency protocol (WEP) is weak and the corresponding cryptography session has been interrupted |
| | The outsider accesses acting a password brute force attack | Inadequate length of the password |
| | | Weak passwords subjected to dictionary attack |
| | The outsider steals an authorized password | The sequence of non-cryptographic identification leads to intrusions |
| | | Low level of monitoring |
| | | Trojan horse installed on the network |
| | A disappointed ex-employee accesses the systems in order to obtain classified information | Non-deleted accounts and passwords after the resignation. The passwords for dial-in servers or WLAN access points have not been deleted after the resignation |
| Financial losses due to fraudulent operations | The attacker simulates a real web operation | Inadequate cryptography and identification in communication application channels |
| | The intruder accesses the client's credit card records | Access controls compromised on a critical database |
| Loss of critical data | A terrorist attack destroys a database | Inadequate backup and redundancy procedures |
| | A "trojan horse" program deletes a hard drive | The employees have not been sensitized to the risk of downloading software from unknown sources |
| | | Not-updated antivirus software |
| Internet not available, causing loss of revenues due to network inactivity | "Denial-of-service" attack through the "ping" technique overcharges servers paralyzing them | The router badly configured cannot detect badly formatted packets |
| | | The server operating system is not updated to the most recent security standards |
| | | Inadequate antivirus defenses |
| | An intruder reconfigures the router in order to block the legitimate traffic | Impossibility of resetting the default administrative password on the system |
| | Continuous demands of applications saturate the server resources | Inadequate application development |
| | | Inadequate identification controls allow fraudulent calls to be accepted as genuine |

In formal terms, the risk (R) is defined as the product logical or mathematic between the event occurrence probability (Pa) and the damage (D), which formula is $R = Pa^*D$. If, at least, one of the two terms of the product goes to zero, the risk is very low.

For qualitative measurements it is necessary to identify a suitable measuring system.

In practice, it is useful to consider two aspects of the risk. The first is called absolute or intrinsic risk and the second defined as residual risk; this latter concept contrary to the first one takes into account the identified countermeasure effects.

### 9.3.10 Countermeasures Definition

During the process of risk assessment, an acceptable level of risk needs to be identified and compared with the available budget. The countermeasures, also known as measures or controls, indicate the organizational and technological measures able to face and reduce risks to a predefined acceptable level.

Within the risk analysis process, the countermeasures can be defined generically, to be subjected to a deeper investigation and further analysis and definition in a more operative viewpoint. It is very important to define acting modes, times, and responsibilities in a proper implementation operative plan.

### 9.3.11 Risk Management

The previously described risk analysis makes it possible to define the most adequate countermeasures to implement. The implementation of the countermeasures and the management and long-term monitoring of the actual security status all belong to the risk management environment.

Controllable and effective security measures must be adopted to effectively counter the risks identified and associated with the use of infrastructures for data management, processing, and exchange. Information security must therefore be considered as a global characteristic, able to meet the desired level of privacy, integrity, and availability of information and services, in keeping with the evolution in time of needs and technologies.

An illustration of the activities involved in a complete risk management process is presented under Fig. 9.5 below.

The illustration clearly shows that the risk management process must be continuative and replicable. To actually safeguard information security by means of careful risk management, an adequate security management system (SMS) must be integrated within the organization responsible for creating, updating, deleting, and maintaining information and organized according to the three dimensions of the problem:

- Processes
- Organization
- Technologies

Failure to analyze one of the three abovementioned dimensions, or a fragmentary and limited approach without a homogeneous overall assessment framework

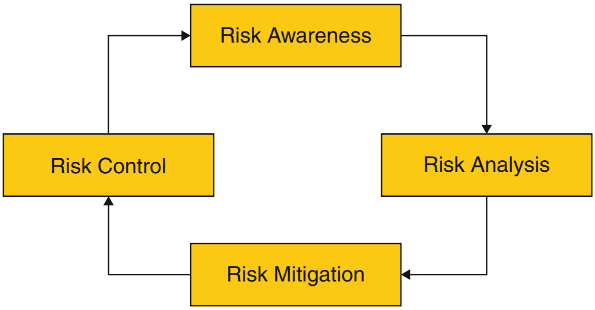

**Fig. 9.5** Risk management life cycle

for the current state of information security, entails the potential ineffectiveness of any corrective actions undertaken because of the limited or incomplete assessment of an identified problem.

Generally speaking, the issues to address are the following:

- Identification and definition of corporate processes and associated risk environments
- Compliance with national and international security standards and provisions
- Definition of a security management strategy
- Decisions about the guidelines an organization intends to adopt in terms of security management
- Preservation of investments previously or about to be made on the security of IT systems

Risk management essentially depends on:

- The corporate mission
- Compliance with laws and standards
- Economic availability

One of the fundamental purposes of a security management system is to reach a reasonable compromise between the cost of security and the costs of non-security; the main objective is to ensure a long-term, stable, and optimum protection level. According to the considerations made so far, risk analysis cannot be considered the only relevant element for comprehensive risk management, but it is important to:

- Effectively implement adequate countermeasures and establish an interactive efficiency monitoring cycle.
- Continuously update risk evaluation by periodically repeating the process or implementing dynamic risk management systems.
- Consider the entire security management context.

The global perception of the problem has led to the current trend of converging risk analysis models and risk management systems, essentially by means of modern analytic methodologies and dynamic evaluations. Such methodologies also take into account changes that have an impact on information resources and the outcome of the incident/attack monitoring which will influence the updating of risk assessment criteria.

## 9.4 IASE: Security Certification

IT systems security evaluation and certification process should have the following characteristics:

- Repeatability: given the same security objectives and requirements initially imposed, the evaluation process should lead to the same final outcome if carried out once again by the same evaluation body.
- Reproducibility: given the same security objectives and requirements initially imposed, the evaluation process should lead to the same final outcome if carried out once again by another evaluation body.
- Impartiality: the auditing and certification process should not be influenced by external factors.
- Objectivity: the outcome of the security auditing should be based on fact as immune as possible from subjective opinions or experiences.

The fundamental aspects that make useful a security evaluation and certification process are the proven effectiveness of reference standards and the third party nature of certification bodies towards end users, system developers, process or product, and certification process financing parties.

The two most important and worldwide known IA-related certification methodologies today in use were standardized by ISO/IEC.

More precisely, in 1999, ISO/IEC adopted a complete series of criteria known as "Common Criteria," allowing the evaluation and certification of ICT product and system security. This adoption was formalized through the issuing of the ISO/IEC IS 15408 and 18045 standards.

As to the second type of certification, in the year 2000, ISO adopted only the first part of the BS7799 standard developed in Great Britain. That started a process that led ISO to issue, in 2005, ISO/IEC 27001 and ISO/IEC 27002.

The ISO/IEC IS 15408 and 18045 (Comon Criteria and Application Methodology) standards and the ISO/IEC IS 17799-1 and BS7799-2 pair of standards are intended to certify two well distinct things: in the case of the Common Criteria (CC), the object of certification is an ITC system or product; in the case of the ISO/IEC 27001 standard, what is certified is the process used by an organization, be it a private company or a public structure, to internally manage IA issues. In the standard, this process is indicated with the acronym ISMS which stands for "information security management system." The ISO/IEC 27001 certification can be considered a corporate certification, like the well-known ISO 9000 certification, but specialized in the field of IA.

However, for the ISO/IEC 27001 certification purposes, it is sufficient to verify that the aforementioned functional requirements are selected on the basis of a correct risk analysis and management and, through the use of sampling, verify that the corresponding security functions are present on ICT systems whenever necessary.

For the Common Criteria certification of one IT system/product, it would be necessary, instead, to verify that the aforementioned functionalities do not have implementation-related faults and are able to resist, up to a fixed severity threshold, to a set of threats specified in a well-defined environment.

### 9.4.1 The Common Criteria

The rational at the basis of the Common Criteria (CC) was drawn from the previous European Information Technology Security Evaluation Criteria – ITSEC criteria. In this context, due to the obsolescence of ITSEC standard and to the CC widespread acceptance, it is not advisable to delve into the ITSEC standard details but to confine the description to the Common Criteria.

According to this rational, it does not make sense verifying if a system/product, called target of evaluation, called after TOE, is secure if the following are not specified:

- "Secure" to do what, represents the security objectives
- "Secure" in which context, represents the security environment
- "Secure" following which evaluation, represents the assurance requirements.

According to the CC, a security objective is defined as the intention to fight a threat or to abide to existing security laws, regulations, or policies. Objectives are attained through the adoption of security measures, both technical like the security functions and nontechnical such as physical, procedural, and concerning the staff.

The security environment is described in terms of:

- Assumed system/product use, i.e., applications, users, processed information, and other assets, specifying the related value
- Environment, i.e., nontechnical security measures, connection to other ICT systems
- Threats to face, specifying the attacker's characteristics like knowledge, available resources, and motivation; the attack methods such as mentioning, amongst other things, the exploitation of possible known IT system/product vulnerabilities; and the assets involved
- Organization security policies

The evaluation process aims at ascertaining that the TOE, its developer, and the evaluator meet appropriate assurance requirements that become stricter and stricter as the evaluation level increases. The CC define seven Evaluation Assurance Levels, the EALs from EAL1 to EAL7, specifying for each level a specific set of assurance requirements.

The inspections performed on the basis of the selected EAL aim at guaranteeing the following:

- Suitable security functions to achieve system/product security objectives
- Absence of errors in the process that from the initial security specifications, i.e., environment and security objectives, leads to practical security function implementation, i.e., technical specification interpretation and programming errors
- Suitable security procedures provided for delivering and installing the system/product to avoid that the system/product delivered to end users might be, even slightly, different from the one submitted to auditing/certification; clear user and administration manuals, i.e., the latter might in fact lead users into behaviors that might introduce vulnerability in the usage of product/system provided with security functions that are fully appropriate and implemented without faults;

and the support the developer will provide to those who will use the system or product to make up for possible vulnerabilities emerged after auditing

Evidence of the absence of faults in the security function implementation process is obtained not only by directly looking for the errors themselves analyzing the documentation submitted by the applicant and by submitting the system/product to functional tests and attacks but also by verifying that in the implementation process was envisaged the use of tools, methodologies, and procedures aimed at reducing the probability of errors.

As the evaluation level increases, more detailed implementation specifications are required, for example, high-level design, low-level design, source code, and the description of specifications become more and more rigorous: informal, semiformal, and formal description.

The evaluation rigor is not only identified by the auditing level but also by another parameter, called strength of functionality (SOF). In fact, the CCs, starting from EAL2, require that the TOE security function be qualified expressing the minimal efforts assumed to defeat its security mechanisms. The SOF for such mechanisms, that is, usually of probabilistic or mathematical nature as password, hashing functions, etc., has to be specified on a three-value scale: basic, medium, and high.

The TOE security functions are described according to the requirements they should meet. These requirements, called functional requirements, like the aforementioned assurance requirements, must be described using a component catalogue included in the CCs. Some exceptions are possible but should be thoroughly justified.

More precisely, the functional component catalogue is part 2 of the CCs, whilst the guarantee component catalogue represents part 3. The catalogues are organized at various hierarchical levels so as to include homogeneous components. For example, as to functional components, the highest hierarchical level provides for a group of 11 classes: audit, communication, cryptographic support, user data protection, identification and authentication, security management, privacy, protection of the TOE security function, resource utilization, TOE access, and trusted path/channels. The TOE acronym is found in some functional class names and indicates the ICT system/product to assess.

Amongst the various documents that the applicant must/can submit to the inspectors, along with the TOE to assess, it is worth mentioning two of them. The first document, called Security Target, is mandatory and is the main auditing document. The Security Target should describe the security environment, security objectives, functional and warranty requirements – and thus the auditing level – the minimum security function robustness, and an initial high-level description of security functions. This last section, instead, is not included in the second document, the Protection Profile, whose remaining structure is similar to the Security Target document. The Protection Profile can optionally be developed with reference to a whole class of products for which the implementation of the security functions is free provided that it meets the functional requirements, rather than to a specific TOE as in the case, instead, of the Security Target. The Protection Profile can be registered and also assessed to verify internal consistency.

The main advantages offered by an evaluation and certification in compliance with the CCs are the following:

- The certification, performed by a third party having specialist knowledge, that the security functionalities of the TOE along with the requested nontechnical countermeasures are suitable to meet the security objectives
- Achievement of preventive actions against IT security accidents
- Availability of rich catalogues concerning ICT security functions and the guarantee requirements that can be adopted
- The possibility to describe in a standard way the security requirements for ICT systems and products

### 9.4.2 ISO/IEC 27001 and 27002 Standards

The main purpose of the ISO/IEC 27001 and 27002 standards is to establish a universally recognized and accepted standard to certify an organization's capacity to protect its own information assets and to maintain such capacity over time. They also represent a series of best practices in the field of information security and offer a methodological reference to manage corporate information asset security.

More specifically, ISO/IEC 27001 is a certification standard specifying requirements for establishing, implementing, operating, monitoring, reviewing, maintaining, and improving a documented ISMS; these requirements are defined in a structured, formal format suitable for compliance certification. On the other hand, ISO/IEC 27002 is a code of best practice for ISMS; the standard provides coverage of the critical subjects that an ISMS should address, but no specific requirements against which an organization's ISMS may be evaluated.

Each organization should protect the information it handles by correctly identifying and managing an information security management system (ISMS) comprising logical, physical, and organizational components. The methodology to approach the problem suggested by ISO/IEC 27001 standard and known with the acronym PDCA (plan, do, check, act) provides for the execution of four steps:

- Plan: defining security policies, objectives, processes, and procedures relevant to manage and minimize risk and improve information security so as to achieve results in accordance with the policies and the objectives of the entire organization.
- Do: implementing and enforcing security policies, countermeasures, processes, and procedures.
- Check: assessing and, where possible, measuring process performance with respect to security policies, objectives, and practical experiences, and the results are reported to the management for revision purposes.
- Act: adopting prevention and corrective measures, based on the management review outcome, in order to provide continuous improvements to the ISMS.

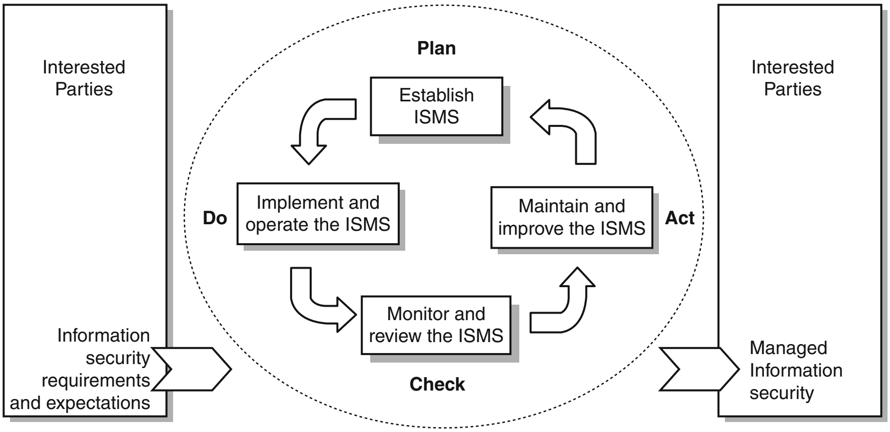

**Fig. 9.6** PDCA model applied to ISMS processes

Figure 9.6 extracted from ISO/IEC 27001 summarizes the fundamental steps of the PDCA methodology.

A fundamental aspect in the correct application of the ISO/IEC 27001 standard is the performance of a correct risk analysis activity. This activity's fundamental bases are described in the ISO/IEC 27005 standard ("Information technology—Security techniques—Information security risk management").

Finally ISO/IEC 27002 provides guidelines and directions for ISMS, but its content, not being adequately structured, is subject to wide interpretation. The standard covers:

- Security policies: correct identification and management of security policies over time
- Information security organization: corporate organization and responsibilities in the field of ICT security, regulating third party access to corporate information systems and outsourcing contracts
- Asset management: classification of corporate assets entrusted with well-defined subjects
- Personnel security: security behaviors for corporate asset users, also including training on the correct use and behaviors in case of IT accidents
- Environmental and physical security: physical security in working environments and of hardware and software tools
- Communications and operations management: intercorporate communication management, management of network-related aspects, protection against malicious software, and failure management
- Access control: information access, network access, user identification, and authentication authorizations
- Information system acquisition, development, and maintenance: use of encryption, aspects related to information integrity preservation, and rules for updating and managing hardware and software systems

- "Business continuity" management: improving and ensuring continuity of critical functionalities
- Compliance to regulations in force: ensuring compliance with regulations in force and with corporate security policies, on the part of both the organization and users

## 9.5 General Considerations About the Impacts of IA Systems Engineering on Space Industry

So far we have shown that each conceivable space system is, as well, an IT system and, indeed, a complex one, to be treated, from the cyber security perspective, trying to implement information assurance systems engineering; in addition, we have described the most significant aspects of this approach, i.e., risk analysis and management, certification, and accreditation. Moreover, it has been emphasized the importance of laws and regulations, and the special rules about classified information. Laws and regulations, in fact, mandate what has to be pursued in terms of security requirements, certifications, and accreditation.

The information provided was general and made reference to many possible contexts; we referred to both the public and the private sector, using generic terms as corporate and organization. In the space sector we do have the following actors: governments, space system manufacturers, service providers, and final users. The government sector is composed by the military and security branches and civil ones; among the latter usually belongs the space agency of a generic country. Space system manufacturers are high tech companies, usually of national strategic importance, which often deal with highly classified information. Service providers may still be strategic companies with access to highly classified information. Final users are organizations involved in space system utilizations and may have access to classified information.

With reference to the abovementioned subjects, cyber security and then IASE will impact on:

1. Everyday business and organization, both for private companies and government bodies, with special emphasis on risk analysis and management as well as on process certification and rule compliance
2. Space systems life cycle and the related project management, which, as previously stated, is an essential aspect of space business, both in government and private sector

The analysis of the first point, being far from trivial, belongs in the realm of cyber security and IASE per se, with no specific relation to the space sector. Hence, it is more effective to tackle the second point, which is mostly meaningful.

Project management has the final goal of satisfying user and stakeholder requirements while achieving the best trade-off between performance, schedule, and financial resources; in the case of space systems, this is done through a phased approach, adopted with minor differences amongst the various implementations by all the space agencies. Table 9.3 below shows the abovementioned phases with a very short definition and a comparison between the ESA and NASA approaches and terminologies.

**Table 9.3** ESA and NASA project phasing comparison

| Phase | ESA | Phase | NASA |
|---|---|---|---|
| **0** | **Mission analysis/needs identification** | **PreA** | **Advanced studies** |
| | Ends with the mission definition review (MDR) | | Ends with the mission concept review (MCR) |
| **A** | **Feasibility** | **A** | **Preliminary Analysis** |
| | Ends with the preliminary requirement review | | Ends with the mission definition review (MDR) |
| **B** | **Preliminary definition** | **B** | **Definition** |
| | System requirements review | | System requirements review (SRR) |
| | Ends with the preliminary design review (PDR) | | System definition review (SDR) |
| | | | Ends with the preliminary design review (PDR) |
| **C** | **Detailed definition** | **C** | **Design** |
| | Ends with the critical design review | | Ends with the critical design review |
| **D** | **Production/ground qualification testing** | **D** | **Development** |
| | Qualification review (QR) | | System acceptance review (SAR) |
| | Ends with the acceptance review (AR) | | Flight readiness review (FRR) |
| | | | Operational readiness review (ORR) |
| | | | Ends with the launch |
| **E** | **Utilization** | **E** | **Operations and support** |
| | Operational readiness review (ORR) | | |
| | Flight readiness review (FRR) | | |
| | Ends with the system operational life | | |
| **F** | **Disposal** | **F** | **Closeout** |

It is intractable to analyze properly the space systems' project-phased approach (see for further study Wertz and Larson 1999; Gerosa and Somma 2011; Spagnulo 2011; NASA 2007 and ECSS Standards); it is sufficient to say, and it is valid for both ESA and NASA, that:

1. The first three phases are about mission concept, operational requirement, preliminary definition, and architecture; they end with a preliminary design review, which establishes the configuration baseline for the upcoming development (development configuration baseline), the technical specifications, the design justification files, and the preliminary interface control documents (ICDs).
2. The C phase is about the detailed design; during this phase the manufacturer delivers the final version of the ICDs and the production master files (PMFs); the critical design review concludes this phase and all the design activities.
3. The last three phases are about production, qualification, utilization, and disposal.

Phase D is essentially about production; according to the ESA approach, it ends with the AR, while according to the NASA approach, it ends with the launch. Phase E and F are similar, except for the fact that ESA E phase includes the launch with the related activities. It is important to observe that the first five phases are mostly focused on delivering a product, i.e., the space system, while phases E and F are essentially about the system utilization and therefore about processes; the only product, in these phases, is the information made available by the space system.

IASE technical details belong essentially to IT; space system peculiarities have been addressed by the Consultative Committee for Space Data Systems (CCSDS), that issued several standards dealing with IASE applications to space systems. Among them see, Consultative Committee for Space Data Systems – CCSDS 350.0-G-2 (2006a), Consultative Committee for Space Data Systems – CCSDS 350.1-G-1 (2006b), Consultative Committee for Space Data Systems – CCSDS 350.4-G-1 (2007) and Consultative Committee for Space Data Systems – CCSDS 730.0-G-1 (2003), which are worth mentioning. Interesting applications and case histories about security and space systems may be found in Angino et al. (2010).

Being technical details beyond the scope of this work, we want now to show IASE activities mapping into the phased approach just summarized. It could be described as follows:

1. Security requirements and risk analysis belong essentially to the first three phases.
2. Security certification should be completed before the acceptance review during phase D; the rationale is that certification activities must be performed and certification issued on the last version of whatever product is being certified.
3. During phase D, as a consequence of the certification process, there may be a revision of the security requirements and, theoretically, should vulnerabilities emerge, of the risk analysis as well.
4. Once the system is fully operational, i.e., after the orbit insertion and the payload commissioning, it is possible to start security accreditation activities if needed; similar considerations apply for risk management issues.

Project managers must pay attention to security issues, respecting the mapping just described. For example, if a required certification is not obtained before launching, and the spacecraft is launched nonetheless, there may be serious consequences; in fact, should the certification process fail, and modifications be necessary, they could be impossible or very difficult to implement. Similar considerations apply for accreditation.

What we discussed so far is the impact of IASE issues with reference to the generic space system seen as a peculiar product; during utilization, however, the perspective changes. The space system, operated by one of the possible space actors as defined above, may be considered as a generic organization; in this case, taking into account the type of information managed and exploited by the system, it is sufficient to apply IASE per se.

It is therefore necessary, with reference to utilization phases, to fully implement to the extent required by laws and regulations in force.

## 9.6 Conclusions

In this paper we discussed the relation between space and cyber security; we have shown that space systems are complex IT systems to which the concepts of IASE may be applied. This approach could be extended to other complex systems that may have a significant content in terms of IT. The impact on the space system life cycle has been investigated, yielding some useful tenets, which indeed are peculiar to space systems.

IASE concepts have to be applied to the space actors: governments, in particular the military/security branches and space agencies, space systems manufacturers, space service providers, and final users. This aspect is not related to space in a specific and intrinsic way; it is rather a consequence of the laws and regulations in force.

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# Space as a Critical Infrastructure

# 10

Markus Hesse and Marcus Hornung

## Contents

**Abstract**

For the last 20 years, critical infrastructure protection came up as an important issue to ensure the safety and security of citizens and the functioning of states. This chapter analyzes the approaches of the United States and the European Union in developing a critical infrastructure protection regarding to its involvement of space technology. After focusing on critical infrastructures in general as well as specializing on space, it concentrates on the milestones in developing a policy of critical infrastructure protection. The analysis shows that the policies refer to space only barely, nevertheless in the United States stronger than in the European Union.

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## 10.1 Introduction

Keeping citizens safe and secure remains one of the core functions of modern governments. For the last 20 years, critical infrastructure protection (CIP) came up in this context as an important issue on American and European security policy agendas. After all, industrialized states and societies are highly depending on their critical infrastructure (CI). In this regard, critical means the boundary between acceptable and nonacceptable conditions with regard to a given set of criteria. In most definitions, critical in this context refers to infrastructure that provides an essential support for economic and social well-being, for public safety, and for the functioning of key government responsibilities, including sectors such as information and communication technology, energy production, water and food supply, transport, and nuclear and chemical industry. The technical term "CI" is in use only since the end of the last century. Prior to that, rather practical concepts such as "emergency supply," "material and technical base of state," or "emergency functions" were common practice (Lima et al. 2012).

Regardless what definition or which school of thought one might refer to, CI are in any case essential for the functioning of the state and for the security of its citizens. Therefore, it is most important to ensure that CI continues to function, even in cases such as severe natural disasters or terrorist attacks. Identifying and safeguarding the vulnerable CI, no matter if they are part of the public or the private sector, will always be a challenging and difficult task. Especially the progressively increasing interdependencies of CI might lead to cascades that would affect further supply networks. As the focus of this essay is on space, as a CI an analysis of these interdependencies and other dependencies would lead too far (for further information, cf. Eusgeld et al. 2011).

The CI – including space technology – are core capabilities of industrialized states as well as the technical systems and the institutions and the organizations that provide them (Schulman and Roe 2007). They are – at least in most cases – networked systems, which are multipurpose and required devices or items for other secondary systems. If the provided services of these infrastructures are vital to national security, they can be denominated as "critical" (Auerswald et al. 2005). Thus, CI is mainly concerned with physical objects or cyber-based systems that seem to be essential vital for the functioning of social and political life.

Today the importance of space technology in the twenty-first century is widely undisputed among scientists. Space applications are essential for the functioning of highly developed countries, such as the United States (US) or the member states of the European Union (EU). Satellite systems in the fields of navigation, communication, observation, positioning, broadcasting, and many other applications have global reach and are interdependent to other CI named above. Even today the usability of innovative space applications seems to be almost unlimited, for example, in domains such as meteorology, research on climate change, telemedicine, disaster management, urban planning, traffic management, and precision farming. The significance of space systems not only for commerce but also for key government responsibilities and security becomes even more obvious by imagining and discussing "a day without space" – also the name of a series of events that were hosted by the George Marshall Institute and the Space Enterprise Council in the last few years.

Space systems are always at risk of damage by natural phenomena, such as solar radiation and asteroids, other spacecraft, and – of course – space debris (COM(2011) 152). Especially the danger due to space debris becomes more and more a subject matter of international space policy (cf. Part 1, ▶ Chap. 14, "Space Technology Export Controls" and Part 3, ▶ Chap. 39, "The Issues of Space Debris" in this Handbook). Given the constantly increasing number of space junk, this is an understandable process. One of the most important instruments to increase the safety and security of space systems under these circumstances is the development of a Space Situational Awareness system (cf. Part 4, ▶ Chap. 21). The main tasks of such a system are the monitoring and the surveillance of critical space infrastructure and of space debris.

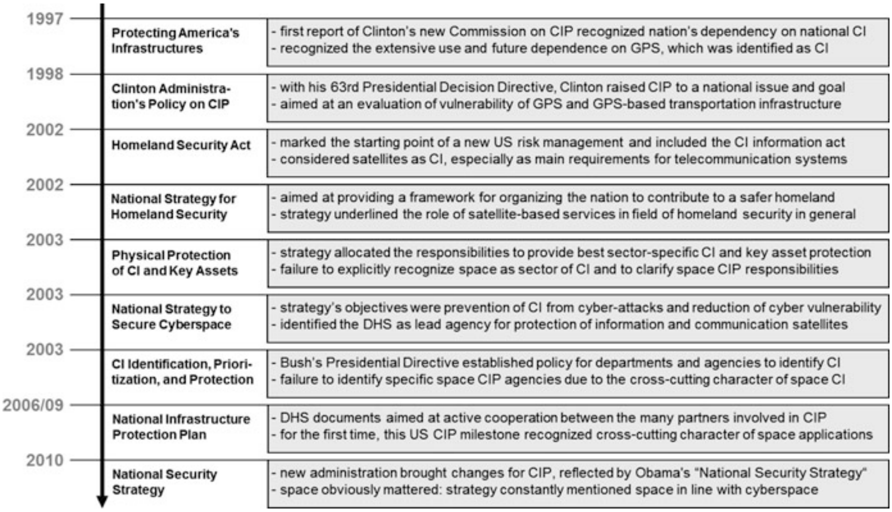
The intrinsic complexity of critical space infrastructures increases their vulnerability as well as the opportunities to exploit them for criminal purposes. Although the importance of critical space infrastructure protection (CSIP) is partly recognized in public speeches and national programs, the benefits of current initiatives are somehow limited as long as there are no international binding contracts (cf. Part 1, ▶ Chaps. 12, "Space Traffic Management" and ▶ 7, "The Role of Space in Deterrence"). Political leaders in the United States and the EU well recognized this general problem and initiated programs on CI protection in general, but only with some regard to space applications and systems.

This chapter aims at presenting an overview of contemporary CIP with the main focus on space applications and technology. Therefore, it presents the latest developments in CIP and its programs in the United States and the EU, due to the fact that those two arguably offer the most advanced project activities on a larger scale in this emerging policy field. As the development and the implementation of CIP and space policy primarily are governmental tasks, the scope of this article is limited to the US national and the common EU level.

## 10.2 The United States and Critical Space Infrastructure Protection

CIP on national level has been on the United States' agenda for more than 15 years. While it is obvious that CIP mattered for all US administrations since then, the role of space as a national CI can only be estimated by short analyses of the so-called milestone documents of the US CIP (Fig. 10.1).

Already in July 1996, the former President Clinton set up his Commission on CIP. This Commission released its first report, named "Critical Foundations: Protecting America's Infrastructures," to the President in October 1997 (Moteff 2011; PCCIP 1997). President Clinton's new Commission worked 15 months on the evaluation of the concept of CI and their vulnerabilities. Its report summarized three main findings – the first was to rethink CIP and to reflect it as a national security issue: "[O]ur fundamental conclusion is that we have to think differently about infrastructure protection today and for the future. We found that the nation is so



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|---|---|---|
| 1997 | Protecting America's Infrastructures | - first report of Clinton's new Commission on CIP recognized nation's dependency on national CI<br>- recognized the extensive use and future dependence on GPS, which was identified as CI |
| 1998 | Clinton Administration's Policy on CIP | - with his 63rd Presidential Decision Directive, Clinton raised CIP to a national issue and goal<br>- aimed at an evaluation of vulnerability of GPS and GPS-based transportation infrastructure |
| 2002 | Homeland Security Act | - marked the starting point of a new US risk management and included the CI information act<br>- considered satellites as CI, especially as main requirements for telecommunication systems |
| 2002 | National Strategy for Homeland Security | - aimed at providing a framework for organizing the nation to contribute to a safer homeland<br>- strategy underlined the role of satellite-based services in field of homeland security in general |
| 2003 | Physical Protection of CI and Key Assets | - strategy allocated the responsibilities to provide best sector-specific CI and key asset protection<br>- failure to explicitly recognize space as sector of CI and to clarify space CIP responsibilities |
| 2003 | National Strategy to Secure Cyberspace | - strategy's objectives were prevention of CI from cyber-attacks and reduction of cyber vulnerability<br>- identified the DHS as lead agency for protection of information and communication satellites |
| 2003 | CI Identification, Prioritization, and Protection | - Bush's Presidential Directive established policy for departments and agencies to identify CI<br>- failure to identify specific space CIP agencies due to the cross-cutting character of space CI |
| 2006/09 | National Infrastructure Protection Plan | - DHS documents aimed at active cooperation between the many partners involved in CIP<br>- for the first time, this US CIP milestone recognized cross-cutting character of space applications |
| 2010 | National Security Strategy | - new administration brought changes for CIP, reflected by Obama's "National Security Strategy"<br>- space obviously mattered: strategy constantly mentioned space in line with cyberspace |

**Fig. 10.1** Timeline "US and Critical Space Infrastructure Protection"

dependent on our infrastructures that we must view them through a national security lens" (PCIIP 1997). Secondly, the Commission recognized a strong dependence on the information and communications infrastructure. Cyber vulnerabilities and threats were for the first time taken into consideration. And thirdly, the report acknowledged that the private and public operators of CI have to be involved in all national CIP efforts. As a result of these findings, the Commission suggested a CIP policy consisting of eight steps: This strategy included the first-time establishing of structured partnerships between operators of CI and the government by sharing basic information. Based on this, a comprehensive awareness program could be installed on the national level. The Commission understood that these goals had to be accompanied by both new legislation and research work. The report analyzed the threats to and vulnerabilities of CI divided into five sectors: "Information and Communications," "Physical Distribution," "Energy," "Banking and Finance," and "Vital Human Services." Since space infrastructures need to be understood as crosscutting, it is not surprising that space did not constitute a sector of CI as such. However, the Commission recognized the extensive use and future dependence on the Global Positioning System (GPS): As an important trend in the sector of physical distribution infrastructure, the GPS was explicitly identified as CI. In line with the proposed policy, the Commission recommended the Secretary of Transportation to "[f]ully evaluate actual and potential sources of interference to, and vulnerabilities of, GPS" and to "[s]ponsor a risk assessment for GPS-based systems used by the civilian sector, projected from now through the year 2010" (PCCIP 1997).

As a reaction to the Commission's recommendations on the need to strengthen the protection of CI, President Clinton released the 63rd Presidential Decision Directive in May 1998. The directive called "The Clinton Administration's Policy on Critical Infrastructure Protection" (Clinton Administration 1998; Moteff 2011) was presented to the public as a white paper. It referred to the fact that the United States represents both a strong military and an economic power and is therefore dependent on well-operating CI- and cyber-based systems. “President Clinton intends that the [US] will take all necessary measures to swiftly eliminate any significant vulnerability to both physical and cyber-attacks on our critical infrastructures [. . .]” (Clinton Administration 1998). Clinton did not only raise CIP to a national issue but also to a national goal. Furthermore the report perceived that both the government and the private economy are threatened by attacks to CI. Within 180 days after the release of the directive, a national infrastructure assurance plan with concrete milestones should be submitted. A vulnerability assessment and as a follow-up, a remedial plan ought to be developed for every sector of CI. Concerning space applications as CI, the white paper recalled the dependence on the GPS in line with the findings from the 1997 Commission report: “The Department of Transportation, in consultation with the Department of Defense, shall undertake a thorough evaluation of the vulnerability of the national transportation infrastructure that relies on the GPS. This evaluation shall include [an] assessment of risks to civilian users of GPS-based systems [. . .]” (Clinton Administration 1998).

The September 11 terrorist attacks painfully demonstrated the CI’s vulnerability. As a logical response, the United States fundamentally strengthened their efforts to regulate this kind of risk. The “Homeland Security Act” (Bush Administration 2002; Svedin 2009), signed into law by President Bush in November 2002, marked the starting point of a new US risk management. Among other institutions the US Department of Homeland Security and the Secretary of Homeland Security were established. Their main goals were to: “prevent terrorist attacks within the [US]; reduce vulnerability of the [US] to terrorism; minimize the damage, and assist in the recovery, from terrorist attacks [. . .]” (Bush Administration 2002). To be consistent with these main focuses, the Homeland Security Act was divided into 17 titles, which clarified particularly the aims to be pursued and the mechanisms to be used. One of these titles was the “Information Analysis and Infrastructure Protection,” wherein the “Critical Infrastructure Information Act” could be seen as an integral part. Within 90 days after the release of the act, determined procedures for the access, protection, and storage should be established. For example, there should be warning mechanisms for different CI areas. The act can be interpreted as an overall starting point of the strengthening of risk reduction efforts in the United States. In the post 9/11 rumors, space as a CI did only play a minor role. However, space had already been on the administration’s agenda: The act considered especially satellites as main requirements for telecommunication systems as CI.

As a main follow-up to the “Homeland Security Act,” the Office for Homeland Security was established by one of President Bush’s executive orders. In July 2002, the office released its “National Strategy for Homeland Security” (Moteff 2011; OHS 2002; HSC 2007). The strategy was updated in 2007. The National Strategy aimed at providing a framework for mobilizing and organizing the nation to contribute to a safer homeland. To implement this aim, the strategy “provide[d] direction,” “suggest[ed] steps,” and “recommend[ed] certain actions” (OHS 2002). The strategic objectives were congruent with the main intention of the Homeland

Security Act. The document focused on six critical mission areas, which were assignable to the strategic objectives, e.g., preventing terrorist attacks, reducing vulnerabilities, as well as minimizing the damage. CIP was identified as an important mission area. Their protection should be improved through eight main initiatives. Among others the document proposed to pool various infrastructure protection initiatives in the Department of Homeland Security. An accurate assessment of sensitive CI and key assets should be established. To enable efficient protection, the development of a National Infrastructure Protection Plan was intended. At the release of the updated National Strategy for Homeland Security in 2007, this National Infrastructure Protection Plan had already been announced. The 2002 strategy identified CI as a so-called critical mission area without explicitly mentioning space applications as CI. Rather the strategy underlined the role of satellite services in field of homeland security in general. However, already the 2007 updated version of the strategy explicitly recognized space as a CI domain. It even took space terrorism into account.

Now that the CIP was identified as one of the core mission areas of the "National Strategy for Homeland Security," the "National Strategy for the Physical Protection of Critical Infrastructures and Key Assets" (Moteff 2011; White House 2003a) represented the first milestone on the road ahead. It was released by the White House in February 2003. The strategy was build up on the National Strategy for Homeland Security and introduced the next steps to protect CI and other key assets. The strategy's sections allocated the responsibilities to provide best protection and identified guiding principles, which substantiated the strategy. To protect key assets and CI, the strategy followed three main objectives: The first was to guarantee the protection of particular critical assets, systems, and functions. The second was to focus on CI, which is subjected to a close threat. And the third main focus lied on the protection of assets, which will be threatened in the near future. In section "securing critical infrastructure," every critical sector was analyzed separately. Again, space was not among these sectors of CI and key assets. The only reference could be found in the sector telecommunications, for which communications satellites were seen as essential. Unfortunately, the many other CI such as the abovementioned GPS were not even addressed by this milestone.

The "National Strategy for the Physical Protection of Critical Infrastructures and Key Assets" was accompanied by the "National Strategy to Secure Cyberspace" (White House 2003b), which was released in February 2003 as well. It represented the second implementing component of President Bush's 2002 "National Strategy for Homeland Security." The purpose of the strategy was "to engage and empower Americans to secure the portions of cyberspace that they own, operate, control, or with which they interact" (White House 2003b). Similar to the above analyzed document, the aim of the National Strategy to Secure Cyberspace was to build a framework to organize and prioritize the efforts regarding the protection of CI. The strategy's main objectives were the prevention of CI from cyber-attacks, the reduction of the vulnerability to cyber-attacks, and the minimization of the damage. Primarily, the strategy dealt with the protection of cyberspace as such. However, due to the fact that cyber infrastructure is relevant for the operation of CI, the safety of cyberspace was shown as strongly connected to CI protection in general. Space applications regularly consist of an in situ and an ex situ element and some data connections in between. All these elements can be threatened by cyber-attacks. The strategy recognized the vulnerability and especially the interdependency of critical space infrastructures: "Reducing the vulnerability of the cyber infrastructure includes mitigating the potentially devastating attacks on cyberspace that can occur when key physical linkages are destroyed. The impact of such attacks can be amplified by cascading impacts through a variety of dependent infrastructures affecting both the economy and the health and welfare of citizens: [. . .] a satellite spun out of control hundreds of miles above the Earth and affected bank customers could not use their ATMs" (White House 2003b). It identified the Department of Homeland Security as the lead agency for the protection of satellites in the branch of information and communication. Other allocations for lead agencies could only be assumed.

At the end of 2003, a unifying framework for the integration of the many abovementioned initiatives for the protection of CI was still missing. To streamline the existing approaches, President Bush released the 7th Homeland Security Presidential Directive on "Critical Infrastructure Identification, Prioritization, and Protection" (Bush Administration 2003; Moteff 2011) in December 2003. The document's main intention was to clarify the allocation of the many responsibilities concerning CIP: It "established a national policy for Federal departments and agencies to identify and prioritize [US] critical infrastructure and key resources and to protect them from terrorist attacks" (Bush Administration 2003). One year after the issuance of the directive, a so-called National Plan for CI and Key Resources Protection should be released. To protect CI, this upcoming plan should include a strategy this protection could be preceded, a summary of activities how the vulnerability could be diminished, a summary of initiatives how information could be shared, and a strategy for the coordination with other Federal activities regarding CI. Furthermore, the Secretary should develop an indication and warning architecture, and sector-specific agencies should report annually about their efforts in complying with the requirements. The directive recalled that each infrastructure sector possesses its own characteristics. Therefore, the document identified designated sector-specific agencies, which would be responsible for CIP coordination. Unfortunately, space as a crosscutting issue was not explicitly mentioned, so that shared competencies and responsibilities had to be assumed. Details could be expected from the requested National Infrastructure Protection Plan.

In the following years, the Department of Homeland Security worked out a first "National Infrastructure Protection Plan" (DHS 2006) to meet all requirements of the 7th Homeland Security Presidential Directive. It was released in June 2006 and aimed at an active cooperation and collaboration between and among the many partners involved in the protection of CI. The plan provided a unifying structure for existing and future protection approaches. It constructed a protection program strategy, which included a risk management framework to promote the improvement of CIP. To be aware of the progress in risk reduction and the current situation of risk management, the effectiveness of these actions was measured. Furthermore the plan provided mechanisms to ensure the program's long-term efficiency. One of the requirements of the seventh Homeland Security Presidential Directive was to maintain a comprehensive inventory of the information needed to identify those assets, systems, networks, and functions that make up the nation's CI. This demand was met by the National Infrastructure Protection Plan, proven by the role critical space infrastructures played. For the first time, the plan recognized the crosscutting character of space applications and treated them apart from single case examples: "Space-based and terrestrial positioning, navigation, and timing services are a component of multiple CI/KR sectors. These services underpin almost every aspect of transportation across all its various modes. Additionally, the Banking and Finance, Telecommunications, Energy, and Water sectors rely on GPS as their primary timing source. The systems that support or enable critical functions in the CI/KR sectors should be identified, either as part of or independent of the infrastructure, as appropriate" (DHS 2006). This also led to the identification of further institutions (intelligence community and the Department of Defense), which could be made responsible for the critical space infrastructure protection as well.

The latest version of the "National Infrastructure Protection Plan" (DHS 2009) was released in January 2009 by the Department of Homeland Security. It was the updated version of the 2006 plan and still represents the present coordination basis of the US CIP efforts. The fundamental ideas of the 2006 National Infrastructure Plan were not modified. In addition to the already existing mechanisms, the updated plan focused on programs and activities to establish an all-hazard environment and "integrate[d] the concepts of resilience and protection" (DHS 2009). When it came to space-based positioning, navigation, and timing (PNT), the 2009 plan announced some direct progress compared to the 2006 plan: "The DHS ha[d] developed a PNT Interference Detection and Mitigation [...] Plan [...]. The policy established responsibilities for multiple departments and agencies within the Federal Government to better plan, manage, and protect PNT services, and assigned to the DHS specific responsibilities governing the protection of PNT services within [CI and key resources]. The [...] Plan detail[ed] the DHS initial response to the policy implementation action and lay[ed] the foundation for further planning and actions necessary to meet the responsibilities" (DHS 2009).

The change of administration in January 2009 brought several smaller changes in the field of homeland security. However, concerning the protection of CI, the administration kept in place much of President Bush's policy. This is also reflected by President Obama's first "National Security Strategy" (Moteff 2011; White House 2010), released in May 2010. The new strategy focused on renewing the American leadership "by building upon the sources of our strength at home, while shaping an international order that can meet the challenges of our time" (White House 2010). In addition to these long-term goals, the document identified top priorities, which should be implemented immediately, like ensuring the safety and security of the American people. An important step towards more safety was to rebuild a safer and a more reliable infrastructure. Whereas the document brought only smaller changes to the CIP in general, it showed that space as a CI matters for the current administration: It constantly mentioned space in line with cyberspace and recognized their threats.

As far as the United States is concerned, CIP successfully developed within the framework of the abovementioned milestone documents. In the course of this development, space has been explicitly recognized as CI. However, space's share in the US CIP set of documents has to be seen as rather limited.

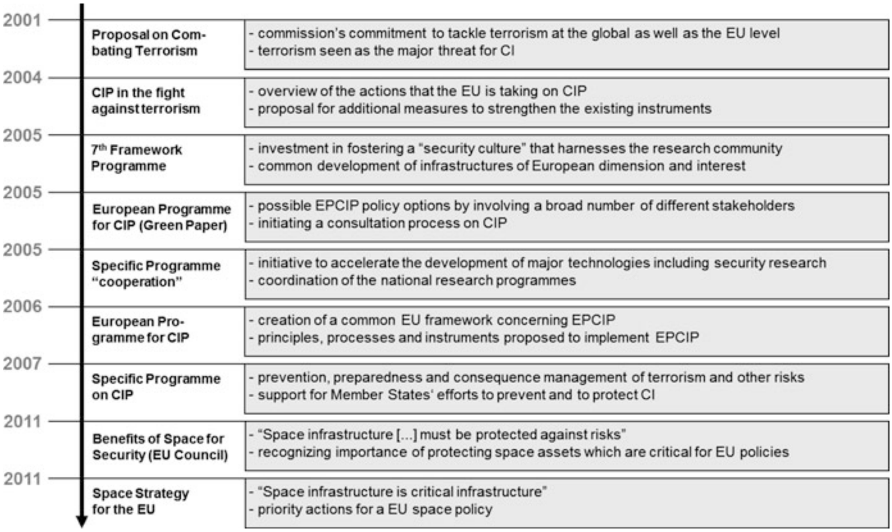
## 10.3 The EU and Critical Space Infrastructure Protection

There are several European national definitions of CI with slight differences, but all of them tend to describe the term rather broad. According to the European Commission, "[c]ritical infrastructures consist of those physical and information technology facilities, networks, services and assets which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of the citizens or the effective functioning of governments in the Member States" (COM(2004) 702 final).

In the last decade, the European Union became more and more involved in homeland security cooperation, counterterrorism policy setting, and CIP. Especially the terrorist attacks in Madrid 2004 and in London 2005 initialized further efforts in the EU member states to organize new policies. This whole area can be described as an emerging policy space, which is an institutional field of political actors, rules, and regulations that addresses a special kind of social issues and problems. In this case, the new policy space is related to efforts of the EU to protect its citizens from transboundary threats that cross borders of states as well as traditional EU policy boundaries (Boin et al. 2008) (Fig. 10.2).

Since the 2000s an increasing number of EU policies now contribute to the main goal of protecting EU citizens against all kinds of threats. In doing so the main focus lies on threats that member states cannot or will not deal with by themselves, mainly because these dangers and risks exceed national capacities. Coming from counterterrorism policy that started with the EU Framework Decision on Combating Terrorism in 2001 (COM(2001) 521 final), the focus shifted to a broader EU approach for CIP. This shift was accompanied by some political and some regulatory output, beginning in 2005 with a Green Paper on a European Programme for CI Protection (EPCIP) published by the European Commission (COM(2005) 576 final). In this Green Paper, the Commission not only raised questions to gain some input from relevant stakeholders and the scientific community but also presented own ideas. The Paper was supposed to be a first step to an overarching legislative and political package including binding legislative EU regulations (Boin et al. 2008).

The Commission funded research projects concerning CIP, for example, in the Preparatory Action for Security Research (2004–2006), and planned activities in the area of security research in its proposal for a Decision of the Council and the European Parliament about the seventh EC Research Framework Programme (COM (2005) 119 final) and in its proposal for a Council Decision concerning the Specific Programme "Cooperation" implementing the Seventh Framework Programme (COM(2005) 440 final). The budget of the Commission for security and space-related research activities under the 7th Research and Technological Development



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| 2001 | **Proposal on Combating Terrorism** | - commission's commitment to tackle terrorism at the global as well as the EU level<br>- terrorism seen as the major threat for CI |
| 2004 | **CIP in the fight against terrorism** | - overview of the actions that the EU is taking on CIP<br>- proposal for additional measures to strengthen the existing instruments |
| 2005 | **7th Framework Programme** | - investment in fostering a "security culture" that harnesses the research community<br>- common development of infrastructures of European dimension and interest |
| 2005 | **European Programme for CIP (Green Paper)** | - possible EPCIP policy options by involving a broad number of different stakeholders<br>- initiating a consultation process on CIP |
| 2005 | **Specific Programme "cooperation"** | - initiative to accelerate the development of major technologies including security research<br>- coordination of the national research programmes |
| 2006 | **European Programme for CIP** | - creation of a common EU framework concerning EPCIP<br>- principles, processes and instruments proposed to implement EPCIP |
| 2007 | **Specific Programme on CIP** | - prevention, preparedness and consequence management of terrorism and other risks<br>- support for Member States' efforts to prevent and to protect CI |
| 2011 | **Benefits of Space for Security (EU Council)** | - "Space infrastructure [...] must be protected against risks"<br>- recognizing importance of protecting space assets which are critical for EU policies |
| 2011 | **Space Strategy for the EU** | - "Space infrastructure is critical infrastructure"<br>- priority actions for a EU space policy |

**Fig. 10.2** Timeline "EU and Critical Space Infrastructure Protection"

(RTD) Framework Programme amounted to €570 million (COM(2005) 119 final). Targeted research which aimed to provide practical strategies or tools for risk mitigation was of prime importance to securing European Community's (EC) CI in the medium to long term.

The Communication from the Commission on a European Programme for Critical Infrastructure Protection (EPCIP) from December 2006 (COM(2006) 786 final) was a further milestone in the development of CIP on the European level. The Communication was supposed to set out the principles, processes, and instruments proposed to implement EPCIP. In addition to the definition of European CI, the document included the EPCIP Action Plan with several work streams going into more detail. One of the most important benefits of EPCIP was the information sharing process among relevant stakeholders that included improved and accurate information and understanding about interdependencies, threats, vulnerabilities, security incidents, countermeasures, and best practices for the protection of CI (COM(2006) 786 final).

The Council Decision of 12 February 2007 established the Specific Programme Prevention, Preparedness and Consequence Management of Terrorism and other security-related risks (2007/124/EC, Euratom) as part of a General Programme on Security and Safeguarding Liberties. This program, which covered the period from 1 January 2007 to 31 December 2013, supports member states' efforts to prevent, prepare for, and to protect CI against terrorist attacks and other security-related incidents such as natural disasters. It contributes to the protection in the areas such as crisis management, transport, research, and technological development, which therefore also includes space policy. The program is organized in the field of terrorism and other security-related risks within the area of freedom, security, and justice.

Within these overall objectives, the program stimulates and promotes initiatives on prevention, preparedness, and consequence management under the supervision of the EU member states and with due regard to existing community competence in that policy area. It provides several types of action under the conditions set out in the annual work program. Among these measures are projects with a European dimension, initiated and managed by the Commission, especially transnational projects, which shall involve partners in at least two member states. For example, in particular, financial support is provided for actions on operational cooperation and coordination as well as for analytical, monitoring, evaluation, and audit activities, furthermore for development and transfer of technology and methodology, particularly regarding information sharing and inter-operability, training, and exchange of staff and experts (2007/124/EC, Euratom).

At this stage the EPCIP seemed to be an ambitious agenda at the supranational political level. The European Commission and the Council of the EU set out high-flying plans and projects for firstly identifying CI, secondly organizing measures for protection, and thirdly analyzing how to react after a "worst-case-scenario." But plans of further cooperation on the European level have met with national resistance, so that the role of the EU remained still unclear. The EPCIP lacked further continuative legislation, also regarding space policy and applications.

As far as space as a CI is concerned, first of all the European Commission seemed to be intent on pushing forward the subject matter on the European level: "Space activities and applications are vital to our society's growth and development" (COM(2011) 152). Space applications are instruments serving the Union's internal and external policies and respond to social, economic, and strategic needs. Especially the flagship programs, Galileo and Global Monitoring for Environment and Security (GMES) contribute directly to achieving the most important objects of the EU and the European Space Agency (ESA).

The European Commission also mentioned "Space and Research" as a sector of CI. Consequently the Commission stated very clearly: "Space infrastructure is critical infrastructure on which services that are essential to the smooth running of our societies and economies and to our citizens' security depend. It must be protected and that protection is a major issue for the EU that goes far beyond the individual interests of the satellite owners" (COM(2011) 152).

The approach of the EU to CIP usually emphasized the so-called worst-case scenarios for several member states. This dramatic view is preaching to the converted as far as most of the crisis experts in the field are concerned. Not only EU politicians but also scientists frequently suggest that people should imagine the unimaginable and by that commend a proactive approach to CIP. This is a proven tool to keep an issue high on the political agenda and to motivate political leaders to act. Compared to the actual experience, the question should be raised: How many of these worst-case scenarios have occurred until today? So the interdependent nature of CI leads to the effect that breakdowns will become more and more severe for people and states. However, the actual experience shows clearly that most modern CI are very reliable and resilient (Fritzon et al. 2007).

One of the most important questions in EU policies concerning space as a CI is now the division between national and supranational levels of policy competence. While community competence, meaning that the EU institutions implement policies in cooperation with the national states, is in use in some policy areas, other areas are completely under control of the member states. The subsidiarity principle is still strong in the EU, leaving as much as possible legislation to be implemented as close to the ground as possible (Svedin 2009). However, most of the policy areas are in between the two extremes. Space policy and CIP are examples of the last category. So who is in charge for which parts of CIP? Should there be more legislation or only coordination at the European level, is the EU authoritative legislator or rather facilitator? Is the participation in the current EPCIP mandatory or voluntarily? These and further questions have to be solved, before other technical questions can be raised and addressed by the European Commission.

At the actual stage, the EPCIP remains work in progress, especially as far as space as a CI is concerned. The related EU policies only establish frameworks and some general directions while they leave it up to the member states to work out the details (Council of the EU (2011/C 377/01)). The arguments for a stronger role of the EU in protecting CI in space seem comprehensible: Breakdowns of space technology will have a transnational effect in almost all cases. Although the Commission seems to prefer a more binding supranational framework, a stronger EU role in protecting critical space infrastructure nevertheless does not appear likely in the view of the technical, institutional, and political difficulties (Svedin 2009). Most capacities for threat and crisis management therefore remain at national levels, the ultimate responsibility for CIP lies with the member state and the infrastructure operator (Lima et al. 2012).

The knowledge of critical space infrastructure vulnerabilities and criticality is still low, and the role of public and private sectors remain unclear – on national and supranational level. For the European level with all its political and interinstitutional issues, the tasks and challenges are even more complex and complicated. To move ahead in this special area, it might be helpful to develop sector-tailored measures and instruments for CIP of space technology. This step towards specific space policy principles for CIP might be a more beneficial strategy to develop binding legislation among the willing EU member states. This could pave the way for at least some European states that use space applications, to follow the US-American lead on future CIP.

## 10.4 Conclusions

The starting point of this chapter was the claim that space applications should be seen and treated as CI. After focusing on CIP in general as well as specialized on space, the article concentrated on the milestones in developing policies of CIP in the United States and the EU. Coming from a rather narrow perspective of counterterrorism policy, the focus of CIP policy today is broader and includes more risks and threats for citizens and states.

The analysis showed that the CIP policies refer to space only barely, but in the United States stronger than in the EU. When the United States and EU act as operators and owners of space applications – e.g., in the cases of GPS and Galileo – this result has to be assessed critically. But as can be assumed from the analyses of the past decade, the share of space within the overall CIP policies will further rise in this decade.

However, the US and EU role is not limited to own space projects, as private and public-private stakeholders become increasingly important. This fact will create new US and EU responsibilities in CSIP: Apart from the protection of the own systems, the coordination and functioning interoperability of the many separate agencies' and enterprises' space CIP approaches will become the main challenge of the US and EU CIP policies in the next years.

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# Space Safety

# 11

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**Abstract**

Space safety is necessary for the sustainable development of space. Space safety practices are now important in a host of different ways for space commerce, applications, science, and exploration. Space safety plays a critical role in minimizing hazards for human spaceflight. It allows for the protection of space infrastructure from orbital debris as we increasingly move from space debris minimization to active mitigation processes. Space safety is now focused to the key role of protecting the Earth's population from reentering objects as well as protecting space assets.

This chapter addresses all these aspects and more. This chapter introduces the many facets of safety that are being addressed by spacefaring nations around the world. Without improved space safety practices and standards, billions of dollars (US) of space assets, many astronaut lives, and even people here on Earth could all be increasingly in peril.

Thus this chapter assesses a wide range of space safety risks. These risks include the different flight phases, from launch, to on-orbit operations, to reentry along with the important concept of Space Traffic Management. A range of human spaceflight safety considerations are also described. The chapter thus provides a broad overview of the field of space safety and its developments.

## 11.1 Introduction

Space safety refers to space mission hazards and relevant risk avoidance and mitigation measures. The space mission hazards include threats to human life, loss of space systems, and pollution of the Earth environment. Space safety, in a wider sense, encompasses the safeguard of critical and/or high-value space systems and infrastructures, as well as the protection of orbital and planetary environments.

Space safety is a necessity for the sustainable development of space activities, whether targeted to minimize hazards for human spaceflight or when directed toward protecting vital space assets so vital to human commerce and safety here on Earth. Space safety is devoted to protecting of space infrastructure from growing human-made orbital debris and even the risks posed to Earth population from reentering objects.

Firstly, the chapter introduces the many facets of safety and discusses acceptable safety levels. Then, we address the risks inherent to each flight phase, from launch to on-orbit and reentry safety risks. Finally, human spaceflight safety considerations are described.

## 11.2 The Many Facets of Space Safety

A total of 22 astronauts and cosmonauts have lost their lives since the beginning of human spaceflight. The first casualty was the soviet cosmonaut trainee Valentin Bondarenko who died in a pressure chamber fire during training in March 1961. Few years later, three American astronauts were killed by a fire during training inside an Apollo capsule. There have been in total three accidents during reentry: Soyuz 1 in April 1967, Soyuz 11 in June 1971, and Shuttle Columbia in February 2003. In the latter case in addition to the loss of crew, the public on ground and the passengers travelling by air were subjected to an unprecedented level of risk due to the US continental-wide path of falling debris, with a projected 1 % chance that a fatal collision with aircraft would occur (Helton-Ingram et al. 2005).

Although they are a rare occurrence, space accidents are not perceived by the public as being caused by random or unfortunate circumstances, but as the dramatic demonstration that human spaceflight programs and perhaps the entire organization behind it failed its core mission. The risk of loss of life in human spaceflight may be less than 1 in 100 flights! Enormous, if we think that the accident rate in commercial aviation is nowadays around 1 in 2 million flights. Although high in percentage, the loss of life in human spaceflight is still very low due to the low number of flights per year. Nevertheless the entire human spaceflight program is putted in question following an accident. The reason is that the ultimate purpose of the program is the achievement of safe (and routine) physical human access to space. An accident makes clear to the public (and to political representatives) that notwithstanding the huge amount of money spent, such objective is far from being achieved. Improving safety is therefore paramount to maintain and expand public support for human spaceflight.

Space safety is not only about astronaut safety. Unmanned space access has become increasingly important to the great majority of countries worldwide. Upon achieving the status of a spacefaring nation, however, a key responsibility that devolves is to establish the technology and processes to protect (national and foreign) life and property against the consequences of malfunctioning rockets and reentry space systems (e.g., satellites, rockets upper stages). Safety risk in space missions also includes general public safety (on ground, on air, and at sea) and safety of launch site personnel. Space safety in a wider sense also encompasses the safeguard strategic and costly systems on orbit (i.e., satellites, international space station, and global utilities), valuable facilities on ground (e.g., launch pads), as well as the safeguard of the space and ground environment.

### 11.2.1 Acceptable Safety Level

The safety level of a system can be objectively determined, but the determination of its acceptability level is much more difficult. The definition of acceptable safety level is based not only on technical state-of-the-art considerations but also on a number of nontechnical factors such as cultural, economic, market, or political assessments. The acceptable safety level of a system or an activity differs often from country to country and also evolves with time and public expectations. For such reason, the safety acceptability level in any field, from drinkable water to toys or nuclear power plants, is generally established by national government regulations and standards. When international commerce is involved, such standards need necessarily to be agreed at international level between governments. One example is the international regulations and standards for air navigation (i.e., the International Civil Aviation Organization, ICAO), which represent one of the most clear-cut successes in the field of international safety cooperation.

Due to the fact that there is nothing as "absolute safety" and given that the "acceptable risk" is usually the one defined by government standards and regulations, new industries (e.g., suborbital commercial transportation) are likely to remain in a legal limbo. This is to say that without a government-defined safety standard, an operator would have a hard time defending the vehicle risk level after an accident. Indeed following a fatal accident, it seems likely that the operator's fleet would be grounded and perhaps made obsolete by newly issued (and likely more strict) standards in the emotional wake of the accident. We can say that obtaining a certification of compliance with safety regulations serves the interests of the customer but at the same time may also protect industry from tort liability by implicitly or explicitly defining the acceptable risk level at the current state of art.

For instance, in 2008, the US Supreme Court ruled in favor of a manufacturer of a balloon catheter that burst and severely injured a patient during an angioplasty. The Court wrote that the Food and Drug Administration (FDA) spent an average of 1,200 h reviewing each device application and granted approval only if found there was a "reasonable assurance" of its "safety and effectiveness." The manufacturer argued that the device design and manufacturing had been in accordance with FDA's regulations and that FDA and not the courts was the right forum on imposing requirements on cutting edge medical devices, arguing that "nothing is perfectly safe." Government regulations and standards protect the customer but also the industry.

### 11.2.2 Safety Standards

Safety standards are typically developed through a consensus process, and they are considered to represent the minimal level of risk that society will accept and tolerate. As we will see later, the risks related to space activities are often of international nature; however, currently there are no international regulations but only few international space safety standards, and when regulations exist at national level, they are often scattered among different government agencies and organizations or not applied in a uniform manner by key players. To explore the different facets of space safety, the next sections will discuss the safety risks associated to the different flight phases, from launch to on-orbit safety (e.g., space debris-related hazards) and reentry. Then, the risks inherent to human spaceflight will be introduced, both for orbital and suborbital flights.

## 11.3 Launch Safety

### 11.3.1 Launch Site Ground Safety Risk

On August 22, 2003, at 1330 (local time), a massive explosion destroyed a Brazilian Space Agency VLS-1 rocket as it stood on its launch pad at the Alcantara Launching Center in northern Brazil. Twenty-one technicians close to the launch pad died when one of the rocket's four first-stage motors ignited accidentally. The investigation report established that an electrical flaw triggered one of the rocket's four solid fuel motors while it was undergoing final launch preparations. The report said that certain decisions made by managers long before the accident occurred led to a breakdown in safety procedures, routine maintenance, and training. In particular, the investigation committee observed a lack of formal, detailed risk management procedures, especially in the conduct of operations involving preparations for launch. As of today, there have been nearly 200 people killed on ground by rocket explosions during processing, launch preparations, and launch. In the last 10 years, there have been also at least six launches which have been terminated by explosion commanded by the launch range safety officer to prevent risk for the public. There have been also several more cases of launchers that did not make to orbit and came back on Earth sometimes in an uncontrolled fashion.

The main ground hazards during launch are explosive, toxic, or radioactive hazards. Explosive hazards (overpressure and fragments thrown by an explosion) are an important component in the launch area. Toxic hazards from the rocket's exhaust products and meteorological conditions are often an additional consideration in defining so-called exclusion areas. Additional sections of the launch complex may be restricted to protect against the kinetic energy of inert debris (i.e., spent stages) or radiation from radars and other support instrumentation. During preparation for launch, a very common issue that the ground processing safety community encounters is lack of recognition of the need for detailed ground safety documentation and rigorous technical safety reviews. Many hardware and mission designers assume that if the hardware is safe to fly, it will also be safe during ground processing. Some also assume that the industrial safety processes used during development and manufacture are sufficient for use at the launch and landing sites.

When an exclusion area is defined, each country has its own procedures for communicating the boundaries of the area. On land, this is commonly through sign postings and guards. Formal notices are frequently used to communicate with operators of ships and aircraft. Moreover, the degree of compliance varies with location and time. When the exclusion area is near the launch complex, ranges frequently employ different forms of surveillance to determine whether any vessels have intruded into the hazardous area. When intruders can be identified, the ranges may request them to depart, passively wait for their departure, or proceed with the launch, based on the decision that the risk to the vessel is sufficiently small.

Nowadays international commercial spaceports are proliferating, and the growing need is felt to equally and uniformly protect worldwide the local personnel as well as the foreign teams which participate to launch campaigns. When in October 2002 a Russian Soyuz exploded at launch killing a young Russian soldier who was watching the launch from the first floor of a building, it was by pure luck that no one was injured of the large international support team on site which was watching the launch from a closer location.

### 11.3.2 Launch Flight Safety Risk

Knowledge of best practices and techniques in launch safety and risk assessment are not widespread and may vary greatly from country to country. Furthermore, currently during launch, a country may take risks on the population of a foreign country that even if equal to that for their own population is a unilateral decision and not the outcome of consultation. Space treaties define liabilities, but they neither define nor require uniform risk assessment and management methods and standards.

The way of achieving public protection from launch activities is by isolating the hazardous condition from populations at risk. When this is not feasible, launch vehicle performance and health is monitored for automatic or manual flight termination. Flight termination strategies are meant to limit rocket excursions from planned trajectory. The residual risk is evaluated with reference to where people may be at risk because of debris generated by flight termination.

Identification of high-hazard areas may range from simplistic rules of thumb to sophisticated analyses. When simple rules are applied, they commonly specify a hazard radius about a launch point and planned impact points for stages, connected by some simple corridor. More sophisticated analyses attempt to identify credible rocket malfunctions, model the resulting trajectories, and determine the conditions that will result in debris such as exceeding the structural capacity of the rocket or a flight termination action by a range safety officer. These analyses typically include failure analyses to identify how a launch vehicle will respond under various failure scenarios. This will include failure response analyses to define the types of malfunction trajectories the vehicle will fly. The vehicle loads are assessed along the malfunction trajectory to determine whether structural limits will be exceeded. Vehicle position and velocity may be compared against abort criteria to assess whether the vehicle should be allowed to continue flight, terminate thrust, or be destroyed. Debris-generating events then become the basis for assessing the flux of debris falling through the atmosphere and the impact probability densities. The debris involved may be screened by size, impact kinetic energy, or other criteria to assess which fragments pose a threat to unsheltered people, people inside various types of buildings, people on ships, and people in aircraft. The resulting debris impact zones are then commonly used as part of the basis for defining exclusion areas.

Although full hazard containment is considered to be the preferred protection policy, it is not always possible. The next line of protection after defining exclusion areas is real-time tracking and control of the rockets. Range safety systems are used for this purpose. They include a means of tracking a launch vehicle's position and velocity (tracking system) and a means of terminating the flight of a malfunctioning vehicle (flight termination system).

Flight termination criteria are customarily designed based on the capability of the range safety system to limit the risk from a malfunctioning launch vehicle. Frequently, ranges assume that they can reliably detect a malfunctioning launch vehicle and terminate its flight whenever good quality tracking data is available. This assumption is based on high-reliability designs customarily used for range safety systems. At present, however, there are no international design standards for range safety systems. Moreover, efforts to assure that the design standard does, in fact, achieve the intended reliability levels are rare.

The final tiers of protection are risk analysis and risk management. Residual risks from the launch are quantified and assessed to determine if they are acceptable. This step involves an extension of the model outlined above for assessing hazardous areas. It is common to perform these protection steps in an iterative manner, using the results of each step to adjust the approach to the others until the desired level of safety is achieved with acceptable impacts on the proposed launch. The current practice is to assess risks for each launch and to approve the launch only when risk levels are acceptable. Unlike most other activities, annual risk levels are addressed by exception.

A proper risk analysis addresses the credible risks from all launch-related hazards. These may include inert debris, firebrands, overpressure from exploding fragments, and toxic substances generated by normal combustion as well as toxic releases from malfunctions. When assessing launch risks, as it occurs for reentry, it is important to account for all exposed populations: people on land, people in boats, and people in aircrafts. Proper consideration must be given to the effect of sheltering (i.e., type of construction and materials of houses, buildings) on the risks. It is often assumed that neglecting sheltering will overstate the risk. When sheltering is adequate to preclude fragment penetration, this assumption is valid. When fragments are capable of penetrating a structure, debris from the structure increases the threat to its occupants. As launch vehicles proceed downrange, they typically leave the territorial domain of the launching country and begin to overfly international waters and the territory of other countries.

Tolerable risks for a launch are commonly expressed in terms of a collective or societal risk level and risk to the maximally exposed individual (individual risk). Collective risk is commonly expressed as the number of individuals statistically expected to be exposed to a specified injury level. Individual risk is commonly expressed as the probability that the maximally exposed individual will suffer the specified injury level. The two most commonly used levels of injury are fatality and serious injury. When it is difficult to quantify risk directly, impact probability for specified classes of debris is often used as a proxy measure. Thus, for example, it is customary to protect people on ships or people on airplanes by creating exclusion zones based on impact probabilities.

Outside of the immediate launch area, surveillance is more difficult and more costly. Consequently, most ranges use surveillance very selectively outside of the immediate launch area, typically restricting surveillance to planned impact areas for spent stages and other planned jettisons. As a result, publishing exclusion areas at these distances is much less effective. More efficient tools for surveying these remote locations and communicating with intruders would enhance the effectiveness of protecting ships and aircraft in these areas.

### 11.3.3 Launch Risk for Maritime and Air Transportation

Controlling risks to seafaring vessels from space launch activities is most successful when mariners are notified about hazard areas and when the responsible launching agency surveys the potentially affected areas to detect intruders and to warn them to leave the exclusion area. Following a mishap, communication with these vessels to proceed at maximum speed in a prescribed direction to minimize impact probability is essential to control undue risks. Currently, costs and technology limit surveillance and communication to locations near land.

For launch preparations, the management of airspace must also consider aircraft traffic. At present, there are limited capabilities for addressing this issue. The Federal Aviation Administration (FAA) has begun an initiative to address these concerns for US operations. It should be noted that the current practice is for each launch range to manage risks on a mission-by-mission basis through Launch Collision Avoidance (LCOLA) processes. Minimal attention is paid to annual risks generated by the range's launch operations. There is no agency – national or international – that monitors and controls risk posed to overflown populations. A city may be placed at risk by launches from multiple launch sites without the performance by involved launching nations of any coordinated assessment to assure that the risk levels are acceptable.

Citizens of all countries should be equally protected from the risk posed from overflying by launch vehicles and returning spacecraft(s). The common practice is to make these determinations on a launch-by-launch basis with no consideration of previous, planned, or future launches. As a result, it is an uncontrolled outcome whether a nation that is subjected to overflight will be subjected to significant annual risks from (1) a single launch facility, (2) a single country's activity, or (3) all nations' launch activities.

## 11.4 On-Orbit Safety

### 11.4.1 Orbital Debris

Space is not an empty vacuum but contains both natural debris (i.e., micrometeoroids, interplanetary dust) and human-made space debris. Humans generally have no involvement in natural debris; thus, here we will concentrate exclusively on human-made debris. Orbital debris generally refers to any human-made material on orbit which is no longer serving its intended function. There are many sources of debris. One source is discarded hardware such as upper stages of launch vehicles or satellites which have been abandoned at the end of their operational life. Another source is spacecraft items released in the course of mission operations. Typically, these items include launch vehicle fairings, separation bolts, clamp bands, adapter shrouds, and lens caps. Various shapes and sizes of debris are also produced as a result of the degradation of hardware due to atomic oxygen, solar heating, and solar radiation and also from combustion of solid rocket motors. Examples of such products are paint flakes, aluminum oxide exhaust particles, and solid motor-liner residuals.

Fifty years of spaceflight have cluttered the space around the Earth with an enormous quantity of human-made debris. Scientists assume that there are approximately 500,000 objects in orbit whose sizes are above 1 cm. Currently, about 21,000 of such objects (i.e., 10 cm in diameter or larger) are being tracked by the US Space Surveillance Network (including about 800 objects representing functional satellites). Only the largest pieces of debris in orbit can be regularly tracked, mainly by using optical sensors. In the geosynchronous geostationary orbit, the minimum size that can be tracked is 30 cm, while in low Earth orbits, it is about 10 cm. Among the tracked pieces of debris, there are about 200 satellites abandoned in Geostationary Earth Orbits (GEO) occupying or drifting through valuable orbital positions and posing a collision hazard for functional spacecraft(s). The survival time of the debris can be very long. Objects in 1,000 km orbits can exist for hundreds of years. At 1,500 km, the lifetime can go up to thousands of years. Objects in geosynchronous orbit can presumably survive for one million years.

The future population of orbital debris will depend upon whether the creation or removal rate dominates. Currently, the only mechanism for removal of debris is orbital decay through atmospheric drag, which ultimately leads to atmospheric reentry. This mechanism is only effective in a restricted range of low Earth orbits (LEO). At higher orbits, it takes hundreds to thousands of years for objects to reenter the Earth's atmosphere. Consequently, there is no effective removal mechanism. Historically, the creation rate of debris has outpaced the removal rate, leading to a net growth in the debris population in low Earth orbit at an average rate of approximately 5 % per year. A major contributor to the current debris population has been fragment generation via explosions. As the debris mitigation measure of passivation (e.g., depletion of residual fuel) comes to be implemented more commonly, it is expected that explosions will decrease in frequency. It may take a few decades for the practice to become implemented widely enough to reduce the explosion rate, which currently stands at about 4 per year.

Several environment projection studies conducted in recent years indicate that, with various assumed future launch rates, the debris populations at some altitudes in LEO will become unstable. Collisions will take over as the dominant debris generation mechanism, and the debris generated will feed back into the environment and induce more collisions. The most active orbital region is between the altitudes of 900 and 1,000 km, and even without any new launches, this region is highlyunstable (Liou and Johnson 2006). It is projected that the debris population (i.e., objects 10 cm and larger) in this "red zone" will approximately triple in the next 200 years, leading to an increase in collision probability among objects in this region by a factor of ten. In reality, the future debris environment is likely to be worse than was suggested, as satellites continue to be launched into space.

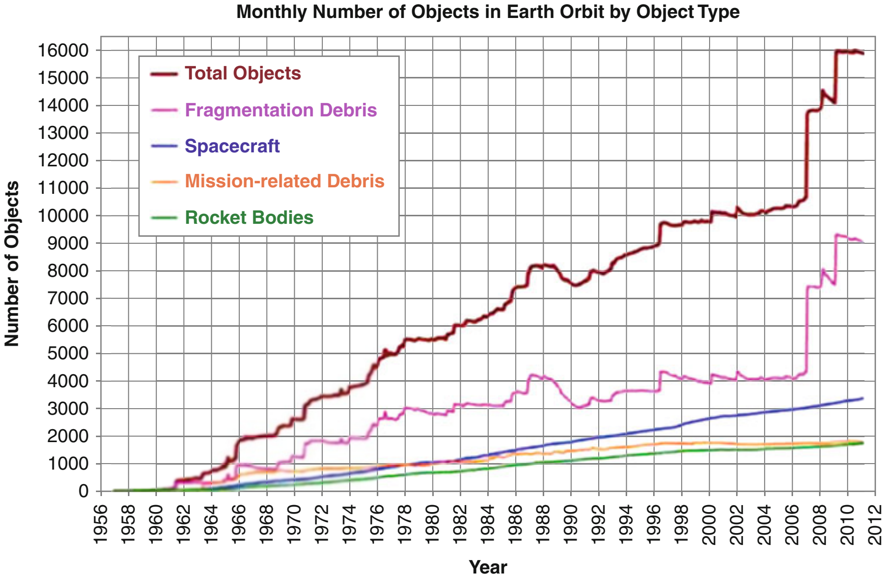
### 11.4.2 Collision Risk with Orbital Debris

Orbital debris generally moves at very high speeds relative to operational satellites. In LEO (i.e., altitudes lower than 2,000 km), the average relative impact velocity is 10 km/s (36,000 km/h). In the geostationary orbits, the relative velocity is lower, approximately 2 km/s, because most objects move in an eastward direction orbit. At these hyper velocities, pieces of debris have a tremendous amount of kinetic energy. A 1 kg object at a speed of 10 km/s has the same amount of kinetic energy that a fully loaded truck, weighing 35,000 kg, has at 190 km/h. A 1 cm sized aluminum sphere at orbital speed has the energy equivalent of an exploding hand grenade. A 10 cm fragment in geosynchronous orbit has roughly the same damage potential as a 1 cm fragment in low Earth orbit.

Pieces or particles of debris smaller than 1 mm in size do not generally pose a hazard to spacecraft functionality. Debris fragments from 1 mm to 1 cm in size may or may not penetrate a spacecraft, depending on the material composition of the debris and whether or not shielding is used by the spacecraft. Penetration through a critical component, such as the flight computer or propellant tank, can result in loss of the spacecraft. NASA considers pieces of debris 3 mm in size and above as potentially lethal to the retired Space Shuttle and the International Space Station. Debris fragments between 1 and 10 cm in size will penetrate and damage most spacecraft. If the spacecraft is impacted, satellite function will be terminated, and at the same time, a significant amount of small debris will be created. If a 10 cm debris fragment weighing 1 kg collides with a typical 1,200 kg spacecraft, over one million fragments ranging in size from about 1 mm and larger could be created. Such collisions result in the formation of a debris cloud which poses a magnified impact risk to any other spacecraft in the orbital vicinity (e.g., other members of a constellation of satellites).

Certain regions of the debris cloud are constricted to one or two dimensions. Such constrictions do not move with the debris cloud around its orbit. They remain fixed in inertial space while the debris cloud repeatedly circulates through them. In many satellite constellations, there are multiple satellites in each orbital ring. If one of these satellites breaks up, the remaining satellites in the ring will all repeatedly fly through the constrictions. If many fragments are produced by the breakup, the risk of damaging another satellite in the ring may be significant. If satellites from two orbital rings collide, two debris clouds will be formed with one in each ring. The constrictions of each cloud will then pose a hazard to the remaining satellites in both rings.

In February 2009, a nonoperational Russian satellite, Cosmos 2251, collided with Iridium 33, a US commercial telecommunication satellite, over Siberia at an altitude of 790 km. This collision, the first of its kind, was the worst space debris event since China intentionally destroyed one of its aging weather satellites during an antisatellite missile (ASAT) test, in 2007. The Iridium satellite that was lost in the collision was part of a constellation of 66 low Earth-orbiting satellites providing


Monthly Number of Objects in Earth Orbit by Object Type

*Monthly Number of Cataloged Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially cataloged by the U,S, Space Survellance Network, "Fragmentation debris" Includes satelite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispedsed, separated, or released as part of the planned mission.*

**Fig. 11.1** Catalogued human-made space objects in Earth's orbit (Credit: NASA)

mobile voice and data communications services globally. As expected, the risk of collision of other Iridium satellites in the same plane dramatically increased with daily announcements of possible collisions (i.e., conjunctions) with Iridium 33 debris. Figure 11.1 presents the evolution in time of the number of human-made debris objects, which highlights the increasing problem impacting the sustainability of the space environment.

In general, orbital debris collision is among the top risk for human spaceflight. The 2003 Shuttle risk assessment performed after the Columbia accident, the first one that incorporated the threat posed by orbital debris, determined that the likelihood of orbital debris bringing down the Shuttle was far greater than that of the widely feared failures of main engines, solid rocket boosters, or thermal protection. Orbital debris colliding with different spots of the wing flaps was the most likely catastrophic failure. Damage would have rendered the wing flap (elevon), unable to steer and slow the Shuttle during the reentry phase.

Orbital debris collision is the primary source of risk for the International Space Station (ISS). To minimize such risk for the crew, the ISS is shielded. The ISS is indeed the most heavily shielded spacecraft ever flown. All together there are 100 different shields protecting the ISS. Critical components such as habitable compartments and high-pressure tanks will be able to withstand the impact of debris as large as 1 cm in diameter.

### 11.4.3 Controlling Orbital Debris Risk

Orbital debris risk is best controlled by limiting creation through a number of design and operational measures, like “passivation,” collision avoidance maneuvers, and end of life disposal.

Passivation is the term used to describe the prevention of satellite and upper-stages explosions by controlled removal of stored energy at the end of useful life. For example, propellant in upper stages and satellites can be eliminated by either venting or burning to depletion. This process is applied primarily to low earth orbit satellites. Batteries can be also designed to reduce risk of explosion.

Spacecraft maneuvers, when possible, can also mitigate orbital debris risk of collision. The International Space Station has maneuvered on several occasions to avoid collisions with orbital debris. Also, in the case of satellite constellations, because a potential collision will lead to the creation of a debris cloud that may result in damage to other members of the constellation, collision avoidance maneuvers may be necessary. Another means to reduce the risk of collision is to remove satellites and upper stages from mission orbits, so-called protected orbits, at the end of operational life. Currently, UN guidelines and other internationally agreed standards (e.g., ISO 24113) recommend that a space system should not remain in its mission orbit for more than 25 years. Such objective is met either by lowering the orbit such that residual atmospheric drag is sufficiently strong to cause decay and reentry or by moving the spacecraft to a “graveyard orbit” outside of protected regions. At orbits above 2,000 km, it is not economically feasible to force reentry within 25 years. Spacecraft operating in the geosynchronous orbits are routinely boosted into a higher disposal orbit at the end of their mission life, except in case of malfunction. Propellants need to be reserved to perform the disposal maneuvers. There are penalties in the form of reduced performance and/or mission life linked to the disposal of space systems. Estimates of the amount of “lost” lifetime for geosynchronous satellites vary between 6 months and 2 years. For example, it has been calculated that if a typical commercial communication satellite that has 24 Ku-band and 24 C-band transponders with bandwidths of 36 MHz has to be boosted into a higher disposal orbit at the end of its mission life, this maneuver would cause the satellite operator an average loss (in terms of how much longer the satellite could have continued commercial operations) of as much as 1 year’s profit. This problem can be mitigated by employing so-called inclined orbit operation so as to preserve fuel since North–South station-keeping requires more than ten times more fuel than East–west station-keeping.

### 11.4.4 Orbital Debris Remediation: Active Debris Removal

In view of the massive amount of debris already in existence in Earth orbits, growing consensus among experts suggests that an active process for the removal of existing debris from space is required, as mitigation is no longer sufficient to ensure the long-term sustainability of outer space activities. Active debris removal (ADR), specifically the removal of nonfunctional spacecraft and spent upper stages,

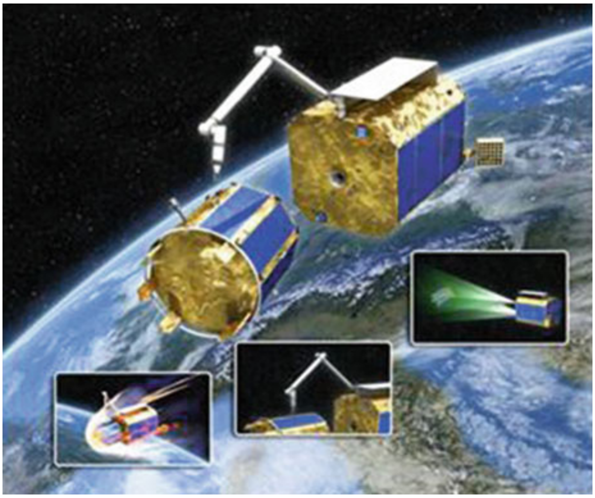


**Fig. 11.2** Active debris removal concept (Credit: DRL)

requires the development of advanced technologies and concepts (Fig. 11.2). Their implementation also raises a number of difficult technical, economic, strategic, institutional, legal, and regulatory challenges that must be addressed at the very outset. For such on-orbit services to become available, the following elements need to be in place: service at the lowest possible cost, spacefaring countries committing to gradually remove their own debris, and new national licensing regulations mandating removal (autonomous or enforced) at end of mission.

To achieve the lowest possible service costs, international technological cooperation, high rate of missions per year, and possibly multiple service targets per mission would be needed at least for an initial period of operations. The international technological cooperation would serve the purpose of making available all existing technologies and share the cost of new developments. Servicing with a single flexible system multiple (international) customers and perform multiple removals within the same mission would also substantially contribute to lower the operational costs. To a certain extent, the same path used once for the development of the satellite telecommunication industry may be repeated with the establishment of an intergovernmental organization on the model of the early International Telecommunications Satellite Organization (INTELSAT) which would later evolve into full commercial services. Another alternative would be to create an international fund for debris removal. Such a fund could start as national and/or regional cooperative and evolve into an international fund supported by all spacefaring nations. The problem with all such plans or concepts is that the current provisions of Article VII of the Outer Space Treaty of 1967 as well as those of the so-called Liability Convention of 1972 structure “liabilities” associated with such removal activities in such a way as to give little incentives for countries to actively remove debris from orbit.

## 11.5 Reentry Safety Risk

As previously mentioned, nonfunctional satellites, spent launch vehicle upper stages, and other orbital debris do not remain in low Earth orbits indefinitely but gradually return to Earth due to residual atmosphere drag. In low Earth orbits, natural orbital decay can take place within few months or requires hundreds or even thousands of years to happen depending on the altitude.

As nonfunctional satellites, spent launch vehicle stages, and other pieces of debris enter denser regions of the atmosphere, they fragment and sometimes explode due to high aerodynamic forces combined with loss of materials strength due to heat caused by friction with air at high velocity. Heat would subsequently cause the demise of major portions of the hardware due to melting and vaporization. However, between 10 % and 40 % of the original mass will survive and reach Earth's surface. In general, parts and components made of aluminum and similar materials with low melting temperatures do not survive reentry, while those made of materials with high melting temperatures, such as stainless steel, titanium, do survive. Also parts with low mass and large surface area, and therefore large aerodynamic drag, will survive due to slow down and related low heating. The surviving fragments represent a hazard to people and property on the ground. They also represent a potential serious risk to air and maritime traffic.

Due to variability of the atmosphere layers around the Earth, it is difficult to predict the exact reentry time of a randomly reentering satellite or upper stage. As a consequence it is very difficult to predict where surviving fragments will hit the surface of the Earth. Over the last 50 years, more than 1,400 metric tons of materials are believed to have survived reentries. The largest object to reenter was the Russian Mir Space Station, which weighed 120,000 kg. Reentries are frequent, in particular upper-stages reentries. In 2011, launch vehicles upper stages reentered at a rate of 1 per week with a total mass that was five times that of uncontrolled spacecraft reentries for the same period (Figs. 11.3 and 11.4). Many of the reentered parts recovered on ground, including tanks up to 250 kg weight, belonged to rockets.

Currently a number of countries prescribe that the risk of any personal casualty due to a single reentry event must be less than 1 in 10,000 reentries. France has the most conservative requirement of less than 2 in 100,000 reentries. Of particular concern, although very remote, is the risk for aviation and the emotional and psychological impact on the general public that a single accident with many casualties would cause (Ailor and Wilde 2008), as described in Sect. 11.5.2.

### 11.5.1 Environmental Risk

There is health risk related to launch ascent failures and reentry of space systems (e.g., rocket bodies and nonfunctional space systems). During normal launches, stages separate sequentially and fall down to Earth. Most launch trajectories and spaceport locations are chosen to ensure that the impact areas are outside populated areas and mainly contiguous to the oceans. Nevertheless there are inland spaceport

**Fig. 11.3** Stainless steel propellant tank of 2nd-stage Delta 2 reentered launch vehicle (US, 1977) (NASA courtesy)

**Fig. 11.4** Reentered titanium motor casting of 3rd-stage Delta 2 (Saudi Arabia, 2001) (NASA courtesy)

locations and land overflying trajectories which lead to stages dropping to ground in sparsely inhabited areas with ensuing soil contamination. Approximately 9 % of the propellant from a launch stage remains in the tank once it is dropped. The penetration of contaminants depends on the nature and properties of the soil and can lead to the contamination of groundwater as well as surface water. For example, hydrazine (UDMH) is often used in hypergolic rocket fuels as a bipropellant in combination with the oxidizer nitrogen tetroxide and less frequently with IRFNA (red-fuming nitric acid) or liquid oxygen. UDMH is a toxic carcinogen and can explode in the presence of oxidizers. It can also be absorbed through the skin. A tablespoon of hydrazine in a swimming pool would kill anyone who drank the water. In a study conducted by Vector, the Russian State Research Center of Virology and Biotechnology in Novosibirsk, health records from 1998 to 2000 of about 1,000 children in two areas in southern Siberia polluted due to launches from Baikonur spaceport in Kazakhstan were examined, comparing them with 330 records from a nearby unpolluted control area. Grouping all cases of disease together, the research team concluded that children from the worst-affected area were up to twice as likely to require medical attention for diseases such as endocrine and blood disorders during the 3 years studied and needed to be treated for twice as long. Contamination can be far worse and massive in case of launch failure. In September 2007 the explosion of a Russian Proton M rocket contaminated a vast swath of agricultural land in Kazakhstan with 200 t of toxic fuel.

Reentries may also cause concern because of the toxicity or radioactivity of materials on board. On 21 February 2008, an uncontrolled reentering satellite was shot down on grounds of public safety. The satellite was destroyed at an altitude of 247 km by a ship-launched missile. The malfunctioning spacecraft, a US spy satellite (USA 193), carried 450 kg of highly toxic frozen hydrazine fuel in its titanium fuel tank. In addition it was expected that about 50 % of the satellite's mass of 2,270 kg would survive reentry, thus adding to public risk on ground.

Currently, there are 32 defunct nuclear reactors circling the Earth as well as 13 reactor fuel cores and at least 8 radiothermal generators (RTGs). RTGs had been used six times in space missions in low Earth orbits up to 1972 and twice in the geostationary geosynchronous orbit up to 1976. Since 1969, another fourteen reactors have been used on lunar and interplanetary missions. The total mass of RTG nuclear fuel in Earth orbit today is in the order of 150 kg. Another form of nuclear power source used in space activities is a nuclear reactor. Most of these reactors were deployed on Soviet radar reconnaissance satellites (RORSATs) launched between 1965 and 1988.

Among the space nuclear accidents (i.e., unwanted/unplanned release of radioactive material), two involved orbital debris, and a third was a close call. In 1978, the RORSAT COSMOS 954 failed to separate its nuclear reactor core and to boost it into a disposal orbit as planned. The reactor remained on board the satellite in an orbit that decayed until it reentered the Earth's atmosphere. The satellite crashed near the Great Slave Lake in Canada's Northwest Territories, spreading its radioactive fuel over an area of about 124,000 km$^2$. Recovery teams swept the area by foot for months. Ultimately, they were able only to recover 12 large pieces which comprised a mere 1 % of the estimated quantity of radioactive fuel on board. These pieces emitted radioactivity of up to 1.1 Sv/h. (It should be noted that usually a nuclear emergency is declared on ground at 500 μSv/h.) A few years later, in 1982, another RORSAT, COSMOS 1402, failed to boost the nuclear reactor core into a storage orbit. The ground controller managed to separate the core from the reactor itself to make it more likely that it would burn up in the atmosphere before reaching the ground. The reactor was the last piece of the satellite to return to Earth in February 1983 when its core fell into the South Atlantic Ocean.

Then, in April 1988, yet another Russian spacecraft, COSMOS 1900, failed again to separate and boost the reactor core into a storage orbit. However, later on, the redundant system succeeded in separating and boosting the nuclear core into a storage orbit, although lower than that originally planned.

### 11.5.2 Risk for Aviation

Many of the practices that apply to launch apply also to reentry, but the latter pose special issues because they are mainly random or related to unique behavior of the reusable vehicle during reentry.

The disintegration during reentry of the Shuttle Columbia on February 1, 2003, was a watershed moment in the history of launch and reentry safety analysis. It highlighted the need to select vehicle reentry trajectories which minimize the risk to ground populations and the need to take measures to keep air traffic away from falling debris if a reentry accident occurs. The Columbia accident initiated a chain of events that demonstrated the need for a deliberate, integrated, and, eventually, international approach to public safety during launch and reentry operations. This is especially true for the management of air traffic and space operations.

Shortly after the breakup of Columbia over a relatively sparsely populated area of Texas, dramatic images of the debris from the breakup were seen around the globe: an intact spherical tank in a school parking lot, an obliterated office rooftop, mangled metal along roadsides, and charred chunks of material in fields. The NASA Administrator testified before the US Senate that it was “amazing that there were no other collateral damage” (i.e., that no members of the public were hurt).

The Columbia Accident Investigation Board (CAIB) raised and answered many questions relevant to public safety during launch and in particular reentry. Given the available data on the debris recovered and the population characteristics in the vicinity, a CAIB study found that the absence of ground casualties was, in fact, the statistically expected result. Specifically, based on census data and modeling methods consistent with US standards and requirements set by other US agencies (e.g., the USAF in the Air Force Space Command Manual and by the FAA in the Federal Register), the study found that “the lack of casualties was the expected event, but there was a reasonable probability (less than 0.5 but greater than 0.05) that casualties could have occurred.” However, a similar event over a densely populated area such as Houston would almost certainly have produced multiple casualties among the public on the ground.

At the time of the Columbia accident, NASA had no formal policy regarding public risk during Shuttle reentry. Following the CAIB report, NASA established a new safety policy (NPR8715.5). The NASA public safety policy embraced many of the risk measures and thresholds already in use by other US agencies, such as individual and collective risk limits in terms of casualties. However, NASA’s public safety policy also putted forward innovative criteria for risk budgets governing distinct phases of flight which have gained broad acceptance. Therefore, the Columbia accident led to greater consensus and innovation in the management of risk to people on the ground from launch and reentry operations.

The Columbia accident also promoted the development of improved methods and standards for aircraft safety during launch and reentry. Following the release of the final report of the CAIB, the FAA funded a more detailed aircraft risk analysis that used the actual records of aircraft activity at the time of the accident. That study found that the probability of an impact between Columbia debris and commercial aircraft in the vicinity was at least one in a thousand, and the chance of an impact with a general aviation aircraft was at least one in a hundred. The analysis used the current models which assume that any impact anywhere on a commercial transport with debris of mass above 300 g produces a catastrophic accident: all people on board are killed. Current best practices are captured in RCC 321–07 "Common Risk Criteria for the National Ranges," which provides a vulnerability model for the commercial transport class. In 2008, the FAA and USAF sponsored the development of vulnerability models for transoceanic business jets based on the same methods.

After the release of the CAIB report, the FAA investigated the need for new decision support tools to better manage the interface of space and air traffic. The relevant procedures were then developed, and they are currently in use as a real-time tactical tool in the event of a catastrophic event like the Columbia accident to identify how to redirect aircraft around a space vehicle debris hazard area.

## 11.6 Existing Regulations and Standards

The sections above have provided an overview of risks associated to launch, on-orbit operations, and reentry. As it has been illustrated, the issues raised above involve risks that are national and/or international in nature. For launch and reentry activities, national regulations exist in some spacefaring nations; however, no international regulation applicable worldwide has been agreed. There have been ever-increasing safety concerns that are now posed by the pollution of the orbital environment (i.e., orbital debris) to operational spacecraft and the international space station. After many years of debate, international space debris mitigation guidelines have been worked out by the Inter-Agency Space Debris Coordination Committee (IADC), and these have been agreed as voluntary standards within the umbrella of the United Nations Committee of Peaceful Usages of Outer Space Activities (UN COPUOS). In addition, the International Organization for Standardization (ISO) has published a standard on space debris mitigation (i.e., ISO 24113) to put forward design and operational practices for implementation in future space systems to minimize the generation of orbital debris.

However, no remediation activities are yet internationally agreed, and therefore, neither standards nor regulations exist in this field. In addition, although different countries have the observational assets to perform space situational awareness services, currently, there are no agreed space traffic management regulations. Clearly these two issues, i.e., space debris mitigation and space traffic management, will constitute the two most important international space safety standards and regulatory issues to be faced in the next few years.

## 11.7 Human Spaceflight Safety

In the following sections, the risks associated to human spaceflight will be presented. Firstly, the concept of system safety for crewed systems would be introduced. Then, the value of regulations and safety standards would be illustrated by real examples in different fields, and a case study based on the emerging industry of commercial suborbital transportation will be examined. Then, the historical and latest developments for human-rating space systems would be presented, and finally, a selected number of risks associated to human spaceflight will be covered.

### 11.7.1 System Safety

Prior to the 1940s, flight safety consisted basically of trial and error. The term fly-fix-fly was associated with the approach of building a prototype aircraft, fly it, and repair/modify if broke, and fly it again. For complex and critical systems, such approach is simply impossible. From 1952 to 1966 the US Air Force (USAF) lost 7,715 aircraft in noncombat operations, in which 8,547 persons were killed. As reported by Olsen (2010), "most accidents were blamed on pilots, but many engineers argued that safety had to be designed into aircraft just as any other functional or physical feature related to performance. Seminars were conducted by the Flight Safety Foundation, headed by Jerome Lederer that brought together engineering, operations, and management personnel. At one of those seminars, in 1954, the term "system safety" was first used in a paper by the aviation safety pioneer C.O. Miller."

In the 1950s, when the Atlas and Titan ICBMs were being initially developed, there was no safety program. Within 18 months after the fleet of 71 Atlas F missiles became operational, four blew up in their silos during operational testing. The worst accident occurred in Searcy, Arkansans, on August 9, 1965, when a fire in a Titan II silo killed 53. The US Air Force then developed system safety assessment and management concepts. Such efforts eventually resulted into the establishment of a major standard, MIL-STD-882D, and System Safety Engineering as a discipline (Leveson 2003).

### 11.7.2 Commercial Suborbital Regulatory Safety Framework: A Case Study

One of the areas of space safety regulation that has received the most attention in recent years has been with regard to overseeing the safety of commercial spaceflights – particularly in the form of suborbital flights.

A suborbital flight is defined as a flight up to a very high altitude beyond 100 km above sea level but in which the vehicle involved does not go into orbit (i.e., does not attain an orbital speed exceeding 11.2 km/s). A suborbital trajectory is defined under US law as "The intentional flight path of a launch vehicle, re-entry vehicle, or any portion thereof, whose vacuum instantaneous impact point does not leave the surface of the Earth." Unmanned suborbital flights have been common since the very beginning of the space age. Sounding rockets covering a wide range of apogees even well above the altitude of the Shuttle and ISS orbits have been

**Fig. 11.5** X-15 crash (Credit: NASA)

routinely launched. Nowadays, suborbital human spaceflight is gaining popularity as demonstrated by the increased interest in space tourism. Still in its nascent phase, the space tourism industry proposes new commercial vehicles which have configurations and operational mode very similar to some early government programs, namely, capsules (e.g., Mercury Redstone) or winged-rocket system (e.g., X-15 aircraft). It should be noted that the two configurations drive very different safety requirements. Safety requirements for the launcher/capsule configuration have been in place for more than 40 years and have been successfully proven, mainly during the performance of (more challenging) orbital flights. The safety requirements for the aircraft-type configuration have a well-established technological basis in the aeronautical engineering field, although they are not reflected in any current civil aviation-type regulation. The experimental aircraft X-15 flew 199 times flights before program cancellation in 1968. The X-15 suffered four major accidents (Fig. 11.5).

In 2004 and then in 2011, the United States passed the so-called Commercial Launch Amendments Act (CSLAA) and the “Commercial Space Launch Activities” Act that was signed into law in January 2012. This Act continues the process of having the US Federal Aviation Administration’s Commercial Space Transportation (FAA-AST) provide experimental licenses to operators of such flights on a case by case basis after a careful review of the application. The spaceports from which commercial flights will occur will likely be reviewed and licensed on a renewable 5 year term. As noted earlier in the space safety regulations section, the US oversight of commercial human spaceflight under the CLAA of 2004 and the more recent Commercial Space Launch Activities Act remains on a case by case “experimental license” basis with seeking to define industry-wide standards for space plane flights, except for aspects of public safety, until December 23, 2012, or until an accident (i.e., design feature or operating practice resulting in a serious or fatal injury) occurs. In short, this fledging commercial suborbital industry is not sufficiently mature to establish general safety standards, until more data is gathered and further experience is gained.

### 11.7.2.1 Self-Regulations: Safety as Business Case

An alternative to government regulations is self-regulations. They are essentially meant to promote a higher level of safety as a business case. Take the example of Formula 1 car racing. In the first three decades of the Formula 1 World Championship, inaugurated in 1950, a racing driver's life expectancy could often be measured in fewer than two seasons. It was accepted that total risk was something that went with the badge. It was the Imola Grand Prix of 1994 with the deaths of Roland Ratzenberger and Ayrton Senna (as shown on direct broadcast TV) that forced the car racing industry to look seriously at safety or risk to be banned forever. In the days after the Imola crashes, the FIA (Fédération Internationale de l'Automobile) established the safety Advisory Expert Group to identify innovative technologies to improve car and circuit safety and mandated their implementation and certification testing. Nowadays, Formula 1 car racing is a very safe multibillion dollar business of sponsorships and global television rights, an entertainment for families that can be enjoyed without risking shocking sights.

Another example comes from the oil industry. The Presidential Commission that investigated the "Deepwater Horizon" disaster in the Gulf of Mexico in April 2010 (11 workers killed plus an oil spill that caused an environmental catastrophe) recommended the establishment of an independent safety agency within the Department of the Interior and that "the gas and oil industry must move towards developing a notion of safety as a collective responsibility. Industry should establish a "Safety Institute"[...] this would be an-industry created, self-policing entity aimed at developing, adopting, and enforcing standards of excellence to ensure continuous improvement in safety and operational integrity offshore."

Nowadays sophisticated techniques are available to remove or control hazards in new systems such to minimize the safety risk of new systems before they enter into operation. Such techniques go generally under the name of "safety case."

### 11.7.2.2 Prescriptive Requirements Versus Safety Case

The RMS Titanic struck an iceberg on her maiden voyage from Southampton, England, to New York and sank in the early hours of 15 April 1912. A total of 1,517 people died in the disaster because there were not enough lifeboats available. During the Titanic construction, Alexander Carlisle, one of the managing directors of the shipyard that built it, had suggested using a new type of larger davit, which could handle more boats giving Titanic the potential of carrying 48 lifeboats providing more than enough seats for everybody on board. But in a cost-cutting exercise, the customer (White Star Line) decided that only 20 would be carried aboard thus providing lifeboat capacity for only about 50 % of the passengers (Titanic 1912). This may seem as a carefree way to treat passengers and crew on board, but as a matter of fact the Board of Trade regulations stated that all British vessels over 10,000 t had to carry 16 lifeboats. Obviously the regulations were out of date in an era which had seen the size of ships reaching the 46,000 t of the Titanic.

The above accident illustrates at the same time what is a prescriptive requirement (i.e., an explicitly required design solution for an implicit safety goal) and how it can sometimes dramatically fail. Instead the safety case regime is based on the principle that the regulatory authority sets the broad safety criteria and goals to be attained while the system developer proposes the most appropriate technical requirements, design solutions, and verification methods for their fulfillment. In other words, the safety case regime recognizes that it is the regulatory authority's role and responsibility to define where the limit lies between "safe" and "unsafe" design (i.e., the safety policy in a technical sense), but it is the developer/operator that has the greatest in-depth knowledge of the system design and operations.

A safety case is documented in the Safety Case Report that typically includes the following: (a) the summary description of the system and relevant environment and operations; (b) identified hazards and risks, their level of seriousness, and applicable regulatory criteria/requirements; (c) identified causes of hazards and risks; (d) description of how causes (of hazards and risks) are controlled; and (e) description of relevant verification plans, procedures, and methods.

The safety of the entire International Space Station (ISS) program is based on a process of incremental safety reviews by independent panels of safety case reports (called safety data packages) prepared by systems developers/operators in response to the (generic) safety requirements (NASA SSP 30599 2009). In the course of the operations, further submittals are made to account for configuration changes, previously unforeseen operations, and corrective actions from on-orbit anomalies.

### 11.7.3 Human Rating: A Historical Perspective

Since the first space programs that achieved human access to space, the identification of system requirements for crewed space systems has been a complex exercise. In the 1950s, the engineering efforts to maximize safety were built on the experience gained about the space environment from unmanned vehicles and experimental platforms with chimpanzees on board, which contributed to gather data for planned crew missions. The concept of human rating (also known previously as manned rated) was used to refer to systems designed to carry humans into space. However, a formal common process designated to grant human-rating certification did not exist at the time, as it is being used in current programs. In the past, the methods for implementing human rating varied as a function of program, across system and subsystems and sometimes across mission phases within a program.

In 1995, 14 years after the Shuttle had entered operations, an agency-wide committee was tasked to develop a human-rating requirements definition for launch vehicles based on conventional (historical) methods. After the revision of past programs both for launchers and spacecrafts such as Gemini, Apollo, and the Space Shuttle, the committee recommended the following definition of human-rating process, that is, "a process that satisfies the constraints of cost, schedule, performance, risk and benefit while addressing the three requirements of human safety, human performance, and human health management and care" in a document reviewing the historical perspective of human rating of US spacecrafts (Zupp 1995). Historically, the human-rating process for Mercury, Gemini, and Apollo programs had been centered on human safety. The Skylab and Shuttle programs added to this an emphasis on human performance and health management. Further details on the history of these programs can be found in (Logsdon and Launius 2008).

For Gemini as well as for other vehicles since then, an important part of assuring crew safety was the development of a crew escape system in case of abort scenarios. The escape system test program was also quite extensive, leading to the identification of improved designs throughout the testing phase and spanned a 3-year period, which lead to the development of a crew escape system, with an ejection seat qualified for flight crew space from pad aborts to 45,000 ft (Ray and Burns 1976). For the Apollo program, launch vehicles (i.e., Saturn IB and V) were designed for human spaceflight (given that no other launcher was able to deliver the required performance). These vehicles had additional redundancy and safety improvements as compared to its predecessors for Mercury and Gemini. Additionally, there was an extensive ground and unmanned flight plan to validate new design features and to certify the launch escape system uniquely developed for Apollo.

For the Space Shuttle, the considerations for crew safety were a tremendous challenge over previous programs mainly because with its configuration (where the Orbiter vehicle and the crew were much closer to the source of explosive yield of fire and overpressure than in the in-line series burn configurations used on the Mercury, Gemini, and Apollo launch systems). The most significant challenge was how to address the issue of abort during first stage. To enable the possible consideration of crew escape, crew ejection, launch pad ejection, or Orbiter separation and fly way, a method for thrust termination of solid rocket boosters (SRBs) had to be developed. It was a technology that was not proven. Various concepts for thrust termination were examined (i.e., pyrotechnically blow out the head end of the booster and neutralize thrust; another concept was to sever the nozzle to accomplish the same result), but all raised major concerns or introduced significant design challenges. Therefore, a decision was made that the additional safety risks and design complexities introduced by thrust termination were of greater concern that the presumed low failure rate of solid motors. For the areas of “high” risk, more stringent design requirements were derived to build in greater reliability for Shuttle SRBs (i.e., structural design factors of safety, case insulation, and segment seals). The Shuttle used a historical performance database to improve safety design and certified the vehicle to be human rated with no first-stage abort capability. The focus was on system-level integrated methodology.

The human-rating process builds upon data and knowledge acquired during development, manufacturing, and operations. The information derived from the evaluation and analysis of this data can only contribute to strengthening the understanding of failure mechanisms and identifying mitigation strategies to address them. Taking into account the lessons learnt from past programs as well as the technological developments of our time, the need for specific requirements for human rating a space system to enhance crew safety and incorporate the knowledge gained through more than 40 years of space activities materialized with the release of the NASA NPR 8705.2A "Human-Rating Requirements and Guidelines for Space Flight Systems" in 2003. In this first standard addressing human-rating certification, NASA proposed the following definition: "a human-rated system is one that accommodates human needs, effectively utilizes human capabilities, controls hazards and manages safety risk associated with human spaceflight, and provides to the maximum extent practical, the capability to safely recover the crew from hazardous situations."

In 2008 and then, 2011, NASA reissued and updated these requirements (i.e., NPR 8705.2B) with slight modifications from its original version, document that was later updated in 2011. This document contains a set of programmatic and technical requirements that establish a benchmark of capabilities for human-rated space systems. It directs programs to perform human error analysis, evaluate crew workload, conduct human-in-the-loop usability evaluations, prove that integrated human-system performance test results are required to validate system designs, and establish a Human System Integration team to evaluate these activities (Hobbs et al. 2008). NASA Constellation Program (i.e., Ares launchers and Orion capsule) was the first program to incorporate these new human-rating requirements. In parallel, activities are undergoing by other agencies (e.g., ESA and JAXA) for the refinement of safety technical requirements for human-rated space systems (Trujillo and Sgobba 2011). In 2011, the Commercial Crew Program (CCP) issued the CCT-1100 Series that communicates roles and responsibilities, technical management processes supporting certification, crew transportation systems, and ISS-related requirements for potential commercial providers.

### 11.7.4 Human Spaceflight Safety Risks

The principal safety issues related to orbital human spaceflight are protection from environmental hazards whether space weather (i.e., ionizing radiation) or space debris, the need to provide escape and safe-haven capabilities, and prevention of collision risk. Collision risk may be divided into (1) the risk of collision during proximity operations (i.e., rendezvous and docking) and (2) risk of collision with other space traffic.

#### 11.7.4.1 Environmental Risk: Ionizing Radiation

The Earth's magnetic field traps electrically charged radiation particles in two belts high above the Earth. The highest extends out to about 40,000 km, and the lowest belt begins at about 600 km above the surface. The intensity of radiation in these belts can be more than a million times higher than on the Earth. For several decades to come, commercial orbital human spaceflight will most probably be limited to low Earth orbit flights where the radiation level is small or negligible. Based on the experience of several decades of human spaceflight in low Earth orbit (Vetter et al. 2002), a safe level of radiation exposure has been defined as that which would increase the lifetime risk of cancer by 3 %, and this translates into a total dose of 100–400 rem depending on age and gender (Cucinotta et al. 2011). For comparison, a maximum of 10 rem is the annual dose allowed for workers in occupations involving radiation. Since health risk increases with the total dose, it is important to monitor the dose and to establish norms for the retirement of (commercial) astronauts who reach that level (NRC 2012).

#### 11.7.4.2 Space Safe and Rescue: Past, Present, and Future

The 1912 Titanic disaster, with a distress message telegraphed in Morse code, was a defining moment in starting the organization of search-and-rescue on a global scale. The shock of the disaster led to the establishment of means for constant distress surveillance on land and aboard ships. In 1914 the first International Convention for the Safety of the Life at Sea (SOLAS) made it an obligation for ships to go to the assistance of other vessels in distress. The system developed and matured gradually in the following decades, and in the early 1950s it was extended to aviation, but it was only in 1985 that a well-organized international search-and-rescue (SAR) system came into force under the International Convention on Maritime Search and Rescue of 1979. The current international SAR system is based on close coordination between international maritime and aviation organizations and relies on uniform worldwide coverage and use of global space-based monitoring and tracking resources available on board GEO and LEO spacecraft (COSPAS-SARSAT Programme).

As with any comparable system, the safety of crew and passengers on board future suborbital and orbital commercial space vehicles will not depend only on design adequacy, robustness of construction, and the capability to tolerate failures and environmental risks, but also upon special provisions which would allow escape, search, and timely rescue in case of emergencies. During a suborbital commercial human spaceflight, an emergency may lead to search and rescue operations at sea or on land not dissimilar from those of an aviation accident. The case of an on-orbit emergency is different, and for that special cooperation, provisions and interoperable means need to be developed. Here, the closest parallel is that of submarine emergencies. Many nations now regularly practice multilateral rescue exercises and coordinate their rescue means and capabilities through the International Submarine Escape and Rescue Liaison Office (ISMERLO).

#### 11.7.4.3 Ascent Emergencies

During the ascent phase, a so-called abort scenario needs to be considered in order to safeguard the life of the crew and passengers on board a commercial space vehicle. Such scenarios apply to any type of space vehicle and would require also planning and cooperation with foreign countries.

Taking the experience of the Shuttle program as an example, depending on the time a malfunction would have occurred, there were Shuttle international launch abort sites at Halifax, Stephenville, St. Johns, Gander, and Goose Bay (all in Canada). There were also Shuttle transoceanic abort landing sites (TAL) at Ben Guerir Air Base, Morocco; Yundum International Airport, Banjul, The Gambia; Moron Air Base, Spain; Zaragoza Air Base, Spain; and Istres, France. Finally, there were eighteen designated Shuttle emergency landing sites spread among Germany, Sweden, Turkey, Australia, and Polynesia, several of which are active international airports. For the purpose of providing the Shuttle program with the necessary assistance, access, and dedicated capabilities at those foreign landing sites worldwide, the US government had to negotiate a large number of specific bilateral agreements. In the future, when commercial human suborbital and orbital spaceflights become common, commercial entities will not be able to gain the same level of assistance on land or at sea and access to foreign facilities unless the necessary international civil space agreements and regulations are put in place by some sort of international space regulatory body similar to ICAO for aviation (Jakhu et al. 2011).

#### 11.7.4.4 Crashworthiness

Additionally, from the lessons learned of the Columbia accident and based on the findings of the Columbia Accident Investigation Board (CAIB), tasked by NASA to conduct a thorough review of both the technical and organizational causes of the loss of the Space Shuttle Columbia. The CAIB recommended that future vehicles should incorporate the following: (a) a design analysis for breakup to help guide design toward the most graceful degradation of the integrated vehicle system and structure to maximize crew survival; (b) crashworthy, locatable data recorders for accident/incident flight reconstruction; (c) improvements in seat restraint systems to incorporate the state-of-the art technology to minimize crew injury and maximize crew survival in off-nominal acceleration environments; and (d) advanced crew survival suites (including conformal helmets with head and neck restrain devices similar to the ones used in professional automobile racing) and avoidance of materials with low resistance to chemicals, heat, and flames among others.

#### 11.7.4.5 Orbital Rescue

In 1990, an International Spacecraft Rendezvous and Docking conference was held at the NASA Johnson Space Center. The purpose was to explore the need and international consensus to establish a set of common space systems design and operational standards which would allow docking and on-orbit interoperability in case of emergency. The attributes for such international standards were summarized as follows: (a) each party could implement them with their own systems and resources; (b) cooperation in such standards does not require subordination (i.e., one party does not have to buy parts of the system from another); (c) success of one project or project element is not required to insure success of the other; (d) no one standard requires subordination to another standard; and (e) the functional requirements of the standard can be implemented with a number of alternative technologies. Definition of the standards does not require the transfer of technology.

In 2008, the objective of developing orbital rescue capabilities was restated by the US Congress in the NASA Authorization Act of that year (H.R. 6063). In fact, Sect. 406, EXPLORATION CREW RESCUE, stated that: “In order to maximize the ability to rescue astronauts whose space vehicles have become disabled, the Administrator shall enter into discussions with the appropriate representatives of space-faring nations who have or plan to have crew transportation systems capable of orbital flight or flight beyond low Earth orbit for the purpose of agreeing on a common docking system standard.”

In 2010, the international docking system standard (IDSS), based on the original androgynous docking system (APAS) developed in the seventies as part of the Apollo-Soyuz Project, became finally a reality through the initiative of the countries participating to the International Space Station program. Although China was not involved in such standardization effort, the Chinese had already chosen as docking system for their Shenzhou vehicle and for the Tiangong-1 space station a docking system variant called APAS-89, which is the same used on the International Space Station (ISS) and is compatible with the new international docking standard. The Chinese docking system was successfully demonstrated on-orbit in 2011 with a robotic mission. In 2012 further dockings will be performed by two Shenzhou (9 and 10), both of which will have at least one astronaut on board. Following Tiangong 1, a more advanced space laboratory, dubbed Tiangong 2, will be launched in 2013 followed by Tiangong 3 in 2015.

In the coming years, two space stations will be orbiting Earth, the ISS and the Chinese Tiangong, thus making possible for the first time an orbital rescue system. In 2004, a cooperative program was launched to implement such capability on the model of the International Submarine Escape and Rescue Liaison Office (ISMERLO) to “establish endorsed procedures as the international standard for submarine escape and rescue using consultation and consensus among submarine operating nations.” As for submarines, also in space, the delay between an accident and rescue attempt must be short. Furthermore, the institutionalized contacts and increased transparency engendered by such cooperation orbital rescue would fit with broader trends toward increasing openness and could constitute an important confidence-building mechanism for wider cooperation in making space operations safe and sustainable.

## 11.8 Conclusions

This review has presented a wide variety of space risks. It has explored the safety risks that experienced space organizations and new spacefaring nations are facing. An in-depth understanding of these risks is important to fully comprehend the scope of the safety challenges ahead. Without such an understanding, it will be difficult if not impossible to mitigate them in an effective manner. Both unmanned orbital space systems and crewed vehicles are adversely affected by the growing amount of orbital debris. The cascading effect produced by space objects is a mounting concern. We must seek to minimize the impact of uncontrolled reentering objects that affect the safety of those on land, air, and sea. In addition, the proliferation of new commercial ventures indicates the need to promote space safety in the area of orbital and suborbital tourism and raises the question as how space traffic management might be addressed in future years. The complexity of space safety issues and the scope and nature of future safety challenges may well need to be tackled through an expanded international regulatory framework – one expanded to address the space safety risks that have been described in this chapter.

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# Space Traffic Management

# 12

William Ailor

## Contents

### Abstract

This chapter gives an overview of the evolution of the near-Earth space environment since the beginning of the space age, discusses the current situation, and projects how future developments such as the growing space debris population and active debris removal will affect that environment. Just as the growth in air travel led to air traffic management, assuring that future space systems will have minimal interference to their operations requires a system to warn operators of

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potential collisions and other hazards. The chapter discusses components of a space traffic management system and the corresponding legal and policy framework.

## 12.1 Introduction

Space traffic management is defined here as an organized process that assures the long-term use of space and space assets without harmful interference. Space traffic management includes policies, regulations, services, and information that:

- Minimize the possibility of short- and long-term collisions, radio frequency, or other interference among orbiting objects, both operating satellites and debris
- Assure compliance with rules and regulations imposed by governments and with best practices adopted by launch and satellite operators
- Minimize interference with and by non-satellite operations such as ground-based telescopes and directed energy sources
- Provide warnings to minimize possibilities of loss of operations or other detrimental effects resulting from space weather and other predictable events

This chapter gives background on the rationale for space traffic management, discusses the various components and requirements, and provides a status and possible future directions.

## 12.2 Evolution of a Problem

The first human-made satellite was launched in 1957 by the Soviet Union. At that time, there was no issue with that object colliding with another human-made object (except the very remote possibly that hardware used to loft the satellite onto orbit or released during its deployment might pose a threat). Of course, early satellites were not the most reliable, and many simply died in their mission orbits. Accepted practice was simply to leave hardware in orbit; very little thought was given to the fact that some of these space objects would remain in orbit for hundreds or thousands of years and could one day cause damage to valuable space assets.

On occasion, some satellites and rocket stages exploded, and fragments from these events joined non-exploding, nonfunctional hardware as “space debris” in orbit. As the space age evolved, deployment systems used metal bands that were exploded to release satellites; lens covers were released and floated away; exploding bolts released clouds of small fragments as sensors deployed; experimenters released clouds of “needles” to test communication strategies; and blobs of liquid metal leaked from nuclear reactors that were left in high-altitude orbits for disposal. The “big sky theory” said that the chance of one of these objects colliding with another object or with an operating satellite was vanishingly small – and it was in the early years.

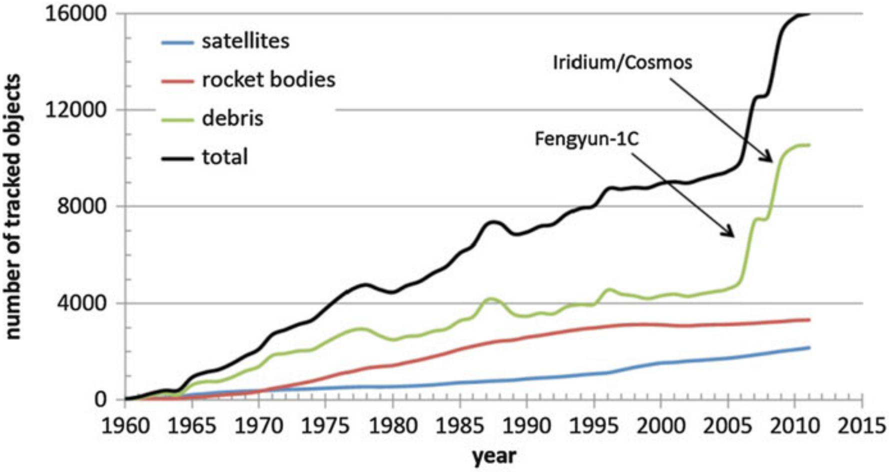


**Fig. 12.1** Number of tracked objects (objects larger than about 10 cm) versus time

As Fig. 12.1 shows, the use of space increased as time progressed, and the number of operating satellites now accounts for about 1,230 of the tracked objects (objects larger than about 10 cm in size) currently in orbit. About 850 of these are in low Earth orbits (LEO), orbits within 2,000 km of Earth's surface, and 320 are in geosynchronous equatorial orbits (GEOs), circular orbits with altitudes of approximately 35,786 km and inclinations near zero degrees. Smaller populations of objects exist in highly elliptical GEO transfer orbits, with apogees approaching geosynchronous altitude and perigees in the LEO region. There are also approximately 60 operating satellites in orbits other than LEO and GEO.

Fortunately, Earth's atmosphere provides a mechanism for removing some objects from orbit. The very small drag force encountered by objects in or passing through the LEO regime gradually lowers their orbits and causes these objects to reenter and "burn up" as aerodynamic heating and loads increase. Note the periodic "dips" in the growth in the number of tracked objects shown in Fig. 12.1. These dips result from the small increase in the atmospheric drag during periods of high solar activity, which result in increased atmospheric density at higher altitudes and therefore earlier reentry. Of course, some fragments survived these reentries, but no injuries are known to have occurred, and probabilities of injuries are extremely low, but not zero – more on this later.

Figure 12.2 shows how the atmosphere affects the lifetime of objects. This figure was developed assuming an average atmosphere and a space object with a ratio of area to mass similar to that for the International Space Station. While the figure shows the orbit lifetime for objects in circular orbits, for objects in elliptical orbits with low-altitude perigees, the small aerodynamic forces during perigee passes will gradually lower the orbit's apogee and cause a relative early reentry. As might be expected, the lifetimes of objects in higher circular orbits (and orbits with higher

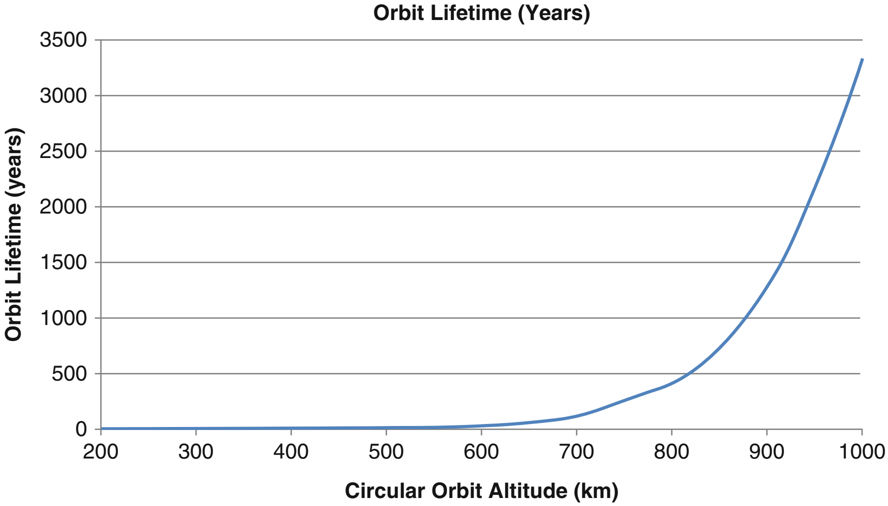


**Fig. 12.2** Variation of satellite lifetime as a function of altitude (assumes circular orbits, average atmosphere, and satellite ballistic coefficient of 150 kg/m$^2$)

perigee altitudes) are substantially longer – debris objects at these altitudes will remain threats to operating satellites for very long times.

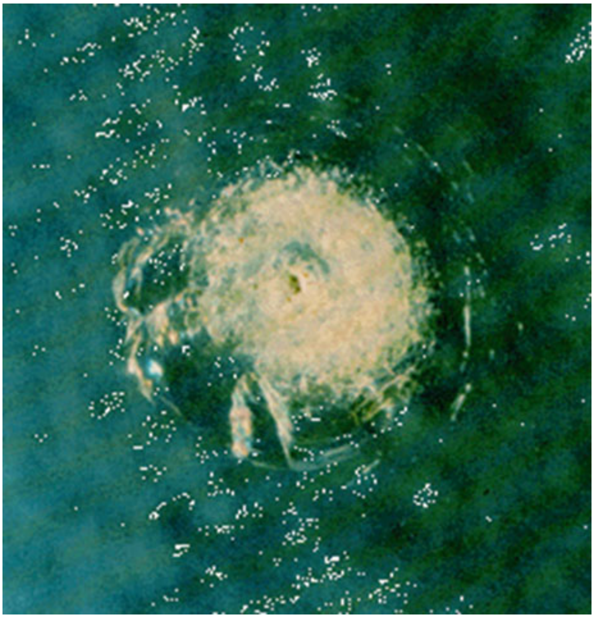
As a result, our first 55 years in space have left our planet surrounded by millions of human-made objects with sizes ranging from tiny flecks of paint to satellites and rocket stages several meters in length. Given this population, the "big sky theory" no longer applies, particularly in the LEO regime, where models predict an increasing frequency of collisions as more objects are added. Events are occurring that support these predictions.

### 12.2.1 Space Object Collisions

The first confirmed accidental collision event was in 1991 when a nonoperational Russian Cosmos navigational satellite collided with debris from a sister Cosmos satellite. The first known collision involving an operational satellite was the collision of Ariane launch stage debris in July 1996 that severed a boom on the French scientific satellite Cerise. Cerise returned to limited service after the collision. Using the best data tracking available at the time, the probability of the Cerise collision was tiny – on the order of 2 in a million (Alby et al. 1997).

Collisions of satellites are bad for two main reasons. First, objects in orbits, particularly in LEO, have orbital velocities in the range of 7–8 km/s, and two approaching objects can be in orbits in different directions, causing the relative velocities at impact to be as high as 10–14 km/s. At these velocities, even a very small object such as a fleck of paint can pit a window (see Fig. 12.3), damage a critical sensor, or affect solar panel performance, and an object as small as 1 cm in

**Fig. 12.3** 4-mm-diameter crater on the windshield of the Space Shuttle orbiter caused by a fleck of white paint approximately 0.2 mm in diameter impacting at a relative velocity of 3–6 km/s (*NASA* photo)



size, the size of a pencil eraser, can terminate operations of a functioning satellite if it strikes a critical area. Secondly, collisions involving both operating satellites and debris release more fragments, increasing the population of orbiting objects and increasing the likelihood of future collisions. Many of these fragments will remain in orbit and pose threats to other satellites for years.

In the late 1970s, concern began to grow that the population of orbiting debris objects would continue to grow to the point where the total population of objects in orbit would reach a tipping point – a point beyond which the population would continue to grow due to collisions among the existing objects even if no new satellites are launched (Kessler and Cour-Palais 1978). It was concluded that some form of space debris mitigation must be initiated before we reached that point.

### 12.2.2 Debris Mitigation Begins

These and other concerns led to the establishment of the Inter-Agency Space Debris Coordination Committee (IADC) in 1993 to coordinate international research into the problem and develop guidelines for space hardware design and operations that would slow the growth of the debris population. Working through the IADC, space agencies have identified the orbital regions shown in Fig. 12.4 as "protected regions," regions that have unique mission-related characteristics and should be protected "with regard to the generation of space debris." These are (1) the low Earth orbit (LEO) region, a spherical region including orbits below 2,000 km in

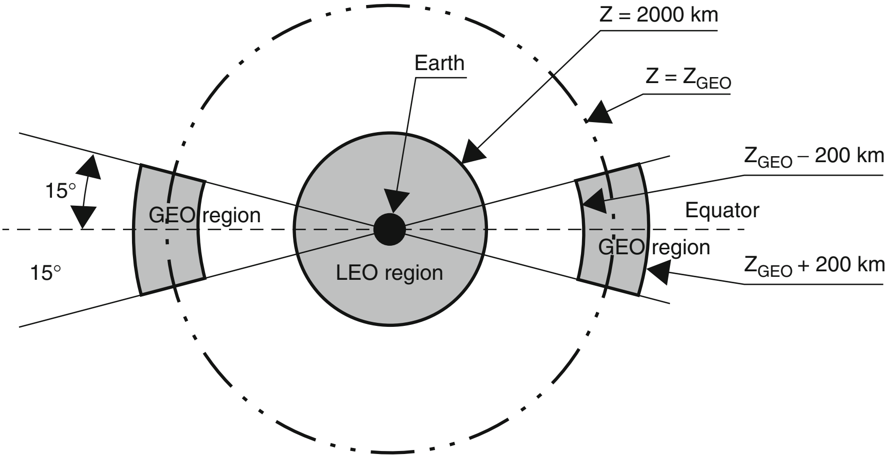


**Fig. 12.4** Protected regions ($Z_{GEO} = 35{,}786$ km)

altitude, and (2) the geosynchronous region, a portion of a spherical shell that includes the altitude of the geostationary Earth orbit, $Z_{GEO}$, 35,786 km.

In addition, the IADC developed the following space debris mitigation guidelines:

1. **Limit debris released during normal operations** by preventing the release of lens covers and other hardware associated with satellite deployment and operations.
2. **Minimize the potential for on-orbit breakups**, either planned or accidental, which will generate long-lived debris. This includes preventing accidental explosions and ruptures during normal operations or at end of mission, as well as planning or conducting intentional destructions that would generate long-lived debris. Spacecraft and orbital launch stages should be passivated (i.e., all sources of stored energy should be depleted) prior to end of life.
3. **Dispose space hardware at the end of its mission.** Typically, this means that satellites and orbital launch stages in or passing through the LEO protected region should either be deorbited into a safe ocean area (controlled reentry – the preferred approach) or, if the casualty expectation for an orbit decay reentry does not exceed a specified limit, moved to an orbit that will naturally decay leading to an uncontrolled reentry within a prescribed time frame (25 years is used in some countries). Note that some nations use a casualty expectation of $1 \times 10^{-4}$ as the limit above which deorbit into a safe area is required. The casualty expectation is the number of injuries or deaths worldwide associated with an object's reentry. Satellites operating in the GEO protected region should be maneuvered at end of mission such that their orbits remain above the GEO protected region for at least 100 years.

4. **Prevent on-orbit collisions.** Designers of spacecraft and orbital launch stages should estimate and limit the probability of collision during the space vehicle's orbital lifetime, and if reliable data is available, operators must maneuver the space vehicle to avoid collisions with known objects. In addition, space vehicle designers should take steps to limit the possibility that impact of small untracked debris will cause loss of control and prevent end-of-mission disposal and passivation.

These guidelines have since been incorporated in government regulations and captured in best practices and international standards (e.g., ISO 24113: Space Systems – Space Debris Mitigation).

### 12.2.3 Collision Avoidance

As humans began visiting and spending significant amounts of time in LEO, safety concerns were raised which led to the development of tools to predict when collisions of other objects with crewed vehicles might be possible. Based on these predictions, the US Space Shuttle was moved several times to avoid collisions, the crew of the Mir space station was ordered to move to their escape pod during close approaches, and more recently the International Space Station (ISS) was maneuvered away from approaching threats. On several occasions, the ISS crew was ordered to move into the crew return vehicles until the collision threat passed.

These close approaches to crewed spacecraft did not go unnoticed by operators of other spacecraft, and in the mid to late 1990s through the early 2000s, two Federally Funded Research and Development Centers (FFRDCs) offered prototype satellite collision avoidance services to commercial and international satellite operators. MIT Lincoln Laboratory provided high-precision services to several operators via Cooperative Research and Development Agreements (CRADAs), and The Aerospace Corporation offered a service combining operator-provided data with publicly available data on tracked objects. The goal of both organizations was to gather information on operator needs for collision avoidance services and to develop recommendations for how the US government might provide such services in the future.

The seriousness of the growing population of orbiting objects was highlighted again in 2007 when China tested an antisatellite capability by striking the Chinese Fengyun-1C polar-orbiting weather satellite operating in an 855 km orbit with an interceptor launched from Earth. This collision added over 3,000 tracked objects to the debris catalog (see the jump in the number of tracked objects at that time in Fig. 12.1) and many of these objects remain in orbit today. Of course, the collision also resulted in a larger number of objects that are hazardous but cannot be tracked due to their small size.

### 12.2.4 First Major Collision

In 2009, a second event occurred that was a game changer: a dead Russian satellite, Cosmos 2251, collided with the operating Iridium 33 satellite at a relative velocity

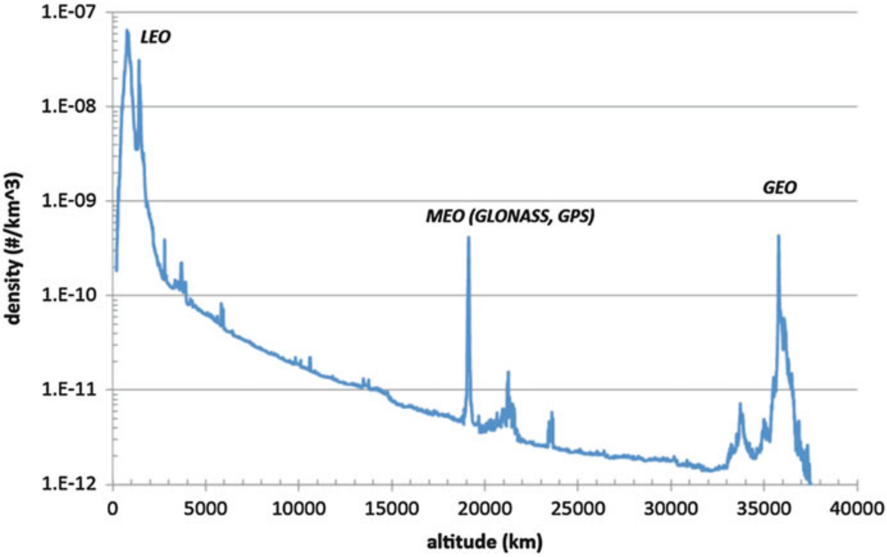


**Fig. 12.5** Number density of tracked objects as a function of altitude. Peaks are in the LEO, Medium Earth Orbit (*MEO*), and GEO regions

exceeding 11 km/s. The collision ended the life of the Iridium 33 satellite and added over 2,000 tracked debris fragments to the catalog of tracked objects. The event likely resulted in the addition of a much larger cloud of smaller objects to the orbiting population. In this case, pre-collision tracking data noted the close approach, but using the best-available tracking data, the probability of the two objects actually colliding was estimated to be in the one in 100,000 range – a risk level where an avoidance maneuver was judged not warranted.

The Iridium-Cosmos collision and the ASAT test alerted space-faring nations that, in addition to creating clouds of debris, collisions could have economic consequences and satellite operators increased requests for collision predictions that were "actionable" – that were accurate enough for threatened satellites to take evasive maneuvers.

### 12.2.5 Effects of Debris on Cost of Operations

A recent study (Ailor 2010; Ailor et al. 2010) describes how the evolving debris environment would affect the costs of space operations over the next 50 years. The study assumed that constellations of satellites are placed in circular orbits at 850 km altitude – the region where, as Figs. 12.5 and 12.6 show, the density of tracked objects (hence the probability that a collision will occur) is the highest. Each constellation was maintained for 20 years after beginning initial operations in 2010, 2020, and 2030. The study looked at the cost of replacing satellites damaged

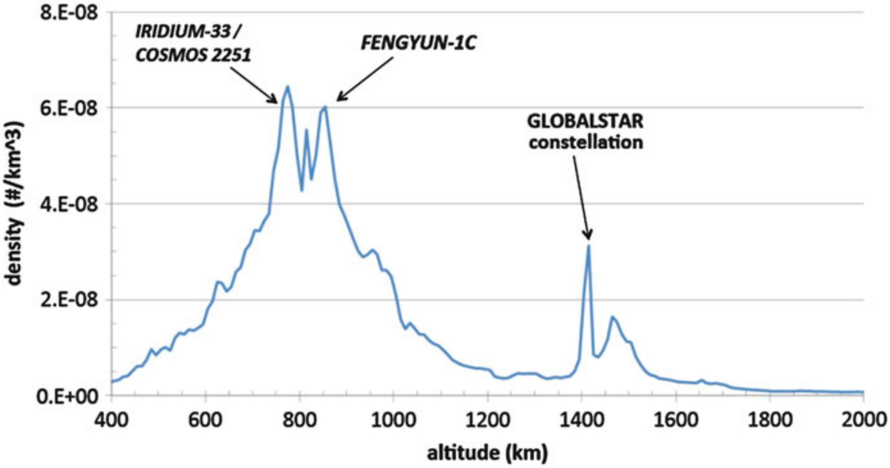


**Fig. 12.6** Number density of tracked objects in the LEO protected region as a function of altitude

by small debris that would "sandblast" solar panels and reduce their power output and by larger debris that might strike a critical component or destroy an entire satellite. The study utilized debris models that projected the current debris environment into the future with satellite launches and collision rates consistent with current predictions.

As might be expected, frequent strikes by small debris led to replacement of the most satellites; collisions with larger tracked objects were much less frequent. As a result, the greatest costs increases, up to 18 % higher than operating in a no-debris environment for satellites launched in 2030, resulted from replacing satellites due to damaged solar panels. Increasing the robustness of solar panels reduced the cost increase to 10 % or less. The study also found that a collision avoidance service would lower the overall cost increases due to the debris environment by approximately 10 % (the service would prevent collisions of satellites in the constellations with other larger tracked objects, but not the smaller untracked objects).

The results noted above show that limiting the growth in the population of very small objects will be important to minimize costs, but operating in the debris environment is manageable for the next half century or so, assuming that the current launch rate continues and that proper end-of-mission disposal becomes accepted practice. But some possible future developments may exacerbate the current situation. For example, small satellites such as nano-satellites or Nanosats (1–10-kg mass) and pico-satellites or Picosats (0.1–1-kg mass) (see Fig. 12.7a, b) are being developed by university and other researchers and carried to orbit as secondary payloads (Janson 2011), hitching rides on launches delivering larger payloads to orbit. While not debris by definition, these objects are relatively inexpensive to build, many can be carried on a single launch, they may not be maneuverable, and most are at the lower bound of our current tracking capability. As a result, they could be a significant collision hazard to other operating satellites.

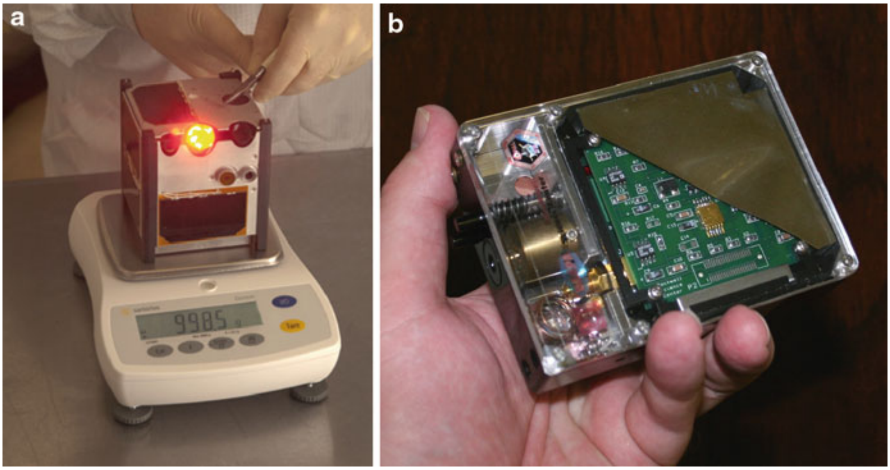


**Fig. 12.7** (**a**) A picosat (**b**) Another picosat (Photos courtesy The Aerospace Corporation)

Figures 12.8a, b show the number of these satellites being launched versus time. There are also proposals (Bekey 2006; Iida and Pelton 2003) for future radar and communications satellite systems in GEOs with arrays of hundreds to a hundred thousand of very small, tethered or untethered Picosats flying in fixed formations that extend 50 km or more. Clearly, proper disposal of these small satellites at end of mission will be critical over the long term, and entities monitoring space traffic and providing space traffic management and collision avoidance services must evolve their tools and capabilities as these types of systems emerge.

### 12.2.6 Other Threats to Normal Operations

Collisions are not the only threats to normal operations of operating satellites. Other threats are:

- Close approaches of satellites are known to have confused sensors that fix satellite orientations, causing loss of communications with ground stations. Since satellites transmit critical data and provide coverage of important events, loss of communications can be a serious problem and can be avoided with sufficient information.
- Radio-frequency interference (RFI) caused by an uncontrolled but broadcasting "zombie" Intelsat Galaxy 15 satellite has caused satellite operators to take evasive measures. Similar to loss of communications, RFI can seriously affect normal operations.
- Impingement of ground-based laser energy can damage sensors (and satellites passing in front of ground-based telescopes can damage telescope sensors, as well).

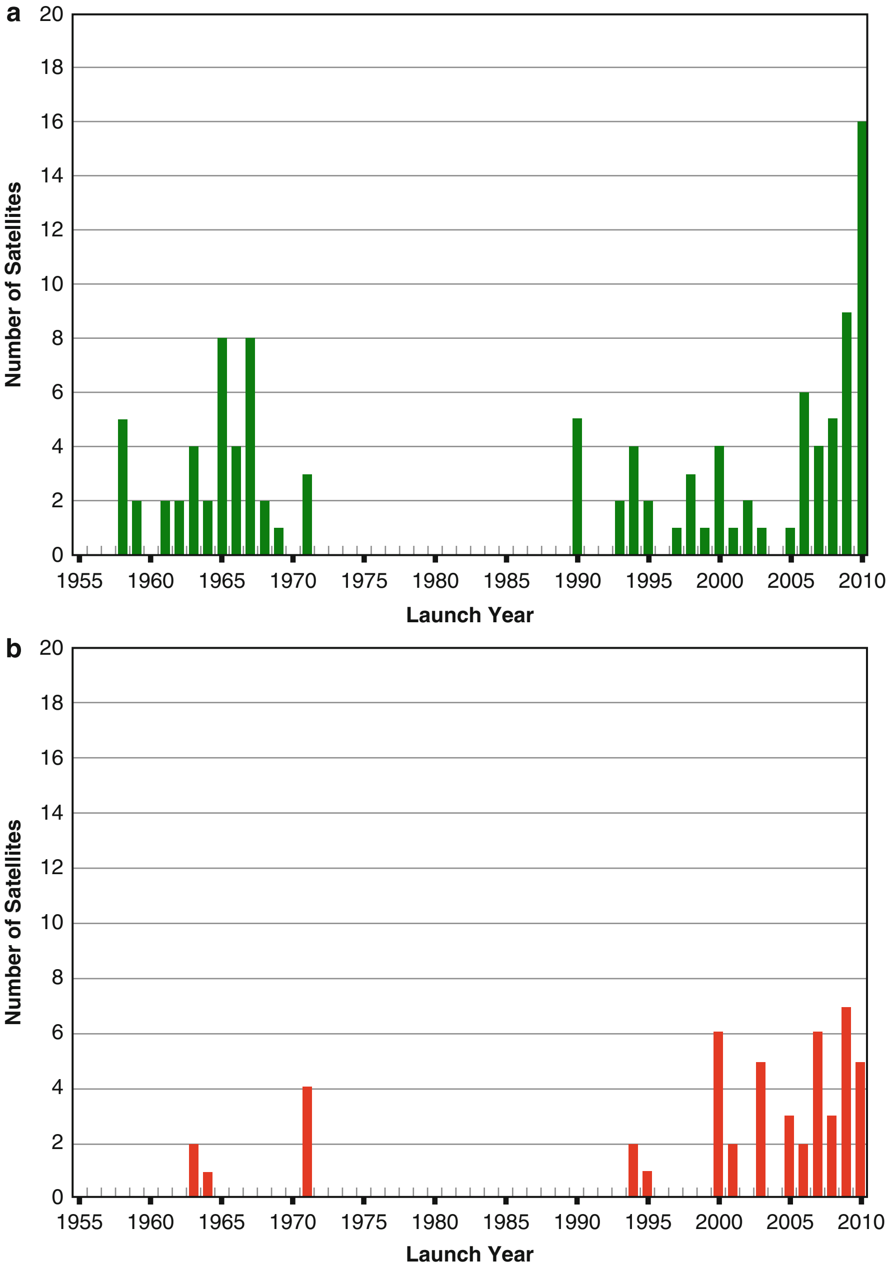


**Fig. 12.8** (**a**) Number of Nanosats launched versus time (**b**) Number of Picosats launched versus time

- Constellations of satellites are planned without regard for the physical presence of other operating satellites in the same vicinity. (There are controls related to limiting the radio-frequency interference of satellites; these controls do not prevent two satellites using non-interfering frequencies from occupying the same physical space.)

Finally, natural space hazard events can also affect normal operations of space systems, and operators can mitigate these effects if provided sufficient, timely information. As an example, in 1999, an event occurred that could have affected many satellites: a yearly passage of Earth through the trail of debris shed in previous passages of comet Tempel-Tuttle. The 1999 passage was predicted to possibly cause a meteor storm on Earth and shower satellites with tiny, fast-moving (70 km/s) comet "dust." During this event, some operators took precautions, including "feathering" solar panels (orienting solar panels parallel to the oncoming meteoroids) and disabling attitude control to prevent activation by electric impulses that might result from impact of high-speed particles. These last actions were in response to a mechanism that might have caused the loss of the European Olympus satellite during the Perseid meteor shower event in 1993, where impact of a micrometeoroid on the satellite's solar panel was suspected of creating charged plasma and a resulting current spike that activated the spacecraft's attitude control jets (Caswell et al. 1995). This action depleted propellant for the attitude control system, making the satellite uncontrollable.

## 12.2.7 The Future

### 12.2.7.1 Active Debris Removal

A recent study predicted that "the debris environment in low Earth orbit (LEO, defined as the region up to 2,000-km altitude) has reached a point where the debris populations will continue to increase even if all future launches are suspended" (Liou et al. 2010). This study shows that active debris removal (ADR) of at least five objects per year combined with implementation of the space debris mitigation measures for new space systems recommended by the IADC will stabilize the LEO environment in the next 200 years. The study suggests that "an effective removal strategy can be developed using a selection criterion based on the mass and collision probability of each object." ADR would likely focus on dead satellites and orbital launch stages in LEO that would be the sources of many additional debris objects in the event of a collision. The study notes that "the fastest debris growth region is between 800 and 1,000 km altitudes, where massive payloads and rocket bodies currently reside, and higher collision probabilities are expected. Even without specifying altitude, the removal criterion based on mass and collision probability effectively reduces the population growth in that critical altitude regime."

ADR designs being proposed include some that might use the force generated by the interaction of Earth's magnetic field with current flowing along long tethers to slowly decrease the altitude of attached debris objects. Other proposals would use

**Fig. 12.9** Reentered debris (Photo courtesy NASA)

lasers to illuminate small debris in LEO to gradually lower their orbits toward reentry or would expel clouds of “dust” or “mist” to intercept and gradually lower small debris objects. At GEO, space tugs are proposed as a means to refuel satellites and to move dead or dying satellites away from the GEO protected region. As is evident, development of these services must be accompanied by the development of policies and regulations that limit the creation of additional debris during grappling and other operations of such devices, plus services that minimize the possibility of interference with operating satellites and collisions with other objects.

Some of these ADR activities, most of which are in very early research and development stages, will challenge services designed to assure that operating satellites avoid collisions with other objects. For example, collision avoidance service providers will need tools and capabilities to predict collisions with tether systems that may be kilometers long and whose orbits will be gradually changing. Predictions will require implementation of new tools plus the ability to incorporate frequent updates on the positions and orbits of the tether systems and on orbiting objects that might be threatened. Long tethers will also be susceptible to breakage if intercepted by space debris, so predicting such interference for tracked debris objects and providing timely and accurate warnings to tether system operators will also be required.

#### 12.2.7.2 Disposal Hazards

One of the first ADR activities may be to move large objects to lower altitudes where the atmosphere will cause their orbits to decay and they will reenter randomly, never to be seen again. Unfortunately, current estimates are that anywhere between 10 % and 40 % of an object’s dry mass (i.e., not including the mass of propellant or pressurized gases) will survive to impact the ground.

Figure 12.9 shows an example of hardware that can survive a reentry. In this case, a 250-kg stainless steel propellant tank that had been part of an orbital launch stage landed 45 m from a Texas farmer’s house after 9 months in orbit. No one was injured in this reentry, and in fact, no injuries or deaths have been reported resulting from space hardware reentries since the beginning of the space age. Should there be an injury or death from such an event, the launching state would be liable according to international space treaties from the 1960s and 1970s. However, if the object had been touched by an ADR entity, the legal community would certainly question whether the ADR entity had the right to interfere with such an object, and the ADR entity might be liable if it interacts with the object – more on this in Sect. 12.4.

As is evident, there are substantial nontechnical issues associated with ownership and liability that must be resolved as ADR concepts move forward.

#### 12.2.7.3 Expanding Services

Future activities that might also emerge and challenge future space traffic management activities include:

- Space-based services such as space tourism and hotels, debris salvage and removal services, asteroid mining services, and possibly orbital "factories" that would use the gravity-free environment for the manufacture of new materials and medicines and shuttle products to and from Earth using small, autonomous vehicles
- Space elevators using cables extending from the Earth's surface to GEO altitudes and beyond
- Tether systems that operate in LEO and GEO regimes
- Constellations of very small satellites for communications and other missions (see Sect. 12.2.5)
- Orbiting objects preserved for historical purposes and as museums

## 12.3 Components of Space Traffic Management

As is evident, human use of space is evolving in similar fashion to human use of resources on Earth: a new resource is discovered, new technologies are developed, there are consequences that were not anticipated, and subsequent management and controls are implemented to assure continued safe use of the resource for future generations. Typically, careful management requires increased focus on the safety of users and the public, cooperative actions among users, and development of appropriate mitigation services, rules, and regulations to minimize hazards. Near-Earth space is such a resource. Over the last 50-plus years, capabilities have evolved that provide the basic foundation for space traffic management services. These basic requirements are discussed below.

### 12.3.1 Knowledge of the Orbital Environment

Similar to information that helps airline pilots avoid adverse weather conditions, providing satellite operators with information that can help them minimize possibilities that space weather (e.g., micrometeoroid storms, solar storms) might cause the loss of a satellite or the loss of a satellite's mission is an important part of an overall space traffic management (STM) system. The STM system would alert satellite operators of natural events that could threaten normal operations.

As has been discussed, human-made objects are becoming a significant part of the orbital environment. Minimizing interference and collisions requires knowledge of where objects are at any given time, where they will be in the future, and some basic characteristics of each object (e.g., is the object an active satellite or space debris). Fortunately, such information exists, with the catalog of space objects maintained by the United States being the most complete. Data from the US Space Surveillance Network is used by the Joint Space Operations Center (JSpOC) located at Vandenberg Air Force Base in California to maintain a catalog of resident space objects. This catalog includes orbits and basic information on objects as small as 10 cm in size in LEO (upgrades are planned that will lower the size limit) and 1 m in size in GEO. A version of this catalog is available to the public via the Space Track website (http://www.space-track.org).

While that catalog is the most complete in the world, it has limitations for certain aspects of STM. In particular, the catalog provides orbit information based on tracking data collected periodically by radar and optical sensors and does not contain position and maneuver information provided by satellite operators (operators have best and most current information on where their satellites are and where they will be in the near future). Thus, satellite maneuvers after the last tracking data were collected are not reflected in the catalog. This information is critical when predicting possible close approaches involving operating satellites. Secondly, the catalog available to the public is not the most accurate, and the software required to propagate the most accurate catalog is also not available. Finally, the catalog available to the public does not contain the total number of tracked objects. Thousands of objects that have not yet been correlated to an owner or event are not included (this is the reason for statements that there are over 20,000 tracked objects, but the number of objects in the public catalog is nearly 16,000, as Fig. 12.1 demonstrates). As a result, even though discovered and tracked, debris from collisions and explosions may not appear in the catalog for weeks or months after the event that created the debris. Needless to say, any service using the publicly available data has limited ability to provide collision avoidance or other interference warning, particularly for objects in the LEO regime where the risk of collision is highest.

In addition to the US Space Surveillance Network (SSN), catalogs have been developed by other nations, by private individuals, and by partnerships that combine data to focus on specific orbital regions. Foremost in this latter group is the International Scientific Optical Network (ISON), which is being organized by the Keldysh Institute of Applied Mathematics (KIAM) of the Russian Academy of Sciences. ISON has established partnership agreements linking 23 observatories in 11 countries operating more than 30 optical instruments (Molotov 2011). Since 2004, ISON has "concentrated on developing and operating the international network of optical instruments capable to search and track faint space debris objects on higher geocentric orbits. The aim is improving our knowledge about pollution of unique regions of the near-Earth space (first of all, GEO) due to launches, on-orbit operations, explosions, deterioration of the spacecraft outer surfaces in time, etc." The network includes subsystems to study bright objects in LEO, HEO, and GEO and maintains a database of space objects.

### 12.3.2 Standard Formats for Data Exchange

A major consideration for developing catalogs of tracked objects is to be able to compare data in each catalog with data for the same object in other catalogs. It also means that data that is shared among satellite operators and with collision avoidance service providers should utilize standard formats. Data is currently exchanged among operators and service providers, and international standards for exchanging some information have been developed (e.g., ISO 26900:2012 (CCSDS 502.0-B-2) CCSDS Orbit Data Messages). Standards will be required that capture rules-of-the-road for satellite maneuvers for avoiding interference, for propagating operational and disposal orbits, for techniques predicting close approaches, and for other features of STM.

### 12.3.3 Best Practices

While services defined above will provide information to operators on possible collisions or other interference, best practices and rules-of-the-road are required to assist operators in deciding who will move, when they will move, and how will they move given a predicted interference involving two operating satellites. In addition, some satellite operations may dictate periodic close approaches or interference with other operators (e.g., overlapping assigned slots at GEO). In these cases, operators may wish to develop cooperative strategies to minimize propellant consumption while satisfying other requirements. Such strategies exist and are in use.

### 12.3.4 Ownership and Operating Characteristics of Spacecraft

The tracking services that develop catalogs of tracked objects, services that predict possible collisions, and governments that want to verify that operators are adhering to operational and disposal requirements need to know who is operating and who is responsible for each satellite, orbital launch stage, and other mission-related hardware in orbit. The object's size and operating characteristics (e.g., station keeping requirements, maneuver and operating characteristics such as ongoing drag compensation and low-thrust orbit transfers, and current status such as operational vs. nonoperational) are important for screening for close approaches. Accurate and current owner and operator information is important for knowing whom to contact in case a problem is detected.

These requirements point to a need for an internationally agreed upon catalog of space objects, possibly maintained by space traffic control service providers, that includes owner, operator, and mission-specific information. Since concerns are increasing about the possibility that a launching satellite might interfere with or impact debris, an operating satellite, or a human-occupied vehicle, there is also a need to know when a launch is planned (specific launch dates and launch windows) and the most current launch profile to be followed. This information, similar to that for an aircraft takeoff and flight plan, can be fed to space traffic control services to assure that interference possibilities with objects already in orbit are minimized. Launch collision avoidance is currently conducted for some high-priority launches.

It should be noted that the International Telecommunication Union (ITU), a United Nations agency that allocates global radio spectrum and satellite orbits, assigns slots in geosynchronous orbits where satellites must operate. Satellite operators are required to register the orbit to be used and specify the broadcast frequency and purpose of the satellite. While these factors limit the number of optimal control slots available in geostationary orbits, the ITU's concern is preventing radio-frequency interference. However, physical interference is still a possibility. The **Cosmic Study on Space Traffic Management** notes that, in general, "the choice of orbits utilized is not regulated by any entity, neither national nor international. The orbits of choice—and the choice of orbits—are determined by the proponents/operators of the satellite system(s)." The reference goes on to state that "Similarly, the number of satellites comprised in any satellite system is the prerogative of the proponents of new systems, and operators of satellite systems already in orbit. Their decisions are based on technical, economic, and political factors, and rarely on legal questions, since there is no world agency that has the authority to limit the number of satellites launched, or the orbits used." Over the long term, foreknowledge of satellite and constellations locations may assist planners in designing orbital systems that minimize interference possibilities.

Once again, agreements at the international level are needed to define what information is appropriate and to specify how, when, and to whom and in what form such information should be provided. Current practices for aircraft flight plan sharing among nations might be appropriate models.

## 12.3.5 Space Traffic Control Service

### 12.3.5.1 Service Requirements

A service is needed that combines data from multiple sources to develop accurate estimates of where all tracked objects will be at future times, that provides warnings to operators of close approaches and other interference events involving close physical approaches, and that can refine the predictions with additional tracking and operator-supplied data. Two services are currently available that provide related services to the general space operations community, but neither is complete and all inclusive in meeting operator needs.

The first is provided by the Joint Space Operations Center (JSpOC). JSpOC services combine US SSN tracking data on all orbiting objects larger than 10 cm in

LEO and 1 m in GEO to develop the most complete and accurate catalog currently available. The JSpOC utilizes that catalog and corresponding orbit propagation software to predict where objects will be in the future and develop information on coming close approaches and can task the SSN to collect updated information to refine close approach predictions. As noted earlier, that catalog does not contain information on satellite positions and planned maneuvers provided by satellite operators. The JSpOC offers a free service for subscribers that does incorporate subscriber inputs to verify satellite maneuvers designed for collision avoidance purposes. When a possible collision is predicted, the JSpOC provides free warnings to any satellite operator, not just to subscribers (Bird 2010).

The JSpOC warning messages are in the form of a Conjunction Summary Message (CSM) that includes detailed information on a coming close approach, including the full details on the close approach, which an operator can then use to estimate the probability of collision. Operators use the probability of collision as a measure of the overall quality of the data being used for the estimate, and some have set thresholds for probability levels where they would request additional data or would begin maneuver planning. Once a maneuver plan is developed, the plan can be sent to the JSpOC for assessment of its effectiveness in reducing the probability of collision and assurance that the maneuver does not significantly increase the probability of colliding with another object.

The JSpOC service is the most complete currently available, but the fact that it does not include operator-supplied data on current location and latest maneuvers for its general collision predictions can lead to inaccurate collision predictions and false alarms. This is one factor that led several commercial operators of satellites in geosynchronous orbits to establish the Space Data Association (SDA), a nonprofit organization headquartered on the Isle of Man. Founded by commercial operators Intelsat, Inmarsat, and SES, the SDA's Space Data Center (SDC) combines operator-supplied data on satellite position and maneuver plans with publicly available data from the JSpOC (not the most accurate catalog) to develop forecasts of close approaches. At present, the SDA/SDC does not have its own sensor network that can be tasked to refine data on debris objects or on satellites operated by entities that are not customers for its service. The SDA/SDC currently provides service to approximately a dozen operators responsible for 237 GEO satellites and 100 satellites in LEO and other orbits. NASA has signed an agreement with the SDA to use the SDA's services.

As stated, current capabilities limit the size of tracked objects (objects with known orbits that can be verified periodically with new tracking data) to approximately 10 cm for LEO objects and 1 m for GEO objects. Catalogs used for collision predictions currently contain on the order of 20,000 of these objects. Once capabilities are available to track and catalog objects smaller than 10 cm, the catalogs could include 100,000 objects or more. Conducting ongoing and timely all-on-all conjunction assessments for this number of objects will require substantial upgrades in computers, in software, and eventually in sensor systems. In addition, many more close approaches of debris objects to operating satellites are likely to be predicted. More predictions mean increasing the load on the JSpOC and other services for detailed assessments of each predicted close approach and point to the need for more accurate initial predictions to avoid unnecessary satellite maneuvers and avoid overloading these services.

Since this service would be in frequent contact with satellite operators, it might also coordinate with appropriate agencies to provide alerts and warnings of other events, including:

- Possible radio-frequency interference due to satellites that may be passing within an operator's sphere of influence
- Existing or planned physical presence of other satellites in nearby orbital regions that may pose threats to normal operations during the lifetime of the operator's satellite or constellation
- Space weather events that may require operator actions to prevent anomalies
- Satellites with periodic close approaches, enabling operators to develop cooperative approaches for minimizing interference

The service might also maintain contact information on other operators to enable development of cooperative maneuver strategies that minimize interference possibilities over the long term.

#### 12.3.5.2 Government Information Requirements

While satellite operators clearly need STM services, governments are also major players in space and have information requirements for the following reasons:

- Governments operate lots of satellites, some of which, based on national security concerns, are not included in publicly available catalogs and may not be available to STM service providers. Thus, protecting these satellites and all satellites from interference requires that governments have access to as much information as possible on other operating satellites, including the best information on satellite positions and planned maneuvers from satellite operators. This is an important consideration as STM services evolve.
- Governments (in the United States via government agencies such as the Federal Aviation Administration and the Federal Communications Commission) and organizations such as the ITU impose requirements on locations where and how satellites may operate and on operations and disposal to limit generation of space debris and require information to be sure satellites are operated in accordance with those regulations and agreements.

Lastly, there will likely be increased presence of humans in space, both as passengers on space transportation systems traveling to and from space and possibly as guests at orbital hotels. Demands for protection of these individuals from hazards during launch and reentry, as well as in space, will increase pressure for an STM system that is closely coordinated with the existing air traffic management system.

All of these factors must be considered when defining and developing a comprehensive STM system.

## 12.3.6 Focus on Safety

### 12.3.6.1 Reentry Events

A space traffic control service would help assure that humans in space are protected from approaching debris, but reentering debris can injure humans on the ground, in ships, and in aircraft. As noted earlier, current guidelines dictate that space systems that reenter randomly must have a casualty expectation for people on the ground less than some prescribed value ($1 \times 10^{-4}$ in the United States), and adherence to this guideline will help minimize this risk. But what is the risk for people in aircraft? The annual worldwide risk of a commercial aircraft being struck with a piece of reentering space debris is on the order of $3 \times 10^{-4}$ (Patera 2008). While this risk is very low, the risk to aircraft from a random reentry is "above the long term acceptable risk *for a flight exposed to such a risk* [italics used in the reference], but below the short term acceptable risk based on risk acceptability guidelines used by the FAA for other types of threats" (Ailor and Wilde 2008). The associated mean time between occurrences of a worldwide accident is about 3,300 years, and to date, there have been no proven cases where an aircraft has been struck by a fragment from a reentering object. For comparison, the likelihood of a meteor striking an aircraft is between $1.3 \times 10^{-5}$ and $1.7 \times 10^{-5}$ (Patera 2008).

The goal is for all hardware with debris that would survive a reentry and pose a serious threat to humans to be purposefully deorbited into safe ocean areas. Notices could then direct ships and aircraft away from these areas when the hazard was expected. Hardware from past launches will continue to reenter and it is possible that some ADR services will be unable to control the reentry location of debris, so there will continue to be large objects entering each year. Ideally, an STM service would be able to warn aircraft away from areas where debris is falling from uncontrolled reentries of large debris objects.

### 12.3.6.2 Air/Space Boundary

While previous discussions have centered on the vulnerabilities in the vacuum of space, with increasing frequency emerging space transportation systems using reusable vehicles, some with humans aboard will cross the air/space boundary and utilize spaceports for landings and takeoffs. For a portion of their flights, these new systems will share airspace with aircraft, whose flight rules have evolved based on a different set of flight characteristics.

Near the end of World War II, the International Civil Aviation Organization (ICAO) developed the ground rules for regulating air traffic and established the basic principle that each nation controls its own airspace. No such basic principle is possible for space, since a single spacecraft passes over many countries in a single orbit and may pass over many different countries in the next orbit or during reentry. In addition, while an aircraft accident might have primary effects only within single country's geographic area, a space accident such as a collision or explosion affects essentially all operating satellites in a similar orbit regime. Thus, it is clear that "safe" space operations are a global issue.

An object in orbit will pass over all areas within the latitude bounds of the object's orbit. This means that just as each nation is responsible for objects launched within its boundaries and traversing its airspace on its way to space, so might each nation be responsible for vehicles returning from space and landing within its borders. A complication is that, similar to the US Space Shuttle, reentry trajectories from orbit can cover thousands of kilometers, and for some nations, significant portions of each reentry trajectory would be within, or perhaps above, another nation's airspace. During these periods, an accident similar to that experienced by the Space Shuttle Columbia would rain debris over another nation's airspace and potentially cause damage to aircraft and injuries on the ground.

It is clear that new rules, regulations, and tools will be required to assure safety of flight for these new systems and for aircraft as these new capabilities evolve. Potentially, the air traffic control system may need to have regular updates from the STM service on when and where a space vehicle will launch or reenter and also add tools to predict hazard areas and issue warnings to aircraft below should there be an accident during reentry.

## 12.4 Legal and Policy Framework

Much of this chapter has discussed the technical background for the current situation in space, but as is evident, there are important nontechnical steps that are required to build an effective STM. Some of these are:

1. **Notification system and data exchange standards.** Similar to protocols for air traffic control, organizations responsible for tracking and minimizing interference involving orbital objects must be notified of planned launches, satellite orbits and maneuvers, reentries (both planned and random), and other activities that might cause interference both during the planning stages and during satellite operations and disposal. Internationally accepted standards specifying formats and protocols for data exchange should be utilized where available or developed as needed.
2. **Framework for handling and protecting resident space object data.** As has been stated, accurate data on where satellites are and will be over the next few days, plus data on planned launches and deorbits of hardware, are essential elements of an effective STM. The best data are owned by governments, satellite operators, and launch service providers; each must be satisfied that its data will be protected and used only in ways it prescribes. These entities would also need to protect space objects for which they are not willing to share data.

   This suggests that an internationally accepted "clearinghouse" might be needed that can accept data from satellite operators and both government and private tracking services. Participating entities will need to agree on and have oversight of how the data are protected, shared, and utilized. By agreement of the data providers, the clearinghouse could be authorized to provide the complete catalog of tracked objects, or subsets of that catalog, to approved entities (one of these entities might be a service that provides ongoing collision and interference warnings to satellite operators). A legal and policy framework that encourages operators and governments to share appropriate data (utilizing accepted formats as noted earlier) is essential for the evolution of space situational awareness services.

3. **Addressing liability.** "We don't want to tell a satellite operator to move," a statement heard in discussions of conjunction services, reflects the concern that if the operator takes action (or does not take action) given information by the service provider and for whatever reason there is a collision, the service provider will be judged to be at least partially at fault. This discussion is made more difficult given the uncertainties associated with the data used. Collision predictions are probabilistic in nature, and it is virtually impossible to say with complete certainty that a close approach will or will not lead to a collision. It is likely that at least in some cases, satellite moves will be sized to lower the probability of collision to below an acceptable level, but perhaps not to zero. Thus, a small probability of impact will remain. Ideally, a service provider will be established that is sanctioned and protected from liability by governments, able to enter into contractual agreements with space operators and launch providers to protect data, and operate in a manner in which all parties are satisfied.

   Liability will also be an issue for ADR services. The 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty), provides that a space object (operating satellite, launch stage, or debris) remains the property of the launching authority for as long as it is registered with/by the launching authority. The launching authority is responsible for damages caused by the space object. As a result, the launching authority would need to give permission (or transfer ownership) and transfer liability before a space object such as a dead satellite or rocket stage could be touched or otherwise interfered with by an entity wishing to remove the object from a protected region in space. Formal agreements could be developed that deal with these issues and also incentivize the testing and operations of systems designed to actively remove space debris. A way forward might be for one nation to identify a set of representative debris objects (e.g., a launch stage and dead satellites with and without extended solar panels) for which it is the launching state and develop the legal framework to support ADR proposals for these objects as a way to encourage private industry to develop and test disposal options.

4. **Internationally accepted space traffic control service provider.** The goal is to have a service to warn satellite operators of coming hazards that is available to all satellite operators, that uses the best data available, that is reliable, that provides timely warnings, that is responsive to operator needs, and that protects sensitive data. An AIAA workshop in 1999 concluded that there is a need for "an internationally recognized entity" to provide these services.

   A government agency such as the JSpOC discussed earlier could take this responsibility, but this approach may not be optimal from the perspective of international operators (Ailor 2002). For example, given that effective space traffic control is a global issue, one option is for all satellite operators, government and nongovernment, to provide satellite maneuver plans and other sensitive or proprietary information to an agency of the United States or other government, and the agency would be required to guarantee data protection and a level of service no matter the political climate. It is not clear that operators and governments will be willing to participate in such a service if they have no direct control over the service itself.

A second option is that a for-profit company might offer a service of this type. For-profit companies are in business to make money, have obligations to boards of directors and stockholders, and can be bought by other companies. Some of these features might again make it unattractive for satellite operators to provide the sensitive, proprietary data required for these services or to become dependent on a single company with a profit motive. There is also the potential risk of lawsuits should there be an unpredicted collision or other event, which might make for-profit companies reluctant to step into this area.

As a third option, a nonprofit organization might be a solution. According to Wikipedia (http://en.wikipedia.org/wiki/Non-profit_organization), “a non-profit organization (abbreviated “NPO”, also “not-for-profit”) is a legally constituted organization whose objective is to support or engage in activities of public or private interest without any commercial or monetary profit.” Continuing, “The extent to which [a NPO] can generate income may be constrained in amount, methods or both, and the use of those profits may be restricted not only in purpose but in proportions regarding self-maintenance and achievement of purpose. NPOs therefore are typically funded by donations from the private, public sector, or both, as well as from program service fees.” Since governments and satellite operators are key stakeholders, the NPO could be run by a board of directors made up of representatives of governments as well as private satellite operators (Ailor 2008). The board would assure that the services offered, data provided to governments, prices for services, data privacy and security, etc., meet the needs of both satellite operators and governments. Board members from governments could also work to bring appropriate tracking data to the nonprofit and assure that the data is protected. The nonprofit could also define relationships with satellite operators by contract, customizing services to operator needs and guaranteeing a level of service. Potential liability could be limited by contract or other means.

As noted earlier, a nonprofit organization that meets some of these requirements has been established. The Space Data Association (SDA) was established by three commercial satellite operators – Intelsat, SES, and Inmarsat – and incorporated on the Isle of Man as a nonprofit corporation. At present, no government has direct oversight of this organization. While SDA’s Space Data Center (SDC) does receive position and maneuver data from operators of the satellites for which it provides services, it does not have access to the best tracking data available on other objects, including space debris. As stated earlier, the most complete tracking data is maintained by government organizations.

Policy questions that must be addressed include the following: Will a service provided by an agency of a single government be accepted as the preferred service provider for international satellite operators for the long term? Is there confidence that such a service would be open to all nations, friend, and foe and that the service would be available no matter the world's political situation? Will a nongovernment nonprofit service, such as the SDA/SDC, be accepted as the long-term provider of these services? Will an outside service have access to a sensor network or be able to request a government to task sensors to refine predictions for specific events? Are there other possibilities? Decisions and agreements need to be made at the international level to build a structure and organization for the long term.

## 12.5 Conclusions

An effective space traffic management system is necessary for the long-term sustainability of space activities and to assure the safety of both humans in space, in aircraft, and on the ground. Such a system should include:

- Collection and utilization of the most accurate data available on satellites, their orbits, and their maneuver plans
- An internationally accepted space traffic control service available to all users of space that warns satellite operators and launch service providers of collisions and other predictable hazards that might affect their operations
- A space traffic management service that provides governments and regulatory agencies information they need to assure that satellites are operated and disposed in accordance with approved plans
- Integration into the air traffic management system of some information on space systems that will be transiting above and reentering airspace
- A service that maintains accurate and current information on satellite owners and operators, future launches and launch profiles, and emerging plans for new satellite systems and constellations
- Policies and procedures that protect the safety of humans in space, on the ground, and in the air
- Development of best practices and international standards for hardware and space operations that mitigate hazards and minimize the creation of new space debris
- Development of a legal and policy framework and implementation infrastructure that encourages exchange of necessary data, addresses ownership and liability related to space debris objects, and incentivizes the evolution of active debris removal technologies

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Treaty on principles governing the activities of states in the exploration and use of outer space, including the Moon and other celestial bodies (Outer Space Treaty, OST) of 1967

# Space Sustainability

# 13

Peter Martinez

## Contents

### Abstract

Space sustainability is a concept that has emerged within the past 10 years to refer to a set of concerns relating to outer space as an environment for carrying out space activities safely and without interference and also to concerns about ensuring continuity of the benefits derived on Earth from space activities. As such, it encompasses the concerns of both space actors and those who are not

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space actors but who nevertheless benefit from space activities. This chapter reviews the role of the various relevant United Nations entities in ensuring space sustainability and provides a detailed review of the Working Group on the Long-Term Sustainability of Outer Space Activities within the Scientific and Technical Subcommittee of COPUOS. Finally, the chapter discusses the relationship of the work in UN COPUOS with related work being done in the Conference on Disarmament, the UN Group of Governmental Experts (GGE) on Transparency and Confidence-Building Measures in Outer Space Activities, and the initiative by the European Union to propose a draft international Code of Conduct for outer space activities.

## 13.1 Introduction

The terms *space security* and *space sustainability* are sometimes used interchangeably to encompass a set of largely overlapping concerns as seen from two somewhat different perspectives. Underlying both of these perspectives is the acknowledgement that space systems underpin the modern information society and now form part of the critical infrastructure of most nations, whether they are spacefaring or not, and that this infrastructure is exposed to a series of risks of natural and anthropogenic origin. Regardless of the perspective from which one sees the problem, the point is that coordinated global action will be required to address these concerns. Acknowledging and addressing these perspectives is one of the challenges that will be faced by multilateral initiatives to promote either space security or space sustainability. Hence, it is instructive in the context of this chapter on space sustainability in a book devoted to space security to elaborate on this issue of the two perspectives.

### 13.1.1 Space Security

*Security* is, in general terms, about being free from danger or threat. In practical terms, this means freedom from doubt, anxiety, or fear based on well-founded confidence that there are mechanisms and processes in place to ensure security as a condition.

However, attempts to pin down exactly what is encompassed by the word *security* prove to be elusive as there is no single universally accepted definition of the concept of "security." In some countries the understanding of the term encompasses human security, environmental security, food security, and so on, while in others the term has a narrower meaning, referring primarily to military- and defense-related issues.

*Space security* is a term that is used among space actors to refer to preserving the safety of the space environment, for space actors, so that they may continue to use outer space for their purposes. Much of the dialogue in this context is concerned with preserving order, predictability, and safety in space and avoiding courses of action that would ultimately undermine freedom of action in outer space. Another key dimension of this dialogue is the notion that, because of growing reliance on space systems in every facet of modern life, security on Earth (regardless of how one defines it) is increasingly underpinned by security in outer space. Hence, one of the key aims of the space security dialogue is to ensure freedom from threats (either ground-based or space-based) to the effective access to and utilization of outer space. For some actors this is closely coupled to concerns about the potential weaponization of outer space, although it is difficult to progress beyond a general acknowledgement of the potential problem to practical measures to avoid it because of disagreements around the definition of what constitutes a space weapon.

The main point of this is that, for those sitting on the sidelines of the debate, space security is sometimes perceived to be predominantly the preoccupation of the advanced space actors and thus far removed from the day-to-day concerns of the non-space nations. However, others (particularly emerging or aspiring space nations) may see the promotion of multilateral space security discussions as an attempt by the leading space actors to advance and preserve their national space interests while erecting entry barriers to aspiring newcomers on the pretext that the space environment is already "saturated" with actors. Neither of these perceptions helps to build multilateral consensus on normative rules of behavior for all space actors.

### 13.1.2 Space Sustainability

The word *sustainability* is derived from the Latin verb *sustinere* (*tenere*, "to hold"; *sus*, "up") and is usually used in the context of being able to maintain an activity at a certain rate or level. Since the 1980s the concept of sustainability has been applied to human habitation and utilization of planet Earth and its resources. This has given rise to the widely used term *sustainable development*. This term was coined in the paper "Our Common Future," published by the Brundtlandt Commission in 1987 (Report of the World Commission on Environment and Development). The definition for sustainable development given in that paper is worth quoting here:

> development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Notice the emphasis on "needs" in this definition. The Brundtlandt Commission's report placed emphasis in particular on the essential needs of the world's poor.

The connection of *sustainability* with *outer space* arises from the perspective that space systems are now major global utilities that meet various societal needs. When seen in this light, *space sustainability* is about using outer space in such a way that all humanity will be able to continue to use it in the future for peaceful purposes and for societal benefit. The sustainability concern here is driven by the realization that the Earth's orbital environment and the electromagnetic spectrum are limited natural resources. This realization leads naturally to a concern for how to ensure that the benefits of space will continue to be accessible to future generations and to all nations and raises issues about equitable and responsible access to and use of space resources.

In other words, from this perspective, space sustainability is seen in the context of wider sustainability discussions and is perceived to be the concern of all beneficiaries of space activities. It is thus an intrinsically multilateral issue. This is a significantly and fundamentally different point of departure for addressing a very similar set of issues driving the space security discourse.

## 13.2 The United Nations and Space Sustainability

The space arena today encompasses a much larger and much more diverse group of space actors than was the case in the first few decades of the space age. These include the “traditional” space actors, such as national space agencies and other national civilian agencies and the military, and a growing number of non-State actors, such as private sector commercial entities, academic and research institutions, and civil society organizations. Since the actions of a single actor can have consequences for all other actors, no single country (or even a group of countries) can control the space environment by its behavior or by its power alone; collective multilateral action is required.

In terms of international space law, States bear international responsibility for all space activities, including the activities of non-State entities (Outer Space Treaty 1967). Hence, in spite of the growing number of non-State actors, the United Nations as a forum for States remains the relevant forum to discuss such issues.[1]

### 13.2.1 Space in the UN System

At present, there are five principal fora at which space issues are discussed multilaterally in the UN system: the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) in Vienna, the Conference on Disarmament (CD) in Geneva, the UN General Assembly in New York (and two of its committees, the Disarmament and International Security Committee (4th Committee) and the Special Political and Decolonization Committee (1st Committee[2]), the UNESCO in Paris, and the ITU in Geneva, which deals with spectrum and geostationary orbital slot assignments. In addition to these, the World Meteorological Organization in Geneva makes use of space systems for monitoring and predicting terrestrial weather and also supports

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[1] Notwithstanding the preeminent role of States in the legal framework of outer space activities, it is worth reflecting on the contribution of civil society to the discussion on space sustainability, since this sector is playing an increasingly prominent and catalytic role in space activities and is in some respects more responsive to the rapidly changing space arena than the “traditional” fora established by States. This sector also has access to a great deal of expertise, particularly in the conduct of space operations.

[2] It may be observed that this de-linking of disarmament issues and other space issues results in a “silo” approach to space issues in the UN).

international coordination of space weather activities, an area of growing importance since space weather affects all space systems.

Space is widely used in the UN system and its entities. Each year approximately 25 UN entities and specialized agencies hold the United Nations Inter-Agency Meeting on Outer Space Activities. They discuss matters of mutual interest in the applications of space technologies to address human needs. Considerations include the implementation of the recommendations of the UNISPACE conferences and space-based contributions of United Nations entities to the achievement of the Millennium Development Goals as well as to the implementation of the recommendations of various World Summits. The meeting issues a report on its deliberations for the consideration of COPUOS.

### 13.2.2 The United Nations Committee on the Peaceful Uses of Outer Space

The United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) is the principal international forum for the development and codification of laws and principles governing activities in outer space. It is a standing committee of the UN, established in 1959 by 24 Member States and given its mandate in UN General Assembly resolution 1472 (XIV). The committee currently comprises 71 Member States and a large number of permanent observers that enrich its work. The technical work of COPUOS is carried out by two subcommittees, the Legal Subcommittee (LSC) and the Scientific and Technical Subcommittee (STSC). Decisions in COPUOS and its subcommittees are reached by consensus. The Secretariat of COPUOS is the UN Office for Outer Space Affairs, which is situated at the United Nations Office in Vienna.

#### 13.2.2.1 What COPUOS Has Done for Space Sustainability?

During the 53 years of its existence, the deliberations in COPUOS have resulted in a number of very positive developments to advance international cooperation in the peaceful uses of outer space. A full discussion of all the activities and outcomes of COPUOS is outside the scope of this chapter, but it may be found in the paper by Hedman and Balogh (2009). Here we focus on the aspects of COPUOS pertaining specifically to the long-term sustainability of outer space activities.

#### 13.2.2.2 The International Legal Framework for Space Activities

COPUOS is the only international forum for the development and codification of international space law. Since its inception, the committee has concluded five international treaties and five sets of legal principles governing space-related activities. The five treaties[3] are:

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[3] The full texts of these treaties are available on the UN OOSA website at http://www.oosa.unvienna.org/oosa/en/SpaceLaw/treaties.html

- *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* (known as the "Outer Space Treaty"), adopted by the General Assembly in its resolution 2222 (XXI), opened for signature on 27 January 1967, and entered into force on 10 October 1967
- *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space* (known as the "Rescue Agreement"), adopted by the General Assembly in its resolution 2345 (XXII), opened for signature on 22 April 1968, and entered into force on 3 December 1968
- *Convention on International Liability for Damage Caused by Space Objects* (known as the "Liability Convention"), adopted by the General Assembly in its resolution 2777 (XXVI), opened for signature on 29 March 1972, and entered into force on 1 September 1972
- *Convention on Registration of Objects Launched into Outer Space* (known as the "Registration Convention"), adopted by the General Assembly in its resolution 3235 (XXIX), opened for signature on 14 January 1975, and entered into force on 15 September 1976
- *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies* (known as the "Moon Agreement"), adopted by the General Assembly in its resolution 34/68, opened for signature on 18 December 1979, and entered into force on 11 July 1984

The 1967 Outer Space Treaty laid the general legal foundation for the peaceful uses of outer space and provided a framework for developing the law of outer space. The four other treaties deal more specifically with certain concepts included in the Outer Space Treaty.

It is instructive to review some of the principles in these treaties that provide the legal context for space sustainability and space security. These include the non-appropriation of outer space by any country; the freedom of exploration, scientific investigation, and the exploitation of natural resources in outer space; State liability for damage caused by space objects; the prevention of harmful interference with space activities and the environment; the sharing of information on space activities; and the registration of space objects.

The treaties affirm the agreement of States that the domain of outer space is a res communes and that the activities carried out therein and the benefits arising there from should be devoted to enhancing the well-being of all countries and humankind. Article I of the Outer Space Treaty is of particular relevance to the space sustainability discussion:

> The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.
>
> Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies.

> There shall be freedom of scientific investigation in outer space, including the Moon and other celestial bodies, and States shall facilitate and encourage international cooperation in such investigation.

These principles provide the reference point for many delegations in COPUOS against which they will judge the relevance and legitimacy of the space sustainability discourse and its outcome.

In addition to the codification of these Treaties and Principles, progress has also been made in developing a common understanding on other issues. All in all, 114 UN General Assembly resolutions or recommendations relating to outer space have been adopted from 1958 to 2012.[4] For instance, a set of voluntary Space Debris Mitigation Guidelines was adopted in 2007. A Safety Framework for Nuclear Power Source Applications in Outer Space is under development jointly by the Scientific and Technical Subcommittee of COPUOS and the International Atomic Energy Agency.

The UN also maintains a Register of Space Objects that contains information provided by Member States and intergovernmental organizations that are party to the Registration Convention.[5] As of 1 January 2011, 56 States had acceded to or ratified the Convention and four others had signed it.

## 13.3 COPUOS and Space Sustainability

### 13.3.1 Sustainability of Space Activities on the COPUOS Agenda

Although several aspects of the work of COPUOS are directly relevant to space sustainability, prior to 2010 these topics were being addressed in isolation; the emergence of a more holistic view of these issues goes back to 2005, as the committee was approaching its fiftieth year. In that year Karl Deutsch (Chair of the STSC from 2001 to 2003) presented a discussion paper to the committee on the future role of COPUOS in its next 50 years. Deutsch made the connection between the sustainability of life on Earth and the full cooperative, international use of space systems, the very subject COPUOS was established to address.

In 2006–2007, the committee was chaired by Gérard Brachet. He highlighted the issue of space sustainability during his term as Chairman of COPUOS. At the 50th session of the committee in 2007, Brachet presented a Working Paper by the Chair[6] that identified the long-term sustainability of outer space activities as one of the key challenges facing the future peaceful uses of outer space. The Working Paper

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[4] The full text of all these resolutions is available online in the six official languages of the UN at http://www.oosa.unvienna.org/oosa/en/SpaceLaw/gares/index.html

[5] The UN Register of Space Objects is accessible online at http://www.unoosa.org/oosa/en/SORegister/index.html

[6] COPUOS document A/AC.105/L.268 available at http://www.unoosa.org/oosa/en/COPUOS/ac105l.html

further suggested that a working group could be established within the Scientific and Technical Subcommittee to produce a technical assessment of the situation and to suggest a way forward.

In 2008, the Scientific and Technical Subcommittee and the Committee discussed the introduction of an agenda item dealing with the long-term sustainability of outer space activities and what such an agenda item could encompass. Subsequently, in 2009, at the 46th session of the Scientific and Technical Subcommittee, a proposal was put forward by the delegation of France to include a new agenda item on the long-term sustainability of outer space activities on the agenda of the Scientific and Technical Subcommittee.

At its 52nd session in 2009, the Committee agreed that the Scientific and Technical Subcommittee (STSC) should include, starting from its 47th session in 2010, a new agenda item titled long-term sustainability of outer space activities and it proposed a multiyear work plan that was to culminate in a report on the long-term sustainability of outer space activities and a set of best-practice guidelines for presentation to and review by the Committee.

In 2010 the STSC established the Working Group on the Long-Term Sustainability of Outer Space Activities under the chairmanship of Peter Martinez of South Africa. The first issue to be addressed was reaching agreement on the terms of reference, scope, and methods of work. These deliberations were concluded at the 54th session of COPUOS in June 2011.

This is a very condensed review of the emergence of the long-term space sustainability work in COPUOS. Readers interested in a more detailed review are referred to the paper by Brachet (2012).

### 13.3.2 COPUOS Working Group on Long-Term Sustainability of Outer Space Activities

The terms of reference for this Working Group[7] mandate it to examine the long-term sustainability of outer space activities in the wider context of sustainable development on Earth, including the contribution of space activities to the achievement of the Millennium Development Goals, taking into account the concerns and interests of all countries.

The Working Group is tasked to consider current practices, operating procedures, technical standards, and policies associated with the long-term sustainability of outer space activities throughout all the phases of a mission life cycle. The Working Group is taking as its legal framework the existing United Nations treaties and principles governing the activities of States in the exploration and use of outer space; it is not considering the development of new legal instruments.

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[7] Report of the Committee on the Peaceful Uses of Outer Space, fifty-fourth session (1–10 June 2011), UN General Assembly document A/66/20, Annex II.

The main outputs of the Working Group will be a report on the long-term sustainability of outer space activities and a consolidated set of voluntary best practice guidelines that could be applied by States, international organizations, national nongovernmental organizations, and private sector entities to enhance the long-term sustainability of outer space activities for all space actors and for all beneficiaries of space activities.

It is instructive to quote from the terms of reference the expected character of the guidelines to be produced. These guidelines should:

> (a) Create a framework for possible development and enhancement of national and international practices pertaining to enhancing the long-term sustainability of outer space activities, including, inter alia, the improvement of the safety of space operations and the protection of the *space environment*, giving consideration to acceptable and reasonable financial and other connotations and taking into account the needs and interests of developing countries;
> (b) Be consistent with existing international legal frameworks for outer space activities and should be voluntary and not be legally binding;
> (c) Be consistent with the relevant activities and recommendations of the Committee and its Subcommittees, as well as of other working groups thereof, United Nations intergovernmental organizations and bodies and the Inter-Agency Space Debris Coordination Committee and other relevant international organizations, taking into account their status and competence.

In developing its terms of reference, the Working Group identified a wide range of topics of relevance to the overall considerations of space sustainability, spanning from developmental issues to operational issues, space debris, space weather, and also regulatory issues.

The topics were clustered to allow more efficient consideration of related matters and four expert groups were established to consider these related sets of topics. These expert groups are populated by experts nominated by their national governments. However, in the deliberations of the expert groups, the experts serve in an ad hominem capacity and do not necessarily represent their governments' positions in all matters. The expert groups are tasked to contribute inputs to the report of the Working Group on long-term sustainability and to propose candidate guidelines for consideration by the Working Group. The Working Group will consider inputs from the expert groups and take any necessary decisions. In this way, there is a clear division between the expert groups as a deliberative forum and the Working Group as a negotiating forum. These two structures are mutually reinforcing in the sense that the output of one is channelled to the other.

Countries can follow and interact with the process through designated national focal points. As of this writing (October 2012), 33 countries are engaged in this Working Group and/or one or more of its expert groups.

#### 13.3.2.1 Consideration of Topics

The expert groups and their scope are discussed below:

### Expert Group A: Sustainable Space Utilization Supporting Sustainable Development on Earth

Co-chaired by Mr. Filipe Duarte Santos (Portugal) and Mr. Enrique Pacheco Cabrera (Mexico)

This expert group is addressing the societal benefits of space activities and their contribution to sustainable development on Earth. It considers space as a shared natural resource, which raises issues of equitable access to outer space and to the resources and benefits associated with it, as well as access to the benefits of outer space activities for human development. This theme also considers the role of international cooperation in ensuring that outer space continues to be used for peaceful purposes for the benefit of all nations.

### Expert Group B: Space Debris, Space Operations, and Tools to Support Collaborative Space Situational Awareness

Co-chaired by Mr. Richard Buenneke (United States of America) and Claudio Portelli (Italy)

This expert group is considering the issues that make the space environment unpredictable and unsafe for space actors. This includes an analysis of risks from space debris and measures to reduce the creation and proliferation of space debris. The implementation of such measures requires strengthened cooperative space situational awareness, which in turn requires the collection, sharing, and dissemination of data on space objects, such as orbits, and prelaunch and pre-maneuver notifications. This expert group is also considering tools to support collaborative space situational awareness, such as registries of operators and contact information and procedures for sharing relevant operational information among space actors. This in turn drives a need for agreement on common standards, practices, and guidelines.

### Expert Group C: Space Weather

Co-chaired by Takahiro Obara (Japan) and Ian Mann (Canada)

This expert group focuses on ways to reduce the risks of detrimental effects of space weather phenomena on operational space systems. Such risks may be reduced through the sharing and dissemination of key data on phenomena related to space weather in real or near real time, as well as sharing of models and forecasts.

### Expert Group D: Regulatory Regimes and Guidance for Actors

Co-chaired by Anthony Wicht (Australia) and Sergio Marchisio (Italy)

This expert group is considering the contribution of international and national legal instruments and regulatory practices to promote the long-term sustainability of outer space activities. This includes considerations of how the existing Treaties and Principles that define the international legal framework for space activities are being implemented at national level through legal and regulatory regimes and how such national regulatory frameworks for space activities can be developed or further strengthened to support the long-term sustainability of space activities.

Not all topics under consideration are of equal urgency. The expert groups may decide to prioritize topics in terms of the need for action in the near term (less than

3 years), medium term (3–5 years), and long term (more than 5 years). One way to consider the topics could be to determine the risk factors posed to the sustainability of outer space activities under each topic and then to perform a risk assessment of those risk factors.

The expert groups are not working in silos. Several issues under consideration by the expert groups are intrinsically multidisciplinary in character and therefore fall within the competence of more than one of the expert groups. For this reason, the expert groups hold joint meetings to discuss overlaps and gaps. If, during the examination of topics within the scope of the Working Group, there are new issues raised that were not previously addressed by another forum, the Working Group may decide to elevate such issues to the Scientific and Technical Subcommittee for further consideration.

#### 13.3.2.2 Inputs into the Process and Consultative Mechanisms

Although the discussions within the Working Group take place at the intergovernmental level of COPUOS, there is a recognition by States that non-State actors play an important role in the space arena and have much knowledge and experience to contribute to the formulation of guidelines based on best practices. The inputs of national nongovernmental organizations and private sector entities are being obtained through relevant States members of the committee.

A number of international organizations and bodies, such as the Consultative Committee for Space Data Systems, the Inter-Agency Space Debris Coordination Committee, the International Space Environment Service, the International Organization for Standardization, the International Academy of Astronautics, the International Astronautical Federation, and the Committee on Space Research, are also providing inputs into the work of the Working Group and its expert groups.

The Working Group is also mandated to liaise with the recently established UN Group of Governmental Experts on Transparency and Confidence-Building Measures in Outer Space Activities, the Conference on Disarmament, the Commission on Sustainable Development, the International Civil Aviation Organization, the International Telecommunication Union, the World Meteorological Organization, and relevant intergovernmental organizations, such as the European Space Agency, the European Organization for the Exploitation of Meteorological Satellites, the Asia-Pacific Space Cooperation Organization, and the Group on Earth Observations.

The overarching principle is that the Working Group should avoid duplicating the work being done within these international entities and should identify areas of concern relating to the long-term sustainability of outer space activities that are not being covered by them.

#### 13.3.2.3 Contribution by Non-state Actors

The civil society is playing an increasingly important role in the identification and articulation of issues in the space arena. Civil society organizations include professional bodies such as the International Academy of Astronautics, COSPAR, and the International Institute of Space Law. These bodies all have international experts among their members. Commercial operators have extensive experience in running their fleets of spacecraft and in dealing with space weather and other on-orbit operational issues. A case in point was the industry coordination that took place during the Galaxy-15 “zombie sat” episode in 2010 (Weeden 2010). Industry associations and entities such as the International Astronautical Federation provide access to the collective expertise of the space industry and space agencies. Finally, there are institutional actors, such as the European Space Policy Institute or the Secure World Foundation, that analyze certain topics in depth and prepare position papers. All of these entities can make very valuable contributions to the space sustainability dialogue.

The role of non-State actors is at times a contentious issue in COPUOS. Some Member States (usually those with a well-established space industry) are comfortable with engaging the private sector in issues on the COPUOS agenda, while others (usually the ones without a space industry) are concerned that the agenda of COPUOS should not be dictated by the interests of commercial entities. Those States are of the view that COPUOS is a forum of States and that States should direct the agenda and discussions in COPUOS.

Because consensus could not be reached on the direct participation of non-State entities in the Working Group, the solution that was agreed upon was to continue with the established practice that States may choose to include in their delegations representatives of non-State entities. In this way the contributions of experts from non-State entities are made possible.

#### 13.3.2.4 Progress and Plans

The Working Group’s mandate in its terms of reference extends to 2014. Initial work in 2011 and 2012 has focused on the adoption of the terms of reference and establishing the expert groups, which will drive the detailed consideration of topics and propose candidate guidelines for consideration by the Working Group. In 2012, the focus was on obtaining inputs from States and intergovernmental entities. In 2013, the focus will be to invite inputs from the commercial sector and other non-State space actors. Development of the draft report and candidate guidelines will also commence in 2013. The report and guidelines will be presented to the STSC at its 51st session in 2014. The guidelines will have legal implications, even if they are not in themselves legally binding. For this reason, COPUOS may decide to request the Legal Subcommittee of COPUOS to review of the draft report and guidelines before their endorsement by the Committee.

## 13.4 Other Initiatives and How They Merge with the Work in COPUOS

The COPUOS work on long-term sustainability is one of several current initiatives that relate to space security and space sustainability. These initiatives are to some extent addressing a set of largely overlapping concerns from the perspectives of different groups of actors and different fora. The question naturally arises: how does the COPUOS work on long-term sustainability relate to these other ongoing initiatives? We will examine each of these in turn.

### 13.4.1 Conference on Disarmament

Given the importance of military and civilian space systems in modern warfare, there is a technical possibility that such systems could be targeted in a conflict situation. The possibility that space-based weapons might be developed and deployed in outer space has given rise to concerns that this could read to an arms race in outer space. Given that COPUOS focuses exclusively on the peaceful uses of outer space, questions of space weaponization and related security implications are dealt with at the Conference on Disarmament (CD), the sole multilateral body for negotiating arms control issues.

Within the CD, a number of delegations, notably China and Russia, have raised the issue of the Prevention of an Arms Race in Outer Space (PAROS). However, the CD has effectively been stagnant since 1988, since the Member States have been unable to agree on the annual program of work. Not only do the members of the Conference disagree over its priorities, but also the consensus rule, which served this body well in the past, is now being used to maintain the deadlock. It is against this backdrop that in 2008 China and Russia introduced a draft Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force Against Outer Space Objects (PPWT). However, not all countries agree that new legal instruments to prevent space weaponization are warranted or even beneficial. So, for the time being, the PAROS discussions in the CD are making no progress because of differences of opinion on some fundamental issues. However, there is agreement on the urgency to make progress in those areas where there is consensus, even if such progress must be made outside the CD.

So, how does this impasse in the CD play out in COPUOS? The main point here is that, for those countries supporting the PPWT proposals in the CD, the long-term sustainability work of COPUOS should not be used as a pretext to circumvent the need for discussions on the prevention of an arms race in outer space and the development of a legally binding framework to prevent the placement of weapons in outer space. Thus, the terms of reference for the Working Group also call for “appropriate liaison” with the CD. The mandate of COPUOS covers only the peaceful uses of outer space, but some of the emerging guidelines could be seen as de facto transparency and confidence-building measures to enhance collective space security. In this way the implementation of the COPUOS guidelines could potentially be useful for improving mutual understanding and for reducing misperceptions and mistrust, thereby ultimately promoting a more favorable climate for arms control and nonproliferation discussions in the CD.

### 13.4.2 UN Group of Government Experts on Transparency and Confidence-Building Measures (TCBMs) in Outer Space Activities

In 2010, the UN General Assembly adopted Resolution A/Res/65/68,[8] which called for the establishment of a Group of Governmental Experts (GGE) on "Transparency and Confidence-Building Measures in Outer Space Activities." The resolution passed with 183 States voting for it and the United States abstaining.[9]

The GGE is to conduct a study on outer space transparency and confidence-building measures, making use of the relevant reports of the UN Secretary-General and without prejudice to the substantive discussions on the prevention of an arms race in outer space within the framework of the Conference on Disarmament, and to submit to the General Assembly at its 68th session a report with an annex containing the study of governmental experts.

The GGE, which comprises 15 experts selected on the basis of their knowledge and geographical representation, held its first session in New York in July 2012 and agreed on its program of work, rules of procedure, and consensus-based decision-making. The GGE also agreed to incorporate inputs from and to interact with a wide range of other States and relevant entities.

In terms of the interaction between the GGE and the UN COPUOS Working Group on Long-Term Sustainability, the chairs of the GGE and COPUOS LTS Working Group have established a good working relationship to ensure that the two Groups are informed of each other's work. The work in COPUOS complements the objectives of the GGE in that the emerging COPUOS guidelines could provide the technical basis for the implementation of a number of TCBMs to be proposed by the GGE.

### 13.4.3 The EU Proposal for an International Code of Conduct for Outer Space Activities

More or less at the same time as the multilateral discussions in COPUOS on long-term sustainability began, the European Union began a political initiative to develop a Code of Conduct for Outer Space Activities. This initiative was pursued outside of the existing multilateral fora, motivated at least in part as

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[8] UN GA Resolution 65/68 available at http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/65/68

[9] US officials explained that their abstention did not reflect lack of support for TCBMs, but rather concern with language in the resolution that linked it to the Chinese-Russian draft PPWT. In her statement to the First Committee on 22 October 2012, the US Ambassador to the Conference on Disarmament Laura Kennedy said: "The United States will also pursue pragmatic bilateral and multilateral transparency and confidence-building measures (TCBMs) to mitigate the risk of mishaps, misperceptions, and mistrust." The full statement may be accessed at http://geneva.usmission.gov/2010/11/03/outer-space/

a means to bypass the stalemate on the PAROS issue in the CD. The EU expressed its intent to open the Code for signature at an international diplomatic conference, to be convened for this purpose. Outside of Europe, no other major space powers openly endorsed the initiative until January 2012, when US Secretary of State Hillary Clinton announced that "the United States has decided to join with the European Union and other nations to develop an International Code of Conduct for Outer Space Activities."[10] Australia's Foreign Minister Kevin Rudd soon followed with a similar statement. However, the initiative has not been embraced by a significant number of non-EU space-capable states, largely because of concerns about the process and the intent of the EU in having kept this initiative out of multilateral fora.[11] This means that the Code of Conduct initiative currently has no formal multilateral mandate, unlike the GGE and the COPUOS processes.

Within COPUOS, a number of delegations have questioned how the long-term sustainability work relates to the EU's efforts to promote a Code of Conduct and whether such a Code of Conduct would in some way "trump" the long-term sustainability discussions in COPUOS. However, there is an important distinction between the Code of Conduct and the long-term sustainability work in COPUOS. The COPUOS work is a technically based bottom-up approach of developing guidelines based on current best practices of space actors with experience. The Code of Conduct initiative is a more political, top-down approach. The two approaches could, in fact, complement each other, provided that the current efforts to "multilateralize" the Code of Conduct initiative are successful.

## 13.5 Conclusions

The golden thread running through the processes in COPUOS, the GGE, and the Code of Conduct initiative is that they are all aiming to produce instruments that are voluntary in nature. However, although such instruments may be legally nonbinding, they are in a sense politically binding. Another important point to appreciate is that *nonbinding* does not mean *nonlegal*, in the sense that States can choose to domesticate their politically binding agreement to such voluntary frameworks in their domestic regulatory practices.

A number of countries have expressed concern that such voluntary instruments are inherently fragile and would not prove effective in preventing the weaponization of and an arms race in outer space. However, there does not seem to be consensus at this point on the desirability of legally binding instruments banning the placement and use of weapons in outer space, so the development of voluntary

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[10] Statement by US Secretary of State Hillary Rodham Clinton on 17 January 2012, accessed at http://www.state.gov/secretary/rm/2012/01/180969.htm

[11] During the development of the draft Code, the EU held numerous bilateral consultations, but no multilateral consultations, until 5 June 2012, when the European External Action Service held an information session on the margins of COPUOS.

frameworks for promoting space sustainability provides some scope for making progress. Voluntary frameworks do not necessarily retard the evolution of binding norms and can in fact pave the way for adoption of binding norms. Historically, many legal rules have resulted from the codification of existing practice adopted by consensus.

Progress will also be made in the sense that the nations that choose to participate in these processes do so because they recognize the urgency of addressing the problems of space sustainability and space security. That awareness in itself may be enough to convince space actors to take corrective and preventative actions on their own. The COPUOS long-term sustainability guidelines, while nonbinding, will have the advantage of being the result of a multilateral consensus-based process and will therefore have a good chance of being implemented by space actors, in their own interest.

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# Space Technology Export Controls

# 14

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## Contents

## Abstract

The exigencies of the Cold War era were among the driving forces behind innovation in the field of space technology. The Janus-faced nature of space technology, serving scientific interests on the one hand and strategic, defense-related objectives on the other, led logically to the imposition of controls concerning the export of such technology. This contribution not only aims to provide a thorough overview of the relevant legal instruments and mechanisms, on the international, the regional, and the national level, and to examine their respective effects on the space industry but also to shed a light on reasons underlying the developments.

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The views expressed are purely personal and do not necessarily reflect the view of any entities with which the author may be affiliated. Legal Developments up to 31 July 2013 have been taken into account.

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## 14.1 Introduction

Export control systems are closely connected to the realm of international cooperation and foreign policy, to national security, and, as for the technical aspects, to space technology and its underlying technical knowledge. Understanding the logic behind the export control systems necessitates considering all four of these areas and their respective interconnections. While space technology determines the object of export controls and its practical scope, national security and international cooperation form the nature of the rules with their political impact. At the same time, it is precisely space technology and its characteristics that influence the national approaches towards its export controls and the willingness to cooperate on an international level. Although these interrelations are apparent and recognized, an analysis revealing their structure and inner functioning is necessarily multifaceted. The tangled connections between the four domains help to develop and give rise to rather complex and very heterogeneous systems of export control rules.

## 14.2 Terminology

For the sake of this article, *export controls* may be defined as the restriction on the export of goods or services imposed by the exporter's own country (Aubin and Idiart 2007, pp. 1–18; http://www.bis.doc.gov/). The laws and regulations governing export controls are in fact posing an exception to the free trade principles of international commercial exchanges. Thus, entities involved in trade of controlled goods and services are obliged to follow and comply with the regulations articulated by national and international regimes, as applicable.

In accordance with numerous relevant laws and regulations, *export* may be defined as the fact that an item is sent from one country (the country of exportation) to a foreign country (the country of destination) regardless of the method that is used for this transfer. The term *item* may encompass hardware, software, and technology. Export is also considered to have occurred if the item leaves the country only temporarily or as an item which is not for sale. Also, the release of information regarding controlled technology to a foreign entity while the item itself remains on the soil of the country of exportation is considered an export.

Export control regulations are in fact a reaction to the need to control items – the hardware, the software, or the technology and services leaving their territory – for the reason of security and technology protection.

The export control systems are often being implemented in the form of licensing authorization processes. In order to estimate whether a license can be granted, several factors are taken into consideration by the relevant administration. First, the goods and the technology submitted to the licensing process have to be examined with regard to their nature. In addition, the end user, the intended end use, and the destination have to be determined.

The technical characteristics of the space item are a crucial factor in this whole process. If an item intended for export is referenced by a specific export control legal or regulatory text, the prescribed necessary measures in order to obtain a license for its export have to be taken.

Classification of goods and their placement on such a list derives from their characteristics. Although no consolidated definition of the term *space technology* can be offered, it can be described as a systematic application of engineering and scientific disciplines to the exploration and utilization of outer space (McGraw-Hill Science & Technology Dictionary).

Within the export control laws and regulations, the term often has a very specialized meaning which is applied in the range of the concerned legal or regulatory text. The export control system typically deals not only with the physical item itself but also with the specific information required for the development, production, or use of an item classified commonly as technical data or technical assistance. The term *space technology* refers simultaneously to the physical item as well as to the technical knowledge the item is built upon.

The categorization of space technologies depends on many factors, among which their function, size, use, or location. Typically, one distinguishes among space items according to the function of the space system the technology supports: launch vehicles, spacecraft, or ground support equipment.

Controls are usually made on exports of nuclear, chemical, biological, military, or dual-use goods, technology, or services. Virtually, the majority of the controlled exports relate to military and dual-use goods and services.

*Dual-use goods* are goods that may be used for both nonmilitary and military applications. Dual-use technology can then be described as specific information required for the development, production, or use of an item that may be potentially used for both civil and military purposes.

Following this definition, it has to be noted that launch vehicles and satellites – as a special type of spacecraft – and their technology have inherent dual-use potential. This fact is due to the historical development of the technology; its application and use; the role space applications that play in modern civil, commercial, and military activities; and the overall policy of states regarding the deployment and use of these goods.

While some early launch vehicles were basically converted military ballistic missiles with almost identical technology which may then have undergone further technological developments, it holds true also for contemporary launch vehicles that are most of the time independent system developments, that they still share many characteristic features and technological bases. Therefore, they are, together with ballistic missiles, classified as delivery mechanisms for weapons of mass destruction.

Satellites and their components are modified according to their intended use, which means that they can also be adapted to the requirements imposed by a military purpose. Satellites as well as satellite components are therefore generally categorized as dual-use and may be considered militarily sensitive.

The possibility to provide support and strategic advantages to military and intelligence operations is regarded as one of the most important export control characteristics of space technologies. Space technologies have already become an essential element of military and intelligence activities and play an important role in its future planning and structures. These characteristics are not based on the technical qualities of the space technologies, but result from their potential use and the benefits they bring.

As a matter of fact, all space items and technologies are inherently dual-use since outer space as such is militarily strategic. The shifts of technology in the aerospace industry, first from military to civil applications after the era of the Cold War and more recently back to military applications, proves that both areas benefit from a cross-fertilization. Items developed strictly for civil or commercial purposes might still be used for military purposes and vice versa. Therefore, the question that needs to be asked is not how to prevent this inherent dual-use nature, as the solution would be clearly beyond the regulatory or even technical possibilities. The question is what the export control regulations concerning these items should look like (Mineiro 2011, pp 3–12).

## 14.3 International Legal Regimes

There are no binding multilateral agreements focusing *exclusively* on space technology export control, yet it must be pointed out that some multilateral agreements concerning space technology used as weapon delivery systems, documents prohibiting their deployment and operation, or some bilateral agreements serving as a basis to exempt respective states from the related licensing process can be found (Mineiro 2008). In this section, we will first peruse the general international export control regimes and their applicability to space technology before examining the impact of the traditional international space law, in a narrower sense, to the subject matter at hand.

### 14.3.1 The Melee of International Legal Instruments on Export Control

Following the events of the first half of the twentieth century, the international community enhanced its cooperation in order to maintain peace and international security. The dialogue between nations resulted in the establishment of a number of international legal regimes intended to balance the international law principle of protection of peace and international security with the right to legitimate self-defense as well as to development and economic freedom (Achilleas 2007, p. 20). Four separate and almost wholly independent functional regimes compose the current export control system, which supplement the provisions of other binding, multilateral treaties primarily focused on the development and possession of weapon technologies, such as the 1968 Nuclear Non-Proliferation Treaty (NPT) (Treaty on the Non-Proliferation of Nuclear Weapons 1968), the 1972 Biological Weapons Convention (BWC) (Convention on the Prohibition of the Development 1972), and the 1993

Chemical Weapons Convention (CWC) (Convention on the Prohibition of the Development 1993; Joyner 2004).

The four functional supplier state regimes are:

- The system of the Nuclear Suppliers Group (NSG; http://www.nuclearsuppliersgroup.org), which governs the area of nuclear weapons and materials;
- The Wassenaar Arrangement (The Wassenaar Arrangement on Export Controls 1996), which sets the rules in the context of conventional weapons;
- The Australia Group (http://www.australiagroup.net/), which deals with chemical and biological weapons proliferation;
- The Missile Technology Control Regime (MTCR) (The MTCR Guidelines 2012), which regulates the export of missile and related delivery system technologies;

In addition, these regimes are complemented by provisions of the Nuclear Non-Proliferation Treaty (NPT), the IAEA Comprehensive Safeguards Agreement and Model Additional Protocol (1997), the Zangger Trigger List (1974), the Limited Test Ban Treaty (LTBT) (Treaty Banning Nuclear Weapon Tests 1963), and the Comprehensive Nuclear-Test-Ban Treaty (CTBT 1996) regarding nuclear materials and tests; by the Geneva Protocol (1925), the Biological and Toxin Convention (Convention on the Prohibition of the Development 1972), and the Chemical Weapons Convention with regard to chemical and biological weapons proliferation; by the Hague Code of Conduct (International Code of Conduct 2002) concerning ballistic missile proliferation; and by United Nations Register of Conventional Arms (UNROCA 1992) in the domain of conventional weapons.

By the conclusion of bilateral or multilateral agreements, states attempt to coordinate their domestic regulations but generally fail to install a specific authority to enforce these obligations. It has to be noted that each State performs export controls of space technologies unilaterally.

There are only a few specific cases, in which international law imposes direct obligations to control space technology exports. One such example is the United Nations Security Council Resolution 1540 (UN Doc. S/Res/1540 2004), which was adopted unanimously on 28 April 2004. In accordance with Article 39 of the UN Charter, the UN Security Council shall make recommendations or decide what measures shall be taken in case of any threat to the peace, breach of peace, or act of aggression. Thus, the UN Security Council may pass a resolution restricting export of space technology in case it might have the abovementioned impact. Security Council Resolution 1540 establishes the obligation under Chap. VII of the UN Charter for all Member States of the UN to develop and enforce appropriate legal and regulatory measures against the proliferation of chemical, biological, radiological, and nuclear weapons and their means of delivery, in particular, to prevent the spread of weapons of mass destruction to non-state actors.[1] This explicit

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[1] On an implementation strategy for Resolution 1540, see Monika Heupel, Implementing UN Security Council Resolution 1540: A Division of Labour Strategy, Carnegie Papers, Nonproliferation Program, Number 87, June 2007.

international obligation also impacts the right of states to export space technologies, to the extent that they could be used as a means of delivery for weapons of mass destruction (Mineiro 2011, p. 21).

In the field of soft-law agreements[2], the Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies (The Wassenaar Arrangement on Export Controls for Conventional Arms 1996) plays a major role. It is a nonbinding export control agreement aiming at "contributing to regional and international security, by promoting transparency and greater responsibility in transfers of conventional arms and dual-use goods and technologies" (Wassenaar Arrangement, paragraph 1). Certain space and satellite technologies are listed in the categories of sensitive and very sensitive dual-use goods in the annexed List of Dual-Use Goods and Technologies and their transfer or denial must be therefore duly notified according to the rules set up by the arrangement (Mineiro 2012; Achilleas 2007, p. 53).

Moreover, the launch vehicle space technologies are addressed in two other nonbinding instruments – in the Guidelines for Sensitive Missile-Relevant Transfers (MTCR 1987) and the International Code of Conduct against ballistic missile proliferation (HCOC 2002). The MTCR apply to rocket systems, including space launch vehicles and sounding rockets whose transfer could possibly make a contribution to deliver systems other than manned aircraft for weapons of mass destruction. According to the provisions of HCOC, states exporting launch vehicle technology must promote the nonproliferation of ballistic missiles capable of delivering weapons of mass destruction and be vigilant in consideration of assistance to space launch vehicle program in any other country. MTCR and HCOC concern the export of satellite technology only indirectly through the control of items enumerated on their lists. When a satellite technology is used together with these items, these two arrangements have to be taken into consideration and complied with.

The above-enumerated international legal regimes relate to export controls of space technology because of its inherent dual-use characteristics and the potential to be applied or incorporated in a system of weapons, missiles, or other applications destined for non-peaceful purposes. However, the trade with space technologies falls also under the restrictions posed by specific regimes applying to outer space.

### 14.3.2 The Specificities of the Outer Space Regime

Outer space as an international zone is subjected to special rules of international public law characterized by principles of peaceful use and non-armament (Achilleas 2007, p. 60).[3] The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other

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[2] On the notion of soft law, see Freeland (2012), with further references.

[3] For an analysis of outer space law and space security, see Steven Freeland, The Laws of War in Outer Space, in this handbook.

celestial bodies (Outer Space Treaty 1967), foresees in its Article IV paragraph 1 that no objects carrying nuclear weapons or any other kinds of weapons of mass destruction shall be placed in orbit around the Earth and no such weapons shall be installed on celestial bodies or stationed in outer space in any other manner. Article IV of the Outer Space Treaty has been considered as one of the first provisions on arms control (Schrogl and Neumann 2009). As may be observed, placing of other than nuclear weapons and weapons of mass destruction in outer space is not excluded; also, a transfer of weapons is not explicitly prohibited. With regard to the fact that the Earth orbits are of an immense strategic and also military value, this loophole may serve states' future interests.

According to Article IV paragraph 2, the Moon and other celestial bodies shall be used "exclusively for peaceful purposes." Since the Outer Space Treaty itself fails to provide a definition of the term "peaceful," its interpretation has over the years given rise to much debate centered on the question as to whether it is to be understood as meaning "nonmilitary" or "nonaggressive," with the latter meaning seeming to gain general acceptance.[4] The establishment of military bases, installations and fortifications, the testing of any type of weapons, and the conduct of military maneuvers on celestial bodies shall be forbidden. Only scientific research and peaceful exploration may be conducted, also by military personnel.

The general freedom to explore and use outer space, as enshrined in Article I of the Outer Space Treaty, is subject to compliance with international law, including the Charter of the United Nations, and has to be carried out in the interest of maintaining international peace and security and promoting international cooperation and understanding, Article III Outer Space Treaty. Thus, it may be concluded that all disarmament and nonproliferation treaties that are part of international law are also applicable to activities carried out *in* outer space. According to Article 38 (1) of the Statute of ICJ, the recognized source of international law includes apart from international conventions also international custom, as evidence of a general practice accepted as law and the general principles of law recognized by civilized nations.

## 14.4 National and Regional Legal Regimes

In order to provide an overview of the complexities related to the legal export control regimes of space technologies, we propose a look at two prominent examples of national and regional legal regimes: the United States' regime on the one hand and the European Union system on the other hand. We round off that picture by a short introduction to the additional particularities of dealing with

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[4] See, for example, Markoff (1967). retracing the evolution in the interpretation by States and the States' practice, for this specific interpretation of the term which may differ from its meaning in other branches of public international law.

export control issues in an international organization dedicated to the promotion of cooperation among its Member States in space research and technology and their space applications, the European Space Agency, ESA.

### 14.4.1 The Export Control Regime of the United States

One basic characteristic of the US export control regime is the extraterritorial jurisdiction it exercises over US goods and technology, also when these goods or technology are located outside the territory of the United States, based on the fact that these items are of US origin or contain significant US content.[5] This extraterritorial application of jurisdiction, which has given rise to criticism and debate over the years,[6] is, however, a fact of law[7] and has a great impact not just on American firms but on exporters all around the world: Any foreign company seeking to reexport a product of American origin or with a certain percentage of American technology[8] will always have to comply with the applicable US regulations, regardless of whether they export from US territory or from any other place in the world. Failure to comply may give rise to prosecution, blacklisting, or other forms of punishment. It is worth pointing out in this context that reexport has been elaborated as follows: "In addition, for purposes of *satellites* controlled by the Department of Commerce, the term 'reexport' also includes the *transfer of registration of a* satellite *or operational control* over a satellite from a party resident in one country to a party resident in one country to a another country" (http://www.bis.doc.gov/policiesandregulations/ear/772.pdf, Part 77).

From a US perspective and understanding, there is no general freedom or right to export goods. Rather, an export license is considered to be a privilege which can be revoked in case of noncompliance with applicable regulations.

Despite their importance for national security and for the overall economy, the US regime of export regulations has not been consolidated into a single and unified text. Instead, there are different rules applied by different departments depending on the individual item and recipient in question:

- **Dual-use goods**, i.e., goods that may be used for both nonmilitary and military applications, are regulated by the Export Administration Regulations, EAR.
- **Military goods** are governed by the International Traffic in Arms Regulations, ITAR.

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[5] For further details, see Gerhard and Creydt (2011).

[6] See, for example, Ress (2000), Clement (1988; http://www.e-parl.net/pages/space_hearing_images/BackgroundPaper%20McGill%20Outer%20Space%20Uses.pdf) also on the historical background.

[7] See for more details Little et al. (http://www.velaw.com/uploadedFiles/VEsite/Overview/IntlGovernmentContractorArticle.pdf)

[8] The details can be found in Part 734.4 (http://www.bis.doc.gov/policiesandregulations/ear/734.pdf)

- Finally, the Office of Foreign Asset Control Regulations, OFAC, relates to **particular countries, organizations, and persons** for the protection of national security interests.

With regard to OFAC, it must be pointed out that, unlike the EAR and ITAR, the main focus of these regulations is not on particular items and services but on targeted countries and end users: OFAC administers, upholds, and enforces economic trade sanctions based on US foreign policy and national security goals against targeted foreign states, organizations, and individuals. OFAC derives its authority from a variety of US federal laws regarding economic sanctions. The effect on the American space industry of these regulations is, however, only marginal given that the targeted countries are not important trading partners in the field of space technology.

#### 14.4.1.1 Dual-Use Goods: The Export Administration Regulations, EAR

The US Department of Commerce is empowered to administer and to enforce rules for the export of dual-use items under the Export Administration Act of 1979.[9] More specifically, its Bureau of Industry and Security is charged with the development, implementation, and interpretation of US export control policy for dual-use items under the EAR.

The EAR establishes a number of general prohibitions (http://www.bis.doc.gov/policiesandregulations/ear/736.pdf, Part 736.2) relating to certain exports, reexports, and other conduct, subject to the scope of the EAR, which necessitate a license from the Bureau of Industry and Security or the qualification for a license exception. Facts that determine the applicability of the general prohibitions are:

- The classification of the item on the Commerce Control List;
- The country of ultimate destination for an export or reexport;
- The ultimate end user;
- The ultimate end use;
- Conduct such as contracting, financing, and freight forwarding in support of a proliferation project;

The relevant details are provided in accompanying lists and schedules. It is interesting to note that the otherwise existing possibility to obtain a license exception is specifically excluded for a number of items, among which feature certain "space-qualified items" (Part 740.2(a)).

Once established that an envisaged export activity does not fall under a general prohibition, the exporter needs to examine the specific license requirements, if any. This examination is accomplished by means of the Commerce Control List and the Country Chart, as well as the established reason for the control of the item (Gerhard and Creydt 2011, p. 198).

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[9] Export Administration Act of 1979, as amended (Public Law 96–72, 96th Congress; 50 U.S.C app. §§2401–2420; 93 Stat. 503). Provisions maintained by several Executive Orders and by the International Emergency Economics Powers Act, as amended (Public Law 95–223; 50 U.S.C. §§ 1701–1706; 91 Stat. 1628).

Criminal sanctions, in addition to administrative and civil penalties, can be imposed where the EAR regulations have been violated (http://www.bis.doc.gov/policiesandregulations/ear/764.pdf, Part 764.3).

#### 14.4.1.2 Military Goods: The International Traffic in Arms Regulations

The International Traffic in Arms Regulations, ITAR (http://pmddtc.state.gov/regulations_laws/itar_official.html), governs the import and export of defense articles and services. Under the Arms Export Control Act of 1976, the State Department has the delegated power to control, enforce, and administrate the regulations. These defense articles and services are listed in the United States Munitions List, USML (http://pmddtc.state.gov/regulations_laws/documents/official_itar/ITAR_Part_121.pdf, § 121). Of particular interest in the context of this chapter is Category IV, which includes, among other items, launch vehicles, guided missiles, ballistic missiles, and rockets. Following the passing of the Strom Thurmond National Defense Authorization Act for fiscal year 1999 (Public Law 105–261 1998), the export control competence concerning commercial satellites was shifted from the Department of Commerce to the Department of State following concerns about the proliferation of sensitive satellite technology.[10] Different license requirements exist for the permanent or the temporary export of any defense article or technical data (Details in §§ 123 and 125 ITAR). The performance of defense services also requires the prior approval by the Directorate of Defense Trade Controls of the State Department, which requires the conclusion of specific agreements between the performer of such services and the respective international partner. (Details in §§ 124.1 ITAR). The famous Technical Assistance Agreements, TAA, are one example.

The ITAR regulations have been criticized as too cumbersome, complex, and time-consuming,[11] which in turn is said to have led to a competitive disadvantage for the US space industry and a decline of exports, as competitors around the globe started to invest in the non-dependance in certain fields of technology.[12]

Responding to these issues, export regulations are currently undergoing reform plans. The US administration is working on adjusting them to achieve a correct balance between favoring commercial activities on the one hand and maintaining the necessary protection of national security interests with regard to defense articles and services on the other hand. On 18 April 2012, the US Departments of Defense and State released their final report to Congress pursuant to Section 1248 of the National Defense Authorization Act for fiscal year 2010, summarizing their joint risk assessment of US space export control policy and concluding that most communication and lower-performing remote-sensing satellites and related components can be moved from the United States Munitions List, USML, to the Commerce Control List, CCL, without harm to

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[10] See, for the background and details, van Fenema (1999, p. 332).

[11] See, for example, Abbey and Lane (2009).

[12] See also Landry (2010) Exploring the effects of International.

national security (http://www.defense.gov/home/features/2011/0111_nsss/docs/). The report also recommends that Congress return to the president authority to determine the export control jurisdictional status of satellites and related items.

## 14.4.2 Export Regulations of the European Union

The European Union, EU, has for many years played a leading role in arms export control, both regionally and internationally. Export control regulations on dual-use goods and defense equipment have been harmonized within the EU under a common regime. Similar to the US approach, products are categorized into either dual-use goods or military products. However, unlike to the situation in the United States, none of the regulations or national laws has extraterritorial effect on third countries outside the EU.

Council Regulation 428/2009 (http://trade.ec.europa.eu/doclib/docs/2009/june/tradoc_143390.pdf) of May 2009 governs the export of dual-use goods from a country within the EU to a third country. In addition, the export of military goods and defense-related products is regulated by Directive 2009/43 (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri¼OJ:L:2009:146:FULL:EN:PDF), the European Union Code of Conduct on Arms and Exports, and the Common Military List of the European Union. Prior to 2009, national rules regulating the transfer of defense equipment did not necessarily distinguish between exports to third countries and transfers between EU Member States. Under the regime established by Directive 2009/43, Member States can issue general licenses for those exports throughout the EU where the risk of reexportation to foreign countries is under control. At the same time, the national states retain their discretion to determine the eligibility of products for the different types of license and to fix their terms and conditions. In 2008, the European Council also agreed on the Common Position 2008/944/CFSP defining common rules governing control of export of military technology and equipment to *third* countries. It should be noted, however, that the impact of these rules on the European space industry is not particularly important, since most space-related items are considered dual-use and not military items. There are also Council Regulations restricting the export against specific countries, e.g., Myanmar (Council Decision 2010/232/CFSP). The aim of this harmonization is to promote European and international security as well as to allow for comparable conditions for all economic entities within the EU's common market. Despite this development, some differences do, however, remain among EU Member States with regard to export control licensing (Gerhard and Creydt 2011, p. 210).

### 14.4.2.1 Dual-Use Items

Council Regulation 428/2009 (http://trade.ec.europa.eu/doclib/docs/2009/june/tradoc_143390.pdf) establishes a common community export licensing system, a common control list, and a common export authorization. Dual-use items which require a license to be exported from the EU are listed in Annex I. On 15 June 2012, Council Regulation 388/2012 (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri¼OJ:L:2012:129:0012:0280:EN:PDF) entered into force which replaced the old Annex with a new version following the review of various international arms control agreements. Most space assets are regarded as dual-use items under Annex I: Category 9, aerospace and propulsion, lists the different systems, equipment, components, materials, software, and technology subject to the regulation. Authorizations, which are valid throughout the community, are granted by the competent authorities of the Member State where the exporter is established (Council Regulation No. 428/2009). Pursuant to Article 22.1 of Regulation 428/2009, dual-use goods items in Annex IV of the regulation are considered to be particularly sensitive and require a license even to be traded *within* the European market. This procedure, which concerns also quite a number of space-related items, constitutes an exception to the principle of free movements of goods (Wetter 2009, p. 54). It is interesting to note that Annex IV establishes some explicit exemptions (OJL 134, p. 264):

> Annex IV does not control the following items of the MTCR technology:
> 1. That are transferred on the basis of orders pursuant to a contractual relationship placed by the European Space Agency(ESA) or that are transferred by ESA to accomplish its official tasks;
> 2. That are transferred on the basis of orders pursuant to a contractual relationship placed by a Member State's national space organization or that are transferred by it to accomplish its official tasks;
> 3. That are transferred on the basis of orders pursuant to a contractual relationship placed in connection with a Community space launch development and production programme signed by two or more European governments;
> 4. That are transferred to a State-controlled space launching site in the territory of a Member State, unless that Member State controls such transfers within the terms of this Regulation.

## 14.5 The Export Control Regulations of the European Space Agency

The European Space Agency, ESA, is an international organization created by the Convention for the establishment of a European Space Agency, which was opened for signature in Paris on 30 May 1975 and entered into force on 30 October 1980. Its Member States entrusted ESA with the specific function to provide for and promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems, Article II of the ESA Convention.

In drawing up the Convention, ESA Member States paid heed to the potentially highly sensitive nature of the technology developed and, introduced with Article XI.5(j) of the ESA Convention, a starting point for ESA's own rules and procedures with regard to export control issues. It provides that

> The ESA Council shall adopt, by a two-thirds majority of all Member States, rules under which authorisation will be given, bearing in mind the peaceful purposes of ESA, for the transfer outside the territories of the Member States of technology and products developed under the activities of ESA or with its assistance.

These rules supplement the regular national export control procedures. Exports remain in their essence governed by national laws and regulations, given their foreign policy and security implications, even in the case of an export of technologies or products developed under the activities or with the help of ESA.

This basic provision of Article XI.5(j) of the ESA Convention is implemented by Chap. IV of the ESA Rules on Information, Data, and Intellectual Property, adopted by the ESA Council on 19 December 2001 (rules), ESA/CCLV/Res. 4 (final). These rules are intended to ensure close liaison between the Agency and the national export control authorities of the Member States. In line with general ESA policy considerations, the rules contribute to promoting the maximum exploitation of ownership rights by drawing a clear distinction between technology and products that are owned by ESA, on the one hand, and those which are owned by Contractors of the Agency, on the other hand: The transfer of technology or products owned by ESA necessitates the *authorization* by the Agency Technology and Product Transfer Board, ATB, whereas the transfer of technology or products owned by Contractors only needs to be subject of a *recommendation* by the ATB.

The ATB's authorization or recommendation, which is – again – not a substitute for the national-level authorization process but rather an additional procedure, is not necessary when the transfer of technology or products is made pursuant to a cooperative agreement between ESA and a government agency of the country of destination. In such case, it is assumed that the ESA Council, when approving the cooperative agreement, has given an overall authorization for the transfer of data and goods in accordance with the relevant provisions of the agreement.

In a first instance, the ATB functions according to a written procedure: When the technology or products are owned by ESA, the transfer proposal is *rejected* when one-third or more of all Member States have communicated their opposition. When the technology or products are owned by a Contractor, a transfer is *not recommended* where one-third or more of all ATB delegations have communicated their opposition. If, however, within a given time frame, one or more ATB delegations request a meeting to discuss the matter, the ATB Chair convenes such a meeting. The decision shall then be taken at that meeting, with a two-thirds majority of all ATB delegations present.[13]

In considering its authorizations and recommendations, the ATB takes into account several factors, such as:

- That the purpose of the Agency is to provide for and to promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications;
- The competitive position of the Member States' industrial entities as a whole and the competitive edge and technical lead for technology and products;

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[13] See the resolution amending the terms of reference for the Agency Technology and Product Transfer Board (ATB), adopted on 11 October 2006, ESA/C/CLXXXIX/Res. 2 (Final), which amends the terms of reference adopted by the resolution on the creation of an Agency Technology and Product Transfer Board, ESA/C/CLXVII/Res. 1 (Final), adopted on 8 October 2003.

- The relevant provisions of the Member States' export control laws and regulations;
- The requirement for timely implementation of the Agency's programs and activities;
- The requirement for restrictions on reexport and/or the existence of any relevant technology transfer agreements;

The ESA's rules do not prejudice the fact that export control is a national competence, governed by the national laws and regulations of the Member States and, in a number of instances, subject to those international agreements by which the Member States are bound. This implies also that a certain technology or product that has been developed under an ESA program may still need to be submitted to the regular national export control procedure in case it is planned to be used in another ESA program by another Member State than the Member State of the originator.

## 14.6 Conclusions

The above account of the current situation in the space industry is faced with concerning export control regulations, procedures, and mechanisms and illustrates the regulatory complexity governing the trade in space items. And the field is moving fast: New technological developments need to be taken into account as well as diverse policy objectives and diversifying policy considerations in a global environment that is evolving at an ever-increasing pace.

The international trade in technology is influenced by the interplay between commercial interests, foreign policy objectives, and national security considerations in respect to the proliferation of sensitive technologies. The different approaches and national concepts to regulate the trading in space items provide therefore a characteristic exemplification of how individual nations balance these different and conflicting interests – what degree of importance they attach in their system of political values to one in relation to the others.

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# Space Transparency and Confidence-Building Measures

# 15

Jana Robinson

## Contents

**Abstract**

This chapter focuses on transparency and confidence-building measures (TCBMs) as traditional tools of diplomacy and international relations that can be applied to outer space activities. Special attention is given to the multilateral dimension of TCBMs. It first reviews the increasing demand for space TCBMs. It then provides an overview of the main space TCBM-related efforts to date, including the more recent ones being undertaken in the UN framework and by the European Union (EU). The chapter concludes with an outlook on the future of space TCBMs.

## 15.1 Introduction

Space capabilities today offer a wide spectrum of critical civilian, commercial, and military-related applications, services, and benefits to a wide spectrum of users. These benefits are accompanied by growing anxiety concerning the safety and security of these assets, as well as the stability and sustainability of the space environment. The large, and growing, number of operators face the ever-present

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challenge of orbital debris, potentially destructive collisions, radio-frequency interference (both unintentional and intentional), as well as other concerns, including the proliferation of new space technologies to both state and non-state actors, enabling them to develop more sophisticated, dual-use capabilities.

Given this reality, countries are currently reviewing models for various TCBMs for space activities. Several of these draft TCBMs call for a voluntary approach to the responsible use of space based largely on self-interest in preserving the integrity and safety of the space environment. Transparency is characterized not only by openness in conveying information on space activities, but also by better understanding the intentions of other space actors. In addition to information-sharing, a number of other confidence-building measures are recognized as being desirable, including consultations and notifications, as well as restraint mechanisms. Despite this compelling logic, space actors have treated TCBMs with a selective and guarded mindset.

One of the biggest hurdles to TCBM adoption and implementation is their credibility historically. TCBMs have been employed terrestrially for decades in the fields of nuclear arms control, ballistic missile non-proliferation, and other arenas, often without achieving the desired outcomes. At the same time, important space TCBM-related precedents were established during the Cold War. For example, after each having tested and deployed anti-satellite (ASAT) weapons, both the USA and USSR ended the ASAT deployment without forging a formal space arms control agreement (Hays 2010).

Experts often argue that negotiations, including those related to confidence-building measures, generally involve substantial concessions in exchange for the promise of improved stability. The level of trust is less important than the extent of the delivered commitment and verification procedures. Accordingly, any security-related cooperative regime involving non-binding TCBMs has to be carefully weighed and include compliance by all relevant parties. Ensuring compliance is an interactive exercise where all parties play a role and none of the parties can be completely controlled. Through TCBMs and mechanisms for their implementation, political and military leaders can create a peer-pressure environment and norms which can help anticipate the behavior of other space actors.

A body of principles and rules governing space activities, including the special international status of outer space and celestial bodies, was established during the second half of the twentieth century. Not surprisingly, the expanding number of space actors, objects, and debris has multiplied the threats to safe and secure space operations. Accordingly, the norms established by the 1967 Outer Space Treaty (OST) are more relevant than ever. Implementation of these principles and rules has, however, lagged for a number of reasons. These include: the “asymmetric” interests in space; the lack of a track record on the multilateral management of an incident in space; the dearth of simulations and tabletop exercises in this arena and other factors. Currently, the international environment is thought by many to be unable to accommodate any new formal space-related regime beyond the existing space treaties.

Indeed, some point out that it is more important at this stage to achieve universal adherence to the OST. Such an emphasis or approach would include signatory responsibilities for authorization, continuous supervision over activities of nongovernmental entities in space, obligations to undertake or request appropriate international consultations before proceeding with any activity or experiment that would cause potentially harmful interference, etc. (Hays 2010).

A review of current space TCBM-related efforts underway would be useful here, with a view to establishing preventive measures to preserve safety, stability, and security of space, as well as providing elements of a more comprehensive management of the space security portfolio globally.

## 15.2 Overview of Space TCBM-Related Efforts

The U.S.-Soviet competition shaped, and was shaped by, space-related behavior. A substantial component of this relationship involved a reasonably good understanding by each side of the intentions and policies of the other which helped deter conflict. Since the 1960s, "negotiated approaches" have dominated the policy landscape and yielded key space treaties. In addition, the Limited Test Ban Treaty (LTBT) of 1963 prohibited nuclear testing, or any other nuclear explosions, in space, constituting a major step toward space security (Moltz 2008). The two space powers recognized the inherent incompatibility of nuclear testing with other uses of space. Space also facilitated nuclear arms control with the help of surveillance satellites as part of national technical means (NTM). Indeed, NTM was the key enabler for the LTBT and the Strategic Arms Limitation Talks (SALT).

There are numerous TCBMs contained in the existing outer space treaties (e.g., the Outer Space Treaty (OST), the Liability Convention, Rescue and Return Agreement, and the Registration Convention). A number of important TCBMs can be found in the OST, including responsible behavior, international consultations, informing the public of space activities, providing alerts concerning potential dangers to astronauts, observation opportunities, to name a few (Hart 2010). Others involve the sharing of data and information relevant for conjunction analysis, pre-notification of launches, and building international partnerships.

The post-Cold War environment has created a more urgent need for new TCBMs, given the increasing number of space actors, both governmental and nongovernmental. As a result, various forms of TCBMs for space were introduced. At its forty-fifth session in December 1990, the General Assembly adopted two space-related resolutions: the UNGA resolution 45/55A on "Prevention of an arms race in outer space" (PAROS) and the resolution 45/55B on "Confidence-building measures in outer space." The latter resolution requested that the Secretary-General, assisted by a group of governmental experts, conduct a research project entitled "Study on the Application of Confidence-Building Measures in Outer Space." The study, carried out between 1991 and 1993, reviewed various aspects related to the application of different confidence-building measures in space.

Since 2005, Russia has been the main sponsor of United Nations General Assembly (UNGA) resolutions on “TCBMs in outer space activities.” Russia and China are also proponents of a legally binding treaty on banning space weapons in the PAROS context, discussed at the Conference on Disarmament (CD). In 1981, the UNGA Resolution 36/97C on PAROS states that the CD, as the single multilateral disarmament negotiating forum, has the primary role in the negotiation of multilateral agreement(s) on PAROS. In 2008, Russia and China proposed a PAROS legal instrument, namely, a draft “Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat of Use of Force against Outer Space Objects.” PAROS discussions at the CD are, however, stalled due to the broader issue of the CD’s inability to implement a work program. Moreover, there are a number of fundamental shortcomings associated with the PPWT proposal. While the proposal prevents the placement in orbit of any weapons, it basically permits the development, testing, and storage of such weapons. More importantly, no verification regime is envisioned to monitor compliance with the provisions of the proposed treaty.

There have been a number of non-binding proposals to advance space security, both of a top-down and bottom-up variety. As referenced in the introduction, the scale is currently tilted on the side of bottom-up approaches as there is a more urgent need to achieve “critical mass” consensus on how to manage key space activities internationally. The principal argument is based on the premise that building, at least initially, a series of voluntary multilateral agreements can positively influence, over time, the overall space security matrix. TCBMs play a supportive role in a number of bottom-up proposals that are in place, or are presently being pursued. For example, the adoption by the UN General Assembly of the Inter-Agency Debris Mitigation Guidelines in February 2008 is an example of a successful bottom-up approach and is perceived as one of the most significant contributions to preserving the outer space environment since the signing of the OST (Flynn 2011).

Behavior that maximizes the utility and stability of space and minimizes the prospects for misconduct and misperceptions has been promoted under the banner of “best practices guidelines,” “responsible behavior,” “code of conduct,” or “rules of the road.” The most prominent recent proposals that involve voluntary TCBMs are: the Long-term Sustainability of Outer Space Activities (LTSSA) initiative of the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS); the UN Group of Governmental Experts (UN GGE) on Outer Space TCBMs; and the draft International Code of Conduct for Outer Space Activities (ICOC).

At the UNCOPUOS Scientific and Technical Subcommittee (STSC), the topics of space debris, space weather, near-earth objects, nuclear power sources in space, and other topics closely related to space sustainability have been on the agenda for many years. A new item on the agenda of the STSC, originally initiated by France and introduced formally in February 2010, is entitled “long-term sustainability of space activities.” It seeks to adopt a comprehensive approach to preserving space for the coming generations. A Working Group (divided into four expert groups) was established and met for the first time in June 2010 to advance establishment of practical measures, accompanied by voluntary guidelines, to enhance space sustainability (Prunariu 2011). A report, and associated recommendations, is planned for release in 2014. The overarching goal is to formulate "best practices guidelines" for safer operations in space.

Many familiar with the consensus-based work of the UN argue that the evolution of space-related realities is proceeding faster than the UN's uneven pace. It has been pointed out that the UNCOPUOS is perhaps being sidelined by other initiatives, including those of private actors. An example of such an initiative is the establishment, by private telecommunications operators, of the Space Data Association (SDA), which enables sharing of Space Situational Awareness – related data among its members. Indeed, private actors are increasingly relevant for deliberations on space activities. Nevertheless, the UNCOPUOS will remain an essential platform with global reach encouraging TCBMs and other space sustainability-related activities, including establishing a mechanism for improved SSA-sharing (Schrogl 2011).

The Group of Governmental Experts (GGE) on Outer Space TCBMs received its mandate through the UNGA resolution 65/68 of January 2011, initially tabled in the First Committee. The GGE, comprised of fifteen experts from different countries, held three sessions (one in 2012 and two in 2013) and in July 2013 concluded a consensus report addressing the need to implement a range of transparency measures, promote international cooperation, consultations, outreach activities, as well as multilateral coordination to enhance space safety and security. The GGE also endorsed the EU's initiative on the International Code of Conduct for Outer Space Activities, described in more detail below.

In December 2008, the EU introduced a preliminary draft of a Code of Conduct for Outer Space Activities. The latest draft of the Code of Conduct was formally introduced in September 2013. By introducing the draft Code of Conduct, the EU supports the notion that voluntary rules of the road, grounded in best practices among space actors, offer a pragmatic approach to achieving, and strengthening, adherence to norms of behavior in space. The Code of Conduct seeks to achieve enhanced safety, security, and sustainability in space by emphasizing that space activities should involve a high degree of care, due diligence, and transparency, with the aim of building confidence among space actors worldwide.

The European External Action Service (EEAS) is leading this initiative and interacts with other nations through bilateral exchanges and open-ended consultations. The first round of such consultations was held in May 2013 in Kiev, Ukraine. Another round of consultations took place in November 2013 in Bangkok with the ultimate aim of finalizing the text of the Code of Conduct sometime in 2014. The initiative is conducted without prejudice to other existing space-related instruments, albeit it currently resides outside of traditional UN space-related fora.

In short, the main purpose of TCBMs is to reduce the incentives and strengthen the disincentives associated with space-faring actors taking harmful, and potentially destabilizing, actions in space. Such actions could be of technical nature (e.g., noncompliance with space debris mitigation guidelines, satellite malfunction, unintentional interference, inaccurate orbital prediction) or the intentional disruption of satellite services and even an attack on space assets.

## 15.3 Conclusion

While acknowledging their limitations, including the issue of compliance, TCBMs for space now play a major role in diplomatic and other venues. This is partially due to the fact that efforts to establish mechanisms for space governance beyond the current legal regime have faced significant challenges. These include different opinions on the scope and objectives, definitional issues concerning defensive and offensive space systems, verification, and enforcement. This is compounded by the emergence of new space systems and technologies of a dual-use nature and the growing involvement of commercial sector in space activities (Hays 2010).

Space-related cooperation is becoming an essential component of foreign policy planning and decision-making. The rational for richer international cooperation in space is more compelling than ever, given the long lead times of most space-related efforts. Moreover, cooperation of this kind helps reaffirm the principle of the peaceful use of outer space. To cooperate meaningfully, however, countries need to share a common appreciation of the value that a collective approach to space security brings versus a go-it-alone policy. To achieve such a consensus is an increasingly delicate dance as many countries have come to understand the quality of space-derived products and services for their military capabilities. That said, different efforts to address space security, both top-down and bottom-up, will likely continue to proceed in parallel, as the fact that irresponsible acts of one actor can have damaging consequences for all supports a joint interest in the safety, security, and sustainability of outer space activities.

This chapter has by no means provided a complete picture of present TCBM-related activities. The purpose has rather been to introduce how the concept of TCBMs for space could contribute to the normative framework for outer space activities. It is the responsibility of governments to find creative ways to strike a balance between multiplying the benefits of enhanced cooperation and security. Space, in its many facets, has simply become too important to day-to-day life for anything less than the sustained engagement of the highest levels of government, NGOs, and the private sector.

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# Part II

# Space Security Policies and Strategies of States and International Organizations

# Space Security Policies and Strategies of States and International Organization: An Introduction

# 16

Jana Robinson

## Contents

### Abstract

This chapter provides an introduction to Section 2 of the Handbook of Space Security addressing the subject of "Space Security Policies and Strategies of States and International Organizations." It covers expert views on space security policies of established spacefaring nations, including the United States, Russia, China, Europe, and Japan. It also reviews space security policies of three emerging space powers – India, Brazil, and Israel – to showcase different approaches to this strategic portfolio. These approaches range from strict emphasis on the peaceful uses of outer space, in the case of Brazil, to space being a crucial domain of national security, in case of Israel. A combination of these drives is the Indian space program. The section also treats the evolution of U.S.–Japan Space Security Cooperation as well as that of space security-relevant multilateral organizations, including the United Nations (UN), the International Telecommunications Union (ITU), and the International Standardization Organization (ISO).

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## 16.1 Introduction

In contrast to the Cold War period, the space environment today involves some 60 countries and government consortia with different strategic objectives and levels of economic and technological development (Schulte 2012). There are also many commercial satellite operators. Earth observation, communications, and satellite navigation, originally supporting mainly military activities, are now part of day-to-day civilian and commercial life. As a result, there is a growing concern regarding how best to preserve safe, stable, and sustainable space operations over the long term.

Established spacefaring nations like the United States, Russia, and some European countries have developed national policies and strategies that address space security issues. This portfolio is also rich with the agenda of other space powers, such as China. Several nations, including Japan, are in the midst of integrating space security into their broader national security and foreign policy agendas. At a multilateral level, a body of principles and rules governing space activities, including the special international status of outer space and celestial bodies, was established during the second half of the twentieth century. Implementation of these principles and rules has, however, lagged for a number of reasons, including the "asymmetric" interests in space, the growing connectivity between terrestrial tensions and space security, the lack of a track record on the multilateral management of an incident in space, and other considerations.

Fortunately, there are a number of multilateral initiatives designed to advance space safety and security based on fostering responsible and predictable behavior in space. The principal objective of most of these initiatives is to protect the space environment as well as space-related assets from natural and man-made risks and threats. Besides the natural hazards of space operations (e.g., space debris, space weather, and near-Earth objects), intentional threats to space, such as intentional satellite jamming, antisatellite (ASAT) attacks, or cyber warfare, are of increasing concern.

This section of the Handbook introduces different approaches to managing space security on the part of select spacefaring nations (i.e., the United States, Russia, China, Europe, Japan, India, Israel, and Brazil). As will be evident from the content of various chapters, there is, as yet, no consensus on what issues constitute the space security domain. There are also significant differences in the main focus of individual national space programs. There seems, however, to be an agreement concerning the need for an improved dialogue on major space security issues (e.g., space debris, radio frequency interference, space situational awareness, counterspace) as well as enhanced international collaboration on securing long-term sustainability of space activities.

## 16.2 Space Security Policies and Strategies of States

The emphasis on the peaceful uses of outer space coexists with the underlying role of space as an instrument of national security and international prestige. Threats to space assets and activities, both natural and man-made, are multiplying, as evidenced by events such as China's 2007 antisatellite (ASAT) test, the 2009 Iridium-Cosmos collision, and a number of uncontrolled satellite reentries over the past year. The Russian meteor explosion over the city of Chelyabinsk and Earth's encounter with asteroid 2012 DA14, both in February 2013, also served as stark reminders of the potentially devastating consequences of an asteroid, or other near-Earth objects (NEOs), striking Earth.

Man-made threats include intentional disruption of satellite services and even attacks on space assets. Intentional jamming could have damaging military, political, and commercial knock-on effects. A prominent example of such deliberate interference has been the repeated jamming of Eutelsat satellites by a source located on Iranian territory. Other threats include directed or kinetic energy ASAT attack or cyber assaults. Cyber attacks against satellites and ground stations are a rapidly growing concern – and vulnerability – and should be added to the list of political and budgetary challenges to enhance security in both the space and the cyber domains.

Although there have not, as yet, been any serious consequences (at least confirmed reports) resulting from the unintentional incidents, these events have highlighted the need for establishing not only national procedures but also diplomatic processes to facilitate the smooth and efficient management of these types of incidents internationally. Although space threats emanating from natural hazards or technical issues warrant genuine concern, the intentional disruption of, or damage to, space assets and systems would generally involve larger – sometimes far larger – geopolitical stakes.

In the United States, the 2010 National Space Policy reaffirmed the right of all nations to engage in the peaceful uses of outer space and the inherent right of self-defense. It also acknowledges the requirement of "stability in the space environment" and states that the United States will engage in "bilateral and multilateral transparency and confidence-building measures to encourage responsible actions in space." Overall, the United States, as the world's leading space power, encourages a more collaborative approach to the international dimensions of space operations. Russia, on the other hand, is seeking to regain the space prominence it enjoyed during the Cold War. The European Union (EU) is in the process of formulating its space security strategy which would accompany the development of Europe-wide space programs (e.g., the Galileo navigation program). China and India have acquired multifaceted space capabilities with dual-use applications (i.e., both civilian and military). These include satellite communications, Earth observation, and navigation.

Other spacefaring nations seek to strengthen the strategic role of space as well as operational experience. In Japan, space policy has been influenced significantly by the nation's overall foreign and security policy. Since the inception of its space activities, Japan has been reluctant to engage in security-related uses of space, largely due to its Constitution. This has been evolving over the past few years. The country passed the New Basic Space Law in 2008 and developed a National Space Plan in 2009, which has created new opportunities for the involvement of Japan in international efforts to address the most pressing space security-related challenges of the twenty-first century. The past year has seen a number of important organizational changes in Japan’s space policy-making processes and management of space activities. In late June 2012, the Upper House of the Japanese Diet passed legislation that created a new Office of National Space Policy (ONSP) within the Cabinet Office that works toward centralizing control of the planning and budgeting of the country’s space program. Japan also leads the Asia-Pacific Regional Space Agency Forum (APRSAF), the most important regional cooperation platform.

Although the global investments in space were rather stagnant in 2012, several countries witnessed sizable budget increases, including India (51 %) and Brazil (30 %). India, like China, set forth plans for increased investment in space in the coming years, including new launch vehicles, satellite systems, and exploration missions. The Indian Navy, for example, plans to launch its first dedicated military communication satellite this year. India has a GPS augmentation system called GPS-Aided Geo Augmented Navigation (GAGAN) and plans to launch a seven-satellite Indian Regional Navigation Satellite System (IRNSS) that will provide coverage mainly for South Asia. India launched its indigenously developed, dual-use radar imaging satellite, RISAT-1, in April 2012.

Overall, India’s space program has moved from a space applications-oriented program serving its population to one promoting high-profile lunar and planetary science missions and a relatively active military space program. This transition was, in no small part, catalyzed by China’s robust military space posture, development of a human space flight program, its successful 2007 ASAT weapon test, the 2007–2010 Chang’e-1 and Chang’e-2 lunar orbit missions, and development of a lunar rover. India’s Ministry of Defense has established an Integrated Space Cell staffed by Army, Navy, and Air Force officers to determine, along with the Indian Space Research Organization (ISRO), near-term space priorities. India also indicated that it is prepared to conduct an ASAT test, using its antiballistic missile system, if deemed necessary (Covault 2012).

Israel, like many other countries, wants to exploit the dual-use aspects of space to advance economic, commercial, security, civil, and foreign policies. As security in the region has been the country’s key concern, Israel’s military space program has, throughout its history, been the main driver of the country’s space activities. The two principal applications have included communications and reconnaissance. The Shavit launch vehicle, operated by the Israel Defense Forces, was developed to enable Israel to launch its military reconnaissance satellites, the Ofeq series. Israel leverages commercial sales of its aerospace, electronic, and optical technologies and systems to support its national security needs. It has focused on small, low-cost space systems and has acquired expertise in small, lightweight optical imaging systems for satellite missions (Correll 2011). India’s RISAT-2, a radar reconnaissance satellite, for example, was purchased from Israel (in exchange for an Indian launch of an identical Israeli Air Force TecSar satellite). More recently, Israel has allocated more money for its civilian space program, led by the Israel Space Agency (ISA), established in 1983. National security programs are managed by the Ministry of Defense’s Directorate of Defense Research and Development and Israeli Air Force.

Brazil's size, thinly populated land borders, long coastline, and proximity to the equator make it a country with great potential to employ space technology. Indeed, Brazil has the most advanced space program in Latin America. The Brazilian spaceport at Alcântara is located within three degrees of the equator, ideally located for GEO launches. After suffering three major launch failures, Brazil successfully launched a midsized rocket in 2010. A joint Brazil-Ukraine venture to launch Cyclone-4 is designed to break new ground in launcher development (Cyclone-4 satellite launch vehicle is currently planned to debut in 2014). As with other countries, Brazil's quest for advanced technology fuels much of its space and ballistic missile programs.

Brazil's space-related objectives are described in the *Programa Nacional de Atividades Espaciais (PNAE) Planejamento 2012–2020*. Between 2012 and 2014, Brazil set out to indigenously develop a geostationary communications satellite, continue to support the joint China-Brazil Earth Resources Satellite (CBERS) program, develop two indigenous Brazilian space launch vehicles, support its joint Brazil-Ukraine Cyclone launch vehicle program referenced above, and establish a science and technology research satellite program. From 2015 to 2020, additional communications satellites, a radar-based Earth observation satellite, and a geostationary meteorological satellite are to be developed. Brazil also plans to expand its space launch capability (The Space Report 2013).

Brazil's focus on space security is only a recent development. An important step in entering this arena was the first dialogue between Brazil and the United States on this issue in April 2012. It was Brazil's first official exchange on this complex, sensitive subject with another country. Brazil is a firm proponent of the peaceful uses of outer space. A Brazilian expert, for example was a member of the 15-member Group of Government Experts (GGE) on Outer Space Transparency and Confidence-Building Measures (TCBMs), established on the basis of UN General Assembly resolution 65/68 in 2011. At the same time, Brazil is still to be persuaded of the benefits of signing up to the voluntary International Code of Conduct for Outer Space Activities, proposed by the EU.

The growing ambitions of countries in space are gradually being followed by concerns over how to protect space systems that enable vital global information flows. All space actors, no matter their level of capability, can influence the safety, stability, security, and long-term sustainability of the space environment. Accordingly, enhanced space security is not entirely dependent on a common assessment of the threat environment. Although most space-related cooperation will be linked to broader bilateral and regional relations, the recognition that protective measures for space-related assets (including those that are ground-based) are necessary is now generally accepted and provides a useful starting point for policy-makers and security professionals.

## 16.3 International Dimension of Space Security

There is no single, formal international body governing the use of space. There are, however, several existing institutions and rules concerned with the conduct of space activities. The legal core is embodied in the space treaties, especially the 1967 Outer Space Treaty (OST), and five sets of legal principles adopted by the UN General Assembly. The latter principles address the conduct of space activities such as broadcasting via satellites, remote satellite observations of Earth, and general standards for the safe use of nuclear power sources in space. There are a number of resolutions related to outer space such as resolutions on registering space objects (UNGA Res. 1721 B (XVI) of Dec 1961 and UNGA Res. 62/101 of Dec 2007), a resolution on the concept of a "launching state" (UNGA Res. 59/115 of Dec 2004), and others. There are also various bilateral and multilateral practices and agreements that relate to Space Situational Awareness (SSA), a space code of conduct, and other initiatives and mechanisms (Robinson 2011).

In terms of an international institutional framework, the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) occupies an important position. UNCOPUOS has ongoing coordination and cooperative efforts underway in a number of areas within the space security portfolio. Radio frequencies are managed by the International Telecommunication Union (ITU) and its World Radiocommunication Conference. This conference helps the ITU review and, if necessary, revise the Radio Regulations, the international regulations governing the use of the radio frequency spectrum from geostationary and non-geostationary satellite orbits. Another organization, the Committee on Earth Observation Satellites (CEOS), is the most prominent multilateral body engaged in coordination of remote sensing satellites, on a voluntary and nonbinding basis. The World Meteorological Organization (WMO) helps govern the use of weather satellites. Both the CEOS and WMO contribute to the political exchanges taking place in the Group on Earth Observation (GEO).

Coordination of civil services stemming from global and regional satellite navigation systems and geostationary augmentation satellites takes place within the International Committee on GNSS (ICG). The ICG's membership includes nation-state system providers, other interested UN member states, and international organizations that represent major user groups (i.e., not just service providers). This group aims at providing compatible, interoperable, and transparent civil services as well as promoting GNSS technology for use by developing countries. Unlike CEOS or the ICG, the Cospas-Sarsat for satellite search and rescue coordination involves a binding agreement among a smaller number of parties. Even CEOS and ICG have subgroups that seek to achieve consensus among system providers, when necessary. There also exists an International Space Exploration Group (ISEG) covering these activities (Robinson 2011).

Multilateral initiatives seeking to improve global-level governance of space activities include the UNCOPUOS Scientific and Technical Subcommittee's (STSC) Long-Term Sustainability of Outer Space Activities (LTSSA) initiative, a Group of Governmental Experts on Outer Space Transparency and Confidence-Building Measures (GGE on Space TCBMs), and the draft International Code of Conduct for Outer Space Activities introduced by the EU (ICoC). The GGE on Space TCBMs seeks to develop a consensus report of voluntary space TCBMs. The draft ICoC seeks to establish a set of entry requirements for new countries engaging in space activities. Whereas the draft Code of Conduct and the GGE on space TCBMs are political initiatives, the UNCOPUOS LTSSA concentrates on the technical and operational aspects of the responsible uses of space. The candidate LTSSA "best-practice guidelines" will be presented in draft form during the main COPUOS session in June 2013. A final report is expected to be released in the course of 2014.

These initiatives seek to emphasize that space sustainability is a concern of not only space actors, but all beneficiaries of space activities. They are viewed by many as an intermediate step that will keep space activities orderly in the near term. The draft space Code of Conduct, GGE on space TCBMs, and the LTSSA guidelines can be complementary and mutually reinforcing, as they range from the political to technical measures. The technical LTSSA guidelines can later support, at an operational level, an initiative such as the more politically oriented International Space Code of Conduct. In short, the three initiatives are not designed to be "stove piped." Five of the members of the GGE on space TCBMs are regular UNCOPUOS delegates (the Chairman of the LTSSA is also a GGE member).

## 16.4 Conclusions

The shared interests of spacefaring nations, as well as those of the multitude of beneficiaries of space activities worldwide, can be expressed by pursuing space governance in a manner that enables continued exploration and exploitation of space for peaceful purposes. The growing volume of orbital debris, increasing number of space actors, and new space technologies all call for a well-crafted architecture for global space security to respond to the emerging challenges in this environment. Although different countries emphasize varying space capabilities, strengthening space security should be a major priority for all of them.

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# U.S. Space Security Priorities: War, Policy, and Spacepower

# 17

Everett C. Dolman

## Contents

**Abstract**

Space capabilities undergird the United States' military future and the national security policies for space guide development and procurement. As the future is never as clear as a planner wishes, the policies are necessarily broad and, to some, indefensibly vague or provocative. This article traces development in the American way of war and discusses several of the more contentious space policy issues that will come to the fore in the next decades. These include increasing congestion, contestation, and competition in outer space and assessments of rules-of-the-road initiatives, cooperative partnering, space situational awareness, deterrence, and planetary defense.

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## 17.1 Introduction

Even as the United States draws down its fixed military presence around the world, it continues a revolutionary military transformation designed to extend its capacity to act responsively. Space capabilities are the lynchpin of this transformation, enabling a level of precision, stealth, command and control, intelligence gathering, speed, maneuverability, flexibility, and lethality heretofore unknown. This twenty-first century way of war promises to give the United States a capacity to use force to influence events around the world in a timely, effective, and sustainable manner.

Russell Weigley described a long-standing American way of war that was based on an essentially isolationist preference to allow issues beyond its borders to sort themselves out (Weigley 1973). Only when events spilled out of hand and threatened US interests directly did America feel compelled to intervene. Only then did it mobilize for war. In the first half of the twentieth century, however, this model had to be substantially refined. It was predicated on taking the fight to the enemy's shores, away from American soil, but only after other means of influence had failed and the military option was deemed the only one likely to succeed. And then, when America finally chose to bring force, it was *overwhelming* force. The country braced for long buildups. American leaders made the public feel confident in its righteousness. Friendly casualties were to be limited to the extent practical, but damage to the enemy could be maximized. The strategy was suitable in an era when the US homeland was safe from attack, when its industrial production ensured the stockpiling of vital supplies and innumerable armaments, and excess resources could be provided to friends and allies to do the fighting where prudent. In these conditions, America could afford to wait for problems to incubate and mature before reacting with colossal expenditure and terrible force. For the most part, this way of war was effective.

But then came the debacle in Vietnam, where US forces won every battle but lost the war, at home as well as in Southeast Asia. Television had come to war; rampant carnage was available for viewing in every American home. Indiscriminant area bombing was particularly horrific, and from that time forward US leaders would not contemplate using such tactics except for desperate times, when the very survival of the state was at stake. In wars of lesser urgency, those characterized by international theorists as wars for less than the vital national interest, it would be incumbent on America to win the hearts and minds of not just the domestic audience, but of allies, potential allies, and erstwhile enemies as well. Overwhelming force on a broad scale would be ruled out in advance. Success would be achieved through the employment of high-tech means and weapons: by computers, satellites, and whole new classes of technological marvel. America's future wars would be less destructive. They would have far fewer casualties, both friendly and enemy. And they would be short.

That this transformation was well underway became evident in 1991, when US forces defeated the world's fourth-largest military in just 10 days of ground combat. The Gulf War witnessed the public and operational debut of unfathomably complicated battle equipment, sleek new aircraft employing stealth technology, and promising new missile interceptors. Arthur C. Clarke went so far as to dub Operation Desert Storm the world's first space war, as none of the accomplishments of America's new look military would have been possible without support from space (Burgess 1991). Twelve years later Operation Iraqi Freedom proved that the central role of space power could no longer be denied. America's military had made the transition from a space-supported to a fully space-enabled force, with astonishing results. Indeed, the military successfully exercised most of its current space power functions, including space lift, command and control, rapid battle damage assessment, meteorological support, and timing and navigation techniques such as Blue Force Tracking, which significantly reduced incidences of fratricide.

The tremendous growth in space reliance from Desert Storm to Iraqi Freedom was evident in the raw numbers. The use of operational satellite communications increased fourfold, despite being used to support a much smaller force (fewer than 200,000 personnel compared with more than 500,000). New operational concepts such as *reach back* (intelligence analysts in the United States sending information directly to frontline units) and *reach forward* (rear-deployed commanders able to direct battlefield operations in real time) reconfigured the tactical concept of war. The value of Predator and Global Hawk Unmanned Aerial Vehicles (UAVs), completely reliant on satellite communications and navigation for their operation, was confirmed. Satellite support also allowed special forces units to range across Iraq and Afghanistan in extremely disruptive independent operations, practically unfettered in their silent movements.

But the paramount effect of space-enabled warfare was in the area of combat efficiency. Space assets allowed all-weather, day-night precision munitions to provide the bulk of America's striking power. Attacks from standoff platforms, including Vietnam-era B-52s, allowed maximum target devastation with extraordinarily low casualty rates and collateral damage. In Desert Storm, only 8 % of munitions used were precision guided, none of which were GPS capable. By Iraqi Freedom, nearly 70 % were precision guided, more than half from GPS satellites (Testimony of Deputy Secretary of Defense Paul Wolfowitz 2003). In Desert Storm, fewer than 5 % of aircraft were GPS equipped. By Iraqi Freedom, *all* were. During Desert Storm, GPS proved so valuable to the army that it procured and rushed into theater more than 4,500 commercial receivers to augment the meager 800 military-band ones it could deploy from stockpiles, an average of one per company (about 200 personnel). By Iraqi Freedom, each army squad (6–10 soldiers) had *at least* one military GPS receiver.

What space-enabled forces could not do, however, was provide overwhelming support for a continuing occupation of foreign lands. Despite the high-tech advantages of increasing numbers of ground troops, a determined low-tech enemy kept conventional forces bogged down, and the so-called COIN (counterinsurgency) wars dragged on and on. To the extent that surveillance and tracking capabilities helped limit surprise attacks and enabled broad area surveillance, US casualties were probably far less than they might have been, but the inability of American military forces to quickly defeat irregular forces and politically stabilize these regions had severely detrimental effects. More than a decade of war has cost America more than 7,000 of its own young men and women killed and tens of thousands permanently maimed, hundreds of thousands of non-American lives lost, and trillions added to the national debt, contributing in turn to severe economic difficulties at home, stressed American military personnel and their families to unprecedented levels, and far from winning the hearts and minds of the people of those occupied lands may have engendered generations of resentment and mistrust.

As America withdraws, questions are already asked: what was gained? Is America better off now than a decade ago? Were all those lives and all that wealth spent wisely? History will judge, but the current public and administrative attitude appears to be leaning away from massive “boots on the ground” deployments and toward concepts such as Air-Sea Battle and Offshore Balancing. With its economy mirroring the world’s, less will be spent on the military in the next decade, and while America will not give up its preeminent position in world affairs, it will be less likely to intervene abroad with the type of commitments it demonstrated in Iraq and Afghanistan. A return to lighter, faster, highly mobile and technologically advanced strike forces will be evident. Such a military force *needs* space power support.

Given the utility of and reliance upon military assets in space, there is no question the United States must guarantee space access if it is to be successful in future conflicts. Its military has stepped well over the threshold of a new way of war. It is simply not possible to go back to the violently spasmodic mode of combat typical of pre-space interventions. The United States must become highly discriminating in the projection of violence and parsimonious in the intended breadth of its destruction. It must do so with a smaller relative budget. Space is the crux of this transformation.

## 17.2 US Space Security Policy

### 17.2.1 Current US Space Policy

The National Security Space Strategy (NSSS) is subordinate to the National Space Policy (NSP), which outlines and defines the overall direction and emphases of America’s space programs. The most recent NSP, published in June 2010, purports to chart a bold new course. It begins with a simple, declarative sentence: “The space age began as a race for security and prestige between two superpowers” (National Space Policy of the United States of America 2010, p 1). The implication is clear. What has been is now gone, and the future impetus for space development shall be different. Humanities’ reliance on space for an increasingly interconnected global network of finance, trade, production, and security has changed the way we live, “and life on Earth is far better as a result” (National Space Policy of the United States of America 2010).

The previous focus of national space development, born of conflict and propelled by Cold War challenges, must give way to a new era of cooperation.

Much ink is spilt on a renewed commitment to international cooperation, the rights of all nations to pursue the peaceful exploration and use of space, and the continuing leadership role of the United States in these efforts. But "in this spirit of cooperation," within the five guiding principles put forth for all states to adopt and follow, is the recognition that among the peaceful purposes advocated therein the right of the United States to use space "for national and homeland security activities [and] consistent with the inherent right of self-defense, [to] deter others from interference and attack, defend our space systems, and contribute to the defense of allied space systems, and, if deterrence fails, defeat efforts to attack them" is maintained (National Space Policy of the United States of America 2010, p 3). Accordingly, the Secretary of Defense is charged with the development, acquisition, operation, maintenance, and modernization of Space Situational Awareness (SSA) capabilities; developing capabilities, plans, and options to deter, defend against, and, if necessary, defeat efforts to interfere with or attack US or allied space systems; maintaining the capabilities to execute the space support, force enhancement, space control, and force application missions; and providing, as launch agent for both the defense and intelligence sectors, reliable, affordable, and timely space access for national security purposes (National Space Policy of the United States of America 2010, p. 14).

### 17.2.2 The National Security Space Strategy

Consistent with 2010 NSP, the Department of Defense published the 2011 National Space Security Strategy (National Security Space Strategy 2011). This document "charts a path for the next decade to respond to the current and projected space strategic environment"(National Security Space Strategy 2011, p. i). That environment, state the authors, is driven by three trends; "space is becoming increasingly *congestive, contested*, and *competitive*" (National Security Space Strategy 2011, p. 1, Original emphasis). *Congestion* here refers to the increasing clutter in space, primarily in low Earth orbit (LEO) that has come as a natural result of space launches, satellite deployments, and, ominously, antisatellite (ASAT) weapons testing. The DOD tracks more than 22,000 objects in orbit, including more than 1,100 active satellites, to assist in payload identification and collision avoidance. Due to the limitations of tracking objects in space with current sensors, through the filter of the Earth's atmosphere, these are all larger than a human fist. Potentially hundreds of thousands of smaller objects also exist in orbit, where the kinetic impact of a pinhead-size bit of metal or ceramic could destroy a satellite or puncture a space suit. In recent years, two events have significantly increased the size of the debris field; a 2007 Chinese ASAT test that obliterated one of its own derelict weather satellites added approximately 3,000 trackable chunks of debris and the 2009 collision of a Russian Cosmos and an American Iridium satellite, resulting in 1,500 additional pieces of observable debris (National Security Space Strategy 2011, p. 2). Not only is this effective physical pollution of LEO expanding exponentially, but the useable radio-frequency spectrum is increasingly stressed, causing usually unintentional interference between satellites and reducing bandwidth-carrying capability.

Space is also increasingly *contested*. "Today space systems and their supporting infrastructure face a range of man-made threats that may deny, degrade, deceive, disrupt, or destroy assets. Potential adversaries are seeking to exploit perceived space vulnerabilities" (National Security Space Strategy 2011, p. 3). The emphasis here is on direct military intervention against US space assets that disrupt the stability and security of the space environment, though it includes unintentional interference through so-called irresponsible behavior.

*Competition* refers to the declining relative edge in space capabilities held by the United States. The NSSS maintains that America's competitive advantage in space access and market share is dissipating, and its lead in space technology is eroding as more states enter into the strategic environment. Assured access to space is challenging America's "abilities to maintain assured access to critical technologies, avoid critical dependencies, inspire innovation, and maintain leadership advantages. All of these issues are compounded by challenges in recruiting, developing, and retaining a technical workforce" (National Security Space Strategy 2011).

Accordingly, the NSSS articulates three objectives: (National Security Space Strategy 2011, p. 4)

- Strengthen safety, stability, and security in space.
- Maintain and enhance the strategic national security advantages afforded to the United States by space.
- Energize the space industrial base that supports US national security.

Consistent with the three objectives are five strategic approaches: (National Security Space Strategy 2011, p. 5)

- Promote responsible, peaceful, and safe use of space.
- Provide improved US space capabilities.
- Partner with responsible nations, international organizations, and commercial firms.
- Prevent and deter aggression against space infrastructure that supports US national security.
- Prepare to defeat attacks and to operate in a degraded environment.

These objectives and approaches are consistent with national policy guidance, and, while broad enough to allow for maximum interpretation, are also problematic for traditional means and methods of a martial organization to satisfy them. The NSSS affirms that presidential guidance will be the basis of future planning, programming, acquisition, operations, and analysis for space and that its own policies, strategies, and doctrine will follow suit – but also recognizes that in a fiscally constrained political setting, these will also be subordinated to "feasibility and affordability assessments and cost, benefit, and risk analyses" (National Security Space Strategy 2011, p. 12). Therein lays the rub: "our ability to achieve long-term goals for space depends upon our fiscal responsibility and making tough choices, such as between capability and survivability" (National Security Space Strategy 2011).

## 17.3 Issues and Challenges

No nation relies on space more than the United States – none is even close – and its reliance grows daily. A widespread loss of space capabilities would prove disastrous for American military security and civilian welfare. America's economy would collapse, bringing the rest of the world down with it. Its military would be obliged to hunker down in a defensive crouch while it prepared to withdraw from dozens of then-untenable foreign deployments. To prevent such disasters from occurring, the US military – in particular the US Air Force – is charged with protecting space capabilities from harm and ensuring reliable space operations for the foreseeable future. As a martial organization, the Air Force naturally looks to military means to achieve these desired ends. Specific to this mandate are guidelines in three core areas: congestion, contestation, and competition. Each is addressed in the following sections, with a fourth section focused on policy guidance not made – those issues and challenges conspicuous in their absence.

The overall mandate is broad – too broad, perhaps, for a military service traditionally constrained by tight political oversight. Nonetheless, the NSSS concludes with the overarching statement that "Active U.S. leadership in space requires a whole-of-government approach that integrates all elements of national power, from technological prowess and industrial capacity to alliance building and diplomatic engagement. Leadership cannot be predicated on declaratory policy alone. It must build upon a willingness to maintain strategic advantages while working with the international community to develop collective norms, share information, and collaborate on capabilities."

### 17.3.1 Congestion

> We seek to address *congestion* by establishing norms, enhancing space situational awareness, and fostering greater transparency and information sharing. Our words and deeds should reassure our allies and the world at large of our intent to act peacefully and responsibly in space and encourage others to do the same (National Security Space Strategy 2011, p. 13).

As near-Earth space becomes increasingly populated, it is in the interest of all spacefaring states to coordinate their activities to limit collisions and radiofrequency overlap and to adjudicate disputes. The optimum solution is an international traffic management system that fairly allocates positions, priorities, and operating parameters and has some capacity to enforce rules or sanction defections, but such a body is still many obstacles from fruition. In the meantime, the United States now supports diplomatic initiatives to achieve a common understanding or rules-of-the-road approach similar to coordination efforts for international air and sea operations. These widely accepted norms allow states and firms to anticipate the behavior of others and thus maximize their activities responsibly, peacefully, and safely. While the devil is indeed in the details, the overall concept is acceptable, and the NSSS supports diplomatic engagement and consensus regarding what voluntary data standards, best practices, transparency and confidence-building measures, and norms of behavior that should be included. This consensus can include arms limitation and control measures so long as they are "equitable, effectively verifiable, and enhance the national security of the United States and its allies" (National Security Space Strategy 2011, p. 6).

Several rules-of-the-road approaches are currently offered, foremost among them the European Union's Code of Conduct for Space and the US-based Stimson Center's proposal.[1] Both seek to regularize space operations by focusing on space debris mitigation, space traffic management, and collision avoidance. Adherence to the rules is voluntary, but it is presumed that if the top spacefaring states endorse one of these codes and abide by their principles, others would follow and cooperation in space would increase. Despite the essentially positive and widely acceptable intent of these coordinating efforts, significant opposition within the United States is evident. The Marshall Center is prominent among critics, arguing that the rules would be unnecessarily binding while decreasing overall US national security (DeSutter et al. 2011; Kueter 2011).

The critical issue for any effort to reduce the problems of an increasingly congested environment is the international capacity for space situational awareness (SSA). Currently, the United States is the primary provider of the location and movement of all near-space objects, and the DOD is the owner of most of the assets that track space activities. While all launching states are required to register the initial intended operating parameters of satellites placed into orbit, only the United States is able to monitor actual global satellite parameters, and as previously noted, these parameters are publicly and freely shared. They are, however, quite limited because all monitoring and observation assets are located on the surface of the earth. These include optical and radio-frequency observations and sophisticated over-the-horizon radar that, due to atmospheric distortion and other limitations, can provide only a partial picture. What is needed to increase visibility, highlight malfeasance or nonadherence to international norms and conventions, and develop collision-avoidance procedures that take into account the myriad of small but deadly detritus surrounding the planet is a robust space-based SSA. Without such a system, nations will continue to effectively fly blind in orbit.

Two problems persist in the fielding of such a capability, both related to the overall goal of increasing transparency. First, it would be tremendously expensive. Second, its transparency would always be in doubt.

A network of surveillance satellites that collect data of on-orbit obstacles and activity is needed, with visible and multispectral real-time imaging capability. So far, only the DOD, with its mandate to ensure freedom of access to space in times of peace and to deny that access to adversaries in times of conflict, has established the limited means to do so from the surface and is stretched too thin in its space

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[1] For details, see Council of the European Union (2010) Krepon et al. (2007)

requirements to do so on orbit. Its output must be weighed against national security priorities, and so users of the data will correctly be concerned that full disclosure is unlikely – military secrets persist and critical sources and methods of intelligence gathering are always protected. If an international consortium were to somehow manage to fund and deploy a network of space-based SSA, it seems likely that only members would be assured of full access. But let us imagine that this UN or other large consortium-funded organization gave full access to all who requested it, states with critical space capabilities could be expected to develop countermeasures to cloak sensitive activities. But let us go further still and imagine that fully transparent activities in space is possible, would it be desirable?

Transparency as a confidence-building measure is a purely Western notion. To Eastern strategists, perfect knowledge of one's capabilities and intentions is sure to promote conflict, for it allows a clever adversary to plan the demise of an opponent in detail. Sun Tsu insists that one must always project uncertainty; never let another know how strong or how weak you are. Indeed, successful criminal activity is predicated on either perfect randomness or absolute knowledge of the victim's movements, capabilities, assets, and predilections.

Synchronization and coordination, possible through anticipations of future behavior and precise awareness of the environment, maximizes operational efficiency. But it also allows for free riders and otherwise overmatched actors to plan for and execute devastating attacks on the status quo. There is no panacea in policy where control is absolute. While behavioral norms, greater transparency regarding adherence and defection, and information sharing undoubtedly reduce problems of congestion, they do not necessarily reduce problems of contestation and competition and may unintentionally exacerbate them.

### 17.3.2 Contestation

> We seek to address the *contested* environment with a multilayered deterrence approach. We will support establishing international norms and transparency and confidence-building measures in space, primarily to promote spaceflight safety but also to dissuade and impose international costs on aggressive behavior. We will improve and protect vital U.S. space capabilities while using interoperability, compatibility, and integration to create coalitions and alliances of responsible space-faring nations. We will improve our capability to attribute attacks and seek to deny meaningful operational benefits from such attacks. We will retain the right and capabilities to respond in self-defense, should deterrence fail (National Security Space Strategy 2011, p. 13).

Deterrence is easy to announce and impossible to measure. It can only be reliably determined when it fails; its success is only ever implied. Its virtue is its relative cheapness (compared with defense). By threatening retaliation if an undesired action is taken, the key aspect of successful deterrence is credibility. Credibility has two vital aspects. *Can* the state fulfill its obligation should a transgression occur – that is, does it have the capacity to carry out the threatened retaliatory action – and is the state *willing* to fulfill its obligation should deterrence fail? Does it have the political and moral authority to do so?

The NSSS offers several means for establishing credibility. These are establishing rules and norms so that violations are clear and irrefutable; interdependence through strategic partnering with other states, in essence making an attack on one spacefaring state an attack on several; developing enhanced SSA so that violators can be identified and, presumably, held accountable for their actions; creating defenses and/or operationally responsive capabilities to add costs and deny operational advantage from an attack on space assets; and last, fielding and maintaining the capacity to carry out deterrent threats with force. All of these, if known to a potential aggressor, increase the credibility of the deterrent.

Unfortunately, deterrence in and for space is highly problematic. A recent Project RAND study concludes that "Deterring adversaries from attacking some U.S. space systems may be difficult due to these systems' inherent vulnerability and the disproportionate degree to which the United States depends on the services they provide" (Morgan 2010, p. ix). Given that loss of space support would be an asymmetric advantage for any nation potentially at war with the United States, the deterrent threat itself is weakened by the act of violation. The means for increasing deterrent credibility listed above are generally in line with the recommendations in the RAND study, but all are fraught with uncertainty.

Engaging multiple nations and corporations through strategic partnering in specific space systems would make those shared assets less lucrative targets to at least members of the consortium and increase the likelihood of an international response should those systems be negated by an outside force. But the types of systems that could readily be partnered are not those that tend to provide force enhancement. National assets for intelligence collection, precise real-time targeting and assessment, indications and warning, and other military support activities are not communally operated. This is unlikely to change in the near future. When military communications are carried on civilian or commercial payloads, they are currently dedicated transponders or purchased as exclusive buyers and are limited to overflow or excess capacity. The only reasonable deterrent today is against broad area or orbit-denying attacks, such as a high-altitude nuclear burst or a dirty engagement in LEO with the intent of making all satellites in the belt vulnerable through the addition of massive amounts of damaging debris. Such an attack is not likely from any state that currently relies heavily on space for its commercial or security infrastructure, but could be seen as highly lucrative to states that are generally cut off from the international community. Such rogue states are already outside the bounds of international norms and are generally perceived as atypical deterrence problems already.

The necessity for enhanced SSA to identify aggression and other violations of international norms has already been discussed and is absolutely necessary to enhance deterrent credibility. But also discussed are the current lack of enhanced SSA and the difficulties of extending SSA capabilities in the future. The DOD does not have sufficient funding to do so, and cooperative agreements with partner states to field such systems are notoriously inefficient. Enhanced public SSA, while a noble goal, is far from reality.

Increasing defensive capabilities for satellites, through hardened exostructures against kinetic impact, enhanced shielding against electromagnetic pulse (EMP) and other directed energy attacks, and high-speed shutter control or other anti-lasing defenses are expensive and heavy, adding enormously to launch costs (currently about $25,000 per kilogram of payload weight). A more efficient means of ensuring that an attack on space assets would be unlikely to achieve debilitating effects is to increase the number of satellites on orbit (redundancy in capabilities), reduce reliance on large, multiple-function single-node failure satellites with expensive-but-fragile components and extended 20–30-year life expectancies (replacing them with networks of small, single-function satellites that are replaced at regular intervals with the latest technologies), and commit to a responsive space-lift capability with the capacity to rapidly replace damaged satellites and to surge satellite populations in crisis. All of these would make limited attacks on spacecraft extremely unlikely to have meaningful positive results for the attacker and would clearly deter states who currently might view a loss of US space-based capabilities as an asymmetric advantage. All of the defensive options listed here would go a long way to enhancing deterrent credibility, but all are extremely expensive relative to business as usual and reliance on diplomatic promises and the hope that a deterrent threat will never have to be carried out.

Finally, fielding the capacity to carry out deterrent threats should they fail is the most critical and least discussed of the credibility enhancing factors offered. The United States has clearly stated that an attack on any of its space systems will be countered within the bounds of international law, treaties to which the United States is a partner, and in accordance with the inherent right of states to self-defense (National Security Space Strategy 2011, p. 10). No details are offered, but as the United States has no plans to deploy or field space-based weaponry, and its ground-based anti-space capabilities are extremely limited, any response would have to be land, sea, air, or cyber-based – called cross-domain response.[2] Indeed, committed anti-military space weapons advocates argue that a deterrent in space is unnecessary as sufficient retaliatory capacities already exist in other, terrestrial domains. Bruce DeBlois, Richard Garwin, R. Kemp, and Jeremy Marwell claim that “Even without space weapons, the United States could respond to an attack on its satellites with its unmatched terrestrial military capabilities. Adversaries would expect a heavy toll to be exacted as a result of any attack on U.S. satellites; that expectation alone would almost certainly suffice to deter any such attack” (Deblois et al. 2005). Echoing the sentiment, Yousaf Butt wrote in *The Bulletin* of *Atomic Scientists*, “A better way to deter attacks on U.S. satellites would be for Washington to make clear that any attack on its space assets would be considered an attack on U.S. soil and result in a heavy conventional retaliatory attack” (Butt 2008). At issue is credibility. Clearly the United States has the capacity to rain down *heavy* damage through conventional means, but would it do so? An unseen attack on a machine in space could have severe

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[2] See, for example, Manzo (2012)

effects on the United States, no doubt. But these would not be direct; no human lives would be lost. Would the United States risk war on earth to retaliate for an attack on a machine in space? Would it bomb a launch site or control facility on earth, a factory that produces satellite components in another state, or some other terrestrial target to make good its deterrent threat? Really?

Of the four means of enhancing credibility – increased partnering, enhanced SSA, defensive countermeasures, and assured military retaliation – only the latter is available now, and its reliability is severely overstated.

### 17.3.3 Competition

> We seek to address *competition* by enhancing our own capabilities, improving our acquisition processes, fostering a healthy U.S. industrial base, and strengthening collaboration and cooperation. Our objectives are to improve safety, stability, and security in space; to maintain and enhance the strategic national security advantages afforded to the United States by space; and to energize the space industrial base that supports U.S. national security. Achieving these objectives will mean not only that our military and intelligence communities can continue to use space for national security purposes, but that a community of nations is working toward creating a sustainable and peaceful space environment to benefit the world for years to come (National Security Space Strategy 2011, pp. 13–14).

The heyday of space spending is long gone. Despite tremendous advantages and technical spin-offs from space research, the US taxpayer has little stomach for more spending on space capabilities that cannot be shown to immediately pay dividends. This is especially true for space exploration – NASA's budget relative to its peak in the 1980s is one-eighth of its former place (de Grasse-Tysen 2012) – and military space spending. Budget constraints forecast for the next decade make entering into new or potentially defining technological developments such as those suggested in the contestation section of the NSSS are highly doubtful (Office of the U.S. Air Force Chief Scientist 2010).

The current vogue is to move away from government spending on fundamental space research and transition military development to the private sector. This has two fundamental problems. First, the most pressing national security needs are rarely profitable without massive government backing. Currently, the United States has no follow-on heavy-lift commercial launch capability to geostationary orbit. Without government assurance of massive subsidies, no such system is likely to be developed privately. China and Russia already offer cut-rate services to geostationary orbit, and the European Space Agency's Ariane rockets are fully booked for the next half decade. The preeminent example of national security initiatives having enormous positive commercial impact is the USAF's Global Positioning System (GPS) satellite. In the 1970s, there was simply no economic forecast that showed profitability in any GPS system. The US military had a need for better standoff targeting and global location support, and so GPS became an Air Force need. Recognizing that a lower-grade capability could be advantageous to global commerce, GPS was initially deployed with a tiered availability and its lower resolution output offered freely to all users – with the caveat that it could be denied in times of crisis. Within a decade, GPS had transformed the global economy. Just-in-time supply and secure Internet financial transactions alone add billions of dollars in efficiencies to global commerce, and new applications for precise geolocation are developed on a daily basis. The commercial and security reliance on GPS today is such that the USAF simply cannot deny its benefits in any conceivable future scenario; it is a global good provided freely to all yet paid for entirely out of the USAF/DOD budget. If market forces had been the primary means to determine the profitability and thus feasibility of space-based geolocation, it likely never would have been developed.

Second, while free markets create the highest variety and quality of goods at the lowest possible prices – a contention that is undeniable in the aggregate – markets do not raise all goods nor participants in them equally. Indeed, it is the capacity of markets to create imbalances that is the engine of its potential. Poor products and performers are weeded out, and successful ones are rewarded by amassing capital. When enough capital is amassed, large (expensive new) ventures are possible. The problem, of course, is when a single participant gains so much advantage that he or she can exercise a monopoly. A monopoly is a market failure, because no internal mechanism exists to purge monopolies. Only an external force – government – can return the market to beneficial competition. For this reason, free market advocates including Adam Smith, Alexander Hamilton, David Ricardo, Milton Friedman, and Jagdish Bhagwati have insisted that states reject the market where national security is at stake. In a pithy analogy, surely it is not in the best interest of America or any other state to rely on the market to supply its nuclear deterrent needs.

There is, of course, a reasonable counter. A managed market can outperform a free market in providing security needs when carefully monitored and controlled. Alexander Hamilton's recommendations to place exorbitant tariffs on the import of guns from Europe were intended to spur domestic industry that otherwise could not compete. An inferior American-made weapon at a fraction of the price of a quality English flintlock would sell. In the twentieth century, such managed market economies outperformed centrally planned economies in times of peace – though not *in* war or when war was imminent. Even the United States moved to a fully managed economy for war materials from 1941 to 1945, the tendrils of which continue today. And this less-managed market system may be the model for moving to more commercially prompted innovation in the near future. Space war is not projected any time soon, and a managed market economy is more likely to follow promising new technologies than a government bureaucracy-driven one. But, should war that could include engagements in space become probable, the United States could find itself outmatched by others taking advantage of temporary imbalances that are sure to occur.

## 17.4 Challenges and Issues Not Addressed

The following issues are not adequately addressed in the policies above nor are they generally discussed in the majority of forums on the responsible use of space power.

The list is not complete or exclusive. They are simply issues or sub-issues that need to be given full consideration.

**Rules of the Road:** If the primary issue is debris contamination, then a treaty requiring signatories not to use kinetic strikes or any other form of satellite engagement that knowingly adds to the total amount of debris in space would be more than palatable to all spacefaring states. Unfortunately, these proposals currently make demands on signatories that cannot be agreed to with the intent of compliance. Limits on all weapons in space, requirements to renounce the first use of force, equal access to national intelligence collections, and the like are piled on to treaty proposals in the manner of so-called poison pill bills in legislatures. A rules-of-the-road approach does not have to insist that *all* rules must be hashed out and agreed upon before *any* rules can take effect. Start with low-hanging fruit. As compliance with generally acceptable rules develops, more cooperation can and should emerge.

For example, requiring transponders on all spacecraft is widely accepted as a reasonable measure and has precedent in air and sea law. Currently, satellites are tracked by optical means or military radar. This is ineffective for secure collision avoidance and finding satellites that are accidentally placed into incorrect orbit – or those the launching state simply does not want to be found. Just as transponders are required on all aircrafts, it seems a reasonable step to do the same for all spacecrafts. This issue does not need to be entangled with any others and could be agreed upon piecemeal as the start of comprehensive rules-of-the-road approach leading to a more stable and self-enforcing body of international space law.

**Debris Mitigation:** While there is a great deal of effort to limiting new debris in orbit, very little attention is paid to eliminating the debris already there. It is generally acknowledged that debris, left alone will eventually decay into the atmosphere or in other manners naturally be expunged, but this is expected to take many thousands – if not hundreds of thousands – of years. Limiting additional debris is a start, but the vast majority of dangerous contamination happens from routine rocket launches and satellite operations. Unless some form of cleanup is foreseen, or human space activities come to a halt, the debris field will increase.

Unfortunately, debris in orbit is a global problem. This makes it unlikely that a single state or consortium will altruistically take on the job unless it can be shown there are additional benefits or profit in doing so. Here is a reasonable entry for the US military. Terrestrially, the US Navy clears hazards and ensures access to international waters as a routine function. This is usually when human-made hazards including deliberately scuttled ships, mines, or other anti-access detritus is evident or when pirates or international criminals (human trafficking, drugs, etc.) restrict safe passage. The US Air Force could receive the go ahead to do so, but to be able to remove debris from orbit would be tantamount to a weapons capability and will likely be opposed internationally. Lasers or directed energy beams could eliminate small particles and push larger bits into the atmosphere. Such a capacity could also target adversary space assets in times of conflict. A tug pulling a debris sweeper, similar to minesweeping operations, would have to be extremely powerful and highly maneuverable to be effective. Such systems would also need to be robust – stronger than current capabilities and able to withstand greater stresses than the current space-fleet – and thus would have inherent defensive capabilities that may be unacceptable to many states. Such capabilities would also require a tremendous increase in SSA and greatly increased heavy launch capacity. These will be expensive, and the advantages in transit and upgraded military capacities in space may well be unacceptable to the American public.

But, the capacities needed to give America a robust and responsive space architecture may be palatable to those who advocate a global space infrastructure to defend the earth from meteors, comets, and other non-terrestrial threats.

**Planetary Defense**: Loosely allied in their concern for an eventual (probably assured) collision with a cosmic body that could wipe out life as we know it, an increasing number of scientists, academics, and popular writers are pushing for an international space defense capability. While war in space seems far more likely than a planet-killing or even city-destroying event in the next half century, creating the capacity for deflecting a cosmic collision would provide any entity doing so the ability to target the earth with extraordinary force. All of the components for an earth-dominating space force are the same for planetary defense: deployment of extremely comprehensive and detailed SSA for indications and warning, development of high-power kinetic weaponry (strong enough to deflecting kilometer-wide asteroids or comets) or high-output-directed energy-beaming satellites (or possibly a lunar or other fixed point installation), and launch on demand or routine heavy-lift earth-to-space capability supporting the vast network of space capabilities deemed necessary. The United States must either lead these efforts or at minimum ensure that no other state can control this ability should international support become evident. Regardless of one's opinion on the validity of planetary defense, it is important that space policy account for it.

**Weapons in Space**: Although every national space policy since the first one issued in 1958 under Eisenhower has reaffirmed America's right to self-defense and reserved the option of weaponizing space should the national interest require it, little detail on how or why space could or should be weaponized has been provided. America and the world need an open debate on the merits of military action in, through, and from space.

## 17.5 Conclusions

The world economy is so intrinsically linked to support from space that should a major outage of satellite capacity occur, financial and trade markets could collapse. A recession spanning the globe would ensue, and security tensions would exacerbate. The increasingly chaotic international environment would be further destabilized by the disastrous incapacitation of US military power. Without the assuredness of space-based surveillance, communications, and navigation support, American and allied military forces would be ordered to hunker down in defensive crouch while preparing to withdraw from dozens of then-untenable foreign deployments.

Such a scenario is not only possible – given the growing investment and reliance on space as a national power enabler – it is increasingly plausible. An attack against low Earth orbit from a medium-range ballistic missile adapted for detonation in space could cause inestimable harm to the national interests of developed and developing states alike. Deterrence may forestall such an attack, but without a space-based defense, any decision by an adversary to disrupt space capabilities on orbit is likely to succeed.

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# U.S. Space Security and Allied Outreach

# 18

Jana Robinson

## Contents

### Abstract

As one of the two early space pioneers, the United States is acutely aware of the evolving nature of the space environment and the need to pursue space security policies that correspond to these new realities. This chapter reviews the main space security elements of the U.S. space policy, including international collaboration in this area. Special attention will be given to the U.S. outreach to Europe and Japan as case studies of American efforts to advance the international dimension of its space security objectives. The underlying rationale is that space security is directly relevant to the broader U.S. defense and strategic dialogue with these key allies. This comparative analysis hopes to illuminate U.S. priorities in its bilateral dialogues with Europe and Japan. In so doing, this chapter seeks to establish the importance of these allies to the U.S. ability to assess, prevent, and preempt various space security threat scenarios.

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## 18.1 Introduction

The U.S. Department of State defines space security as "space sustainability, stability, safety, and free access to, and use of, space to support vital national interests of all nations" (Rose 2012). The principal objective of most space security initiatives is to protect the space environment, as well as space-related assets from natural and man-made risks and threats. The U.S. Air Force Space Command is responsible for assuring that the following capabilities are available for the military's various missions: protected, survivable communication, and missile warning capabilities; position, navigation, and timing (PNT); space situational awareness (SSA) and battlespace awareness; defensive and offensive space control; assured space access/spacelift and responsive spacelift; satellite operations (i.e., telemetry, tracking and commanding, maneuvering, monitoring state of health, and maintenance and sub-functions for the spacecraft and payloads); tactical communications; space-to-surface intelligence, surveillance, reconnaissance (ISR); terrestrial environmental monitoring; and nuclear detonation detection (Space News Editor 2012).

As one of the two early space pioneers, the United States is acutely aware of the evolving nature of the space environment which now involves some sixty countries and government consortia with different strategic objectives, levels of economic and technological development, as well as many commercial satellite operators. The National Security Space Strategy (NSSS) of 2011 states that "an evolving strategic environment increasingly challenges U.S. space advantages" and space is "becoming increasingly congested, contested and competitive." Space is viewed as increasingly congested due to the amount of space debris, operational and non-operational spacecraft, and high demand for the radio-frequency spectrum. It is more contested with the development and deployment of counterspace systems by more nations and non-state actors. Finally, it is more competitive primarily due to lowered market-entry barriers (NSSS 2011).

Accordingly, the U.S. actively engages in various bilateral, multilateral, and international space security exchanges to protect its space assets from orbital debris as well as potential "mishaps, misperceptions, and mistrust, and irresponsible actors and their actions" (Rose 2012). The topics of discussion include space debris mitigation and remediation, collision avoidance, radio-frequency interference, counterspace activities, SSA sharing, space transparency and confidence-building measures (TCBMs), and overall space crisis management.

The U.S. seeks to engage all spacefaring nations, including new space entrants, in discussions on some of the less politically sensitive space security challenges, such as orbital debris mitigation and remediation, behavioral space norms, and space sustainability. These discussions are mostly led by the Department of State. The U.S. is also trying to structure its dialogues with close allies to address some of the more sensitive space security challenges, including those that are defense-related. The Pentagon takes the lead here, in coordination with the State Department. While progress is being made toward a consensus on threats such as space debris, the often sensitive debates on man-made threats (e.g., counterspace) continue to prove challenging and remain somewhat underdeveloped. The public diplomacy dimension and the protection of privileged information are also vexing issues.

Adequate appreciation of the vulnerability of existing space assets and the priority attention that defending these assets deserve on the part of senior U.S. and allied policy-makers still appears to fall short of what is required. This includes Europe and Japan, where the U.S. often encounters a certain amount of political and cultural aversion to conversations concerning the widely understood relevance of space-based assets to terrestrial conflict scenarios and the vulnerability of these assets to attack in the event of hostilities. As a result, the U.S. is treading a fine line when seeking to align its domestic space security priorities with those of its allies.

This chapter reviews briefly the main space security elements of U.S. space policy, including international collaboration in this vital area. Special attention is accorded to U.S. outreach to Europe and Japan, as case studies of U.S. efforts to advance the international dimension of its space security objectives. Europe has been selected due to the long-standing transatlantic security partnership with established security channels. Japan was chosen not only because it is the closest U.S. ally in the Asia-Pacific region but also because Japan faces possibly the most imminent space security threat due to its increasingly strained relationship with China, a country which has invested heavily in sophisticated counterspace capabilities.

The bottom line is that space security is directly relevant to the broader U.S. defense and strategic dialogue with its allies. This comparative approach hopes to illuminate the U.S. priorities as they are pursued through bilateral channels with Europe and Japan. In so doing, this chapter also hopes to establish the importance of these allies joining the U.S. in the ability to assess, prevent, and preempt various space security threat scenarios. Precrisis planning, which can bolster the international security environment, is likewise integrated into the broader foreign and security policy deliberations of these allies.

## 18.2 U.S. Space Security Posture

The Obama Administration and the U.S. Congress are grappling with a number of challenging issues related to the future of manned space flight, the role of the private sector in civil space endeavors, and the proper level of fiscal investment to pursue various space-related agendas. Although there are a number of outstanding questions, President Obama set forth several objectives relevant to space security in his June 2010 U.S. National Space Policy (NSP). The appreciation of space assets as a component of overall U.S. defense planning, including the need to defend these assets against the counterspace capabilities of potential adversaries, is clearly identified. This policy document states that: “The United States will employ a variety of measures to help assure the use of space for all responsible parties, and, consistent with the inherent right of self-defense, deter others from interference and attack, defend our space systems and contribute to the defense of allied space systems, and, if deterrence fails, defeat efforts to attack them." (NSP 2010).

This document also instructs that the Secretary of Defense and the Director of National Intelligence, in consultation with other agencies and departments, take on the following tasks to underscore the attentiveness of the U.S. to the counterspace mission, including more robust allied coordination in the arena. They are, among other tasks, to:

- "Develop and implement plans, procedures, techniques, and capabilities necessary to assure critical national security space-enabled missions. Options for mission assurance may include rapid restoration of space assets and leveraging allied, foreign, and/or commercial space and nonspace capabilities to help perform the mission;"
- "Improve, develop, and demonstrate, in cooperation with relevant departments and agencies and commercial and foreign entities, the ability to rapidly detect, warn, characterize, and attribute natural and man-made disturbances to space systems of U.S. interest."
- The Secretary of Defense is to: "Develop capabilities, plans, and options to deter, defend against, and, if necessary, defeat efforts to interfere with or attack U.S. or allied space systems;"

Concerning international cooperation, the Secretary of State is called upon to:

- "Demonstrate U.S. leadership in space-related fora and activities to: reassure allies of U.S. commitments to collective self-defense; identify areas of mutual interest and benefit; and promote U.S. commercial space regulations and encourage interoperability with these regulations;"
- "Lead in the enhancement of security, stability, and responsible behavior in space;"
- "Promote appropriate cost- and risk-sharing among participating nations in international partnerships;" and
- "Augment U.S. capabilities by leveraging existing and planned space capabilities of allies and space partners."

The Pentagon's National Security Space Strategy (NSSS) also emphasizes the sustainability of the space environment, international cooperation, and government reliance on commercial space capabilities. A Department of Defense Directive of October 18, 2012, seeks to systematize the NSP and NSSS for defense purposes. Where the NSP, for example, asserts the U.S. right to self-defense in space and states that purposeful interference with space systems or infrastructure is a violation of a nation's right, the Directive declares that: "Purposeful interference with U.S. space systems, including their supporting infrastructure, will be considered an infringement of U.S. rights. Such interference, or interference with other space systems upon which the United States relies, is irresponsible in peacetime and may be escalatory during a crisis. The United States will retain the capabilities to respond at the time and place of our choosing." (DOD Directive 3100.10 2012).

The Pentagon points out potentially serious consequences resulting from malevolently exploiting the vulnerabilities of U.S. space assets, employing the concept of deterrence, including collective deterrence. This is also evident from the document's emphasis placed on promoting responsible behavior among spacefaring nations, including through transparency and confidence-building measures (TCBMs). It also underscores the importance of efforts to improve U.S. space situational awareness capabilities, including through integrating data from foreign and commercial sources (Space News 2012).

## 18.3 U.S. Space Security Collaboration with Europe and Japan

The space policy agendas of the U.S., Europe, and Japan are continuously evolving into new configurations. It is, however, quite clear that space security is being accorded greater priority not only in Washington but also in Brussels and Tokyo. This should be regarded as good news with respect to the potential for allied cooperation to ensure that, when common threats are taken into account, new policies, strategies, as well as investments complement, rather than duplicate, one another. The fact that the U.S., Europe (mainly France and Germany), and Japan are still in the early stages of strengthening Space Situational Awareness (SSA) capabilities, however, is evidence that allied cooperation on the defense-related aspects of space security has not adequately progressed. It is partially due to efforts by Europe and Japan to ensure that their internal architecture is well developed prior to serious bilateral or multilateral outreach, in part due to domestic political barriers. Fortunately, there is a willingness on the part of these allies to consider a prudent level of complementary space security capabilities.

Overall, current discussions on this topic among allied capitals are in a relatively nascent stage. This makes the coming few years especially important in working on bottlenecks to current collaboration. Questions to be addressed include: what constitutes an incident or conflict in space and proportionate responses that may be necessary? what are the implications of the active involvement of nongovernmental actors in space and their role in the enhancement of the space security portfolio? what transparency and confidence-building measures could be jointly promoted? and how does one configure effective space crisis planning and response mechanisms? (Robinson 2011). The three allies would be more effective in promoting their respective space security objectives by identifying areas where mutually reinforcing collaboration exceeds the benefits of competition. In short, it is past time for an allied space security architecture at least at the level of terrestrial defense planning and asset allocation.

Success in breaking free of various constraints, such as competition over space-related technology that prioritizes indigenous development over collaboration, or political aversion to discussing defense-related realities of the "peaceful uses of outer space," will depend on hard-headed political leadership, an emphasis on shared interests, realistic milestones, and improved handling of sensitive data and information. After all, there are a number of space security challenges caused by non-intentional factors, such as space weather and orbital debris, which require governments to focus on space security even in the absence of an adequate appreciation for intentional threats or the political will to tackle them. The advancement of space security is not entirely dependent on the same assessment of the threat environment. The reality that protective measures for space-related assets (including those that are ground-based) are necessary is generally accepted by all spacefaring nations and provides a useful starting point for policy-makers and security professionals within allied governments.

There is still significant ambiguity as to which assets (including civilian and commercial) are considered to be of national security relevance and how best to deter and defend against behavior threatening the integrity of those assets. This is true for the U.S. as well as Europe and Japan. As long as Europe and Japan lack an independent capability to defend their space assets, or respond effectively to an attack, however, they will depend on their partnerships with the U.S. to discourage potential adversaries from disrupting or even attacking their assets. Active US involvement is also needed to promote behavioral norms for space.

## 18.4 U.S. Space Security Collaboration with Europe

One of the 2010 NSP's goals states that the U.S. will seek to "strengthen stability in space through: domestic and international measures to promote safe and responsible operations in space; ..." (NSP 2010). Under strategic approaches, the U.S. NSSS lists "partnering with responsible nations, international organizations and commercial firms" in order to "augment the U.S. national security space posture across many mission areas." It also asserts its leadership in "building coalitions of like-minded space-faring nations" (NSSS 2011). European allies, who are, according to President Obama, the "cornerstone" of the US efforts to maintain global security, are natural partners for preserving a secure space environment.

The EU is well aware of how the changing strategic environment is impacting on Europe's security, including instances of international instability nearby (e.g., the Middle East) as well as in more distant parts of the world (e.g., Afghanistan) and the effects of a more globalized world. The EU seeks to be a global player capable of mobilizing economic, commercial, humanitarian, diplomatic, and military resources to shape the international environment. Space security-related cooperation with the U.S. represents a vital building block of its overall space strategy.

That said, the development and utilization of space assets for Europe's crisis management is being supervised by the EU, in close collaboration with the member states and ESA. The European External Action Service (EEAS), which defines the coordination and resourcing mechanisms associated with the use of space for terrestrial crisis management and "external action," has not, as yet, systematically integrated space security into its operations. Accordingly, in terms of operationalizing space security, the U.S. allies in Europe are currently better positioned at the individual member state level to offer actual capability as well as value added with regard to militarily sensitive contingency planning.

There are different opinions as to whether Europe' space security collaboration with the USA should be conducted through NATO. With most space assets owned by individual member states that remain reluctant to "contribute" such assets to NATO, some view the organization as ill-equipped, at least at this juncture, vis-à-vis the required resources to plan collaboratively on the management of potential space crises.

NATO's Allied Command Transformation (ACT) located in Norfolk, Virginia, published in April 2011 a report entitled, "Assured Access to the Global Commons" (Maj.Gen. Barrett et al. 2011). It was designed to stimulate attention within NATO to the need to maintain unfettered access to shared domains, identified by this report as including maritime, international airspace, cyberspace, and outer space. The interest in preserving access to these domains serves broad economic and security interests. Indeed, this report had its idea continuing through the Multinational Experiment 7 (MNE-7) that took place over the course of 2011 and 2012 and which evaluated these four domains. (The Multinational Experiment (MNE) series have been running since 2001. Each 2-year experiment is designed to examine a topical defense and security issue and MNE-7 (the latest in the series) is focused on access to the global commons. The experiment involved 17 participating countries and NATO and ran until December 2012).

A space handbook, prepared as part of the MNE-7, entitled "Space: Dependencies, Vulnerabilities and Threats," includes, in its case study 5, a narrative on how space operations are conducted and managed in practice in the continuous presence of threats and hazards and an environment of military secrecy and commercial sensitivity (i.e., how the space and ground segments of space operations are successfully managed). It separates space operations into four separate functions, which include monitoring space, analysis, operations planning, and operations conduct.

The NATO ACT report on global commons and the MNE-7 exercise is anticipated to help define the potential roles and responsibilities of member states in assuring access to these areas for economic and national security purposes and establish a more defined role for NATO to advance allied collaboration on a range of issues, including space security.

One of encouraging recent developments was the inclusion, for the first time, of seven NATO members in the "Schriever Wargame 2012 International" (i.e., Denmark, France, Germany, Greece, Italy, the Netherlands, and Turkey) (NATO ACT 2012). The Space Innovation and Development Center on behalf of the U.S. Air Force Space Command facilitated this war game. Also attending were Australia, Canada, and the UK. A NATO official observed, "This is a significant development in what was predominately a U.S. event and reflects the need to cooperate and share information to develop future capabilities that benefit NATO collectively" (Hale 2012). Indeed, the "Smart Defense" initiative launched by NATO at its Chicago Summit in May 2012, designed to optimize and leverage defense spending, appears to include equipment acquisitions relevant to counterspace.

Clearly, this important step is overdue and hopefully represents a harbinger of much more such collaboration to come. A NATO official went on to state, "The U.S. has been encouraging its European allies to invest more in these capabilities and allowing them to participate in the Schriever Wargame provides an opportunity to work together on space-based systems that will be increasingly important to future observations" (Hale 2012). A threshold appears to have been crossed by the U.S. Air Force Space Command concerning the trade-off involved in keeping the circle small to protect highly classified information and broadening alliance cooperation and burden sharing in addressing the counterspace challenge. The objectives of the war game were also instructive:

- "Examine options for optimizing space efforts from participating allies and Australia in support of a notional NATO expeditionary operation;
- Identify ways to increase the resilience of space capabilities in a contested environment through expanded international and private-sector cooperation and coordination;
- Determine operational challenges associated with defense of space capabilities employed in support of the operation;
- Examine the operational integration of cyber into defense of the space domain;
- Expand understanding of the operational benefits of broader international participation in combined space operations."

Overall, the current European international agenda on space security is dominated by the debates and diplomacy associated with the proposed International Code of Conduct for Outer Space Activities initially introduced by the EU in 2007 and revised in 2010, 2012 and 2013. The Code has, over the past few years, attracted priority attention internationally. Although the EU is a relatively recent space actor at a global level, it is striving to establish policies and procedures that protect Europe's space assets. This is especially important at a time when current EU policy heavily emphasizes the development of independent European access to, and use of, space (including Europe's next-generation launching capability, Earth Observation, navigation, space-based terrestrial crisis response infrastructure, and SSA).

There has been significant debate regarding the Code, with those opposed to the plan highlighting the lack of adequate negotiation procedure, as well as verification, compliance, and enforcement provisions of the proposal, and the flexibility and exceptions it appears to grant to signatories for actions that are deemed to be in their respective national interests. It is feared that the Code will tie the hands of responsible governments and open the door for irresponsible regimes to gain an upper hand through "cheating" or adopting a liberal, self-serving interpretation of the agreement. There has not been sufficient discussion of – or solutions provided for – what member states might do, in reasonably precise terms, in the event that the identified rules of the road are violated. That said no better approaches have, so far, been tabled.

One brighter point, however, is increasing transatlantic emphasis on SSA, which holds great importance for both the civilian/commercial and military/defense dimensions of Europe's overall space policy. It also represents a potential "icebreaker" to broader defense-related space cooperation. In this area, France and Germany are Europe's leaders in national space surveillance capabilities. Although Europe is today largely dependent on the U.S. Joint Space Operations Center (JSpOC), which houses the bounty of data collected by the U.S.

Space Surveillance Network and reports to USSTRATCOM, it has committed to developing an indigenous SSA capability.

Although there is no doubt that the incidental or naturally caused space security issues are significant, the real challenge for the EU will be to address man-made threats to a secure space environment. The implications of increasingly sophisticated counterspace systems in the hands of less-responsible actors are still to be addressed in Europe. At the same time, the EU is increasingly sensitive to this disparity in transatlantic treatment of international threats to a secure space environment, and accordingly, Brussels is seeking to play catch-up on this element of space security. NATO is likewise keen to establish a more robust role in space, but it is constrained by its lack of institutional resources, space assets, and willingness on the part of member states to expand their modest contributions of sensitive technologies and capabilities.

## 18.5 U.S. Space Security Collaboration with Japan

A special security relationship has long existed between the U.S. and Japan, including the preexisting framework it provides for security-related conversations. Space policy has been influenced significantly by the nation's overall foreign and security policy. Since the beginning of its space activities, Japan has been reluctant to engage in security-related uses of space, largely due to its constitution. This has been evolving over the past few years. The country passed the New Basic Space Law in 2008 and developed a National Space Plan in 2009, which has created new opportunities for the involvement of Japan in international efforts to address the most pressing space security-related challenges of the twenty-first century. The Strategic Headquarters for Space Policy was established in the Cabinet in August 2008 in order to reorganize Japan's space management structure and coordinate space-related activities with other ministries (e.g., MEXT, METI, MOFA, JMOD).

The year 2012 has seen a number of important organizational changes in Japan's space policy-making processes and management of space activities. In late June 2012, the Upper House of the Japanese Diet passed legislation that created a Office of National Space Policy within the Cabinet Office that works toward centralizing control of the planning and budgeting of the country's space program.

Although in the U.S. it is the Air Force that has preeminence over the space domain, in Japan, the Maritime Self-Defense Force (MSDF) is probably best equipped to serve this function. Reasons include their resource base, expertise and field experience leveraging space-related assets for sea-lane protection, and the administering of missile defense cooperation with the U.S. via their AEGIS-equipped destroyers and joint SM-3 missile program. Moreover, the MSDF tends to have primacy in theaters from which the most likely threats – including to space-related assets – are likely to emerge, such as the East China Sea.

Since 2005, the main institutional framework for the U.S.-Japan interaction on bilateral security issues has been the Security Consultative Committee (SCC), informally known as the "2 + 2 Ministerial" involving the U.S. Secretaries of

Defense and State and the Ministers of Foreign Affairs and Defense from Japan. Within the “2 + 2 Ministerial” structure, government officials have been generally encouraged of late by the progress made over the relatively short period of time that space has been included as a serious topic of discussion. The Japan-U.S. Joint Statement made during former Japan’s Prime Minister Yoshihiko Noda’s trip to the White House in April 2012 called for bilateral measure to “deepen cooperation regarding…space and cyber space security,” among other items (Weitz 2012). Specific joint projects are now being discussed, including in the area of SSA.

Engagement on SSA is viewed by Japanese policy-makers as an important aspect of space security, as well as broader security-related cooperation. Accordingly, Japan seeks to expand gradually its involvement in international SSA-related discussions and cooperation (especially with the U.S.), as well as to develop a framework for strengthening its own SSA capabilities. For this purpose, the Japan Space Forum (JSF) organized, with the support of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), an International Symposium on Sustainable Space Development and Utilization for Humankind. The JSF convened a second SSA Symposium in spring 2013.

Notwithstanding this progress, space security remains largely absent from the short list of leading issues on the bilateral strategic agenda, which are presently dominated by the pressing day-to-day challenges of troop deployments, base locations and relocations, the Iranian nuclear crisis, Afghanistan funding, maritime intrusions, missile defense, and other important topics. In short, the dialogue on space security has not yet earned a permanent seat at the table. Elevating the importance of space security within the bilateral security relationship should be a priority in the period ahead. Of course the realm of the possible in such discussions has only recently been expanded in the wake of the above-referenced legislative changes.

The inclusion of space security within the “2 + 2 Ministerial” is evidence that such a scenario is viewed as realistic enough to warrant some level of security-minded consideration. Interestingly, the Obama Administration’s NSP included a section that called upon departments and agencies within the U.S. government to identify areas for international cooperation and offered as a possible example the “use of space for maritime domain awareness” (NSP 2010). This would be a logical area for Japan to assert itself. This might be accomplished by forging a tighter space security relationship with the USA, and possibly Europe, which leverages the existing experience of the Japan’s MSDF with missile defense, the use of space assets, and maritime domain awareness and takes full advantage of the door opened in this area by this Presidential policy document.

## 18.6 Prospects for the Advancement of U.S. Space Security Priorities Through Collaboration with Europe and Japan

As evidenced from the above, the U.S. is well positioned to bring together the space security communities of Europe and Japan and lead an allied space security architecture that is comprised of its bilateral collaboration with Europe and its bilateral relationship with Japan. To do so effectively, the U.S. should find ways how to enhance its coordination role. This could include:

- The improvement of the interagency (e.g., NASA, the Department of Defense, the Department of State) reporting structure for proper coordination of space security policy outreach.

  The Department of Defense strays, from time to time, into diplomatic conversations with foreign partners that are better suited to be led by the Department of State (often included in such sessions). It is similarly common for NASA to answer questions posed by foreign partners that might better have been posed to the Department of Defense. The National Security Council (NSC) could bring executive oversight to the agencies involved as well as overseeing the conversations with allied partners that are often perplexed over who they might best meet with for specific collaborative discussions on issues related to space crisis planning. The problem today appears to be that the NSC has not been sufficiently mandated to take on this role.
- Systematic implementation of the National Security Policy's directives with regard to allied or international cooperation (the Department of State currently places priority on diplomatic discussions involving the International Space Code of Conduct and the pursuit of other multilateral initiatives such as the Long-Term Sustainability of Outer Space Activities under the UNCOPUOS or the Group of Governmental Experts (GGE) on Outer Space Transparency and Confidence-Building Measures under the UN First Committee).

  Despite the many references in the NSP to incorporating allies into the U.S. space security posture, it appears that the reality of the existing dialogue with close allies, such as Europe and Japan, has often not lived up to those objectives. As noted above, the NSP calls for developing options for leveraging allied space capabilities to enhance system resiliency, promoting cost and risk sharing among international partners and augmenting U.S. capabilities by leveraging the present and future space capabilities of allies. Implementing a collaborative framework will require greater assertiveness and determination on the part of the U.S. in the period ahead.

## 18.7 Conclusions

The U.S. is leaning toward a view that, with the increasing number of space actors, collaboration with other countries, especially its allies, is the most prudent way to ensure space sustainability and protect its space assets over the long term. The dialogue, and some concrete action, has been mainly in the arena of nonmilitary threats to safe and secure space operations (e.g., space debris, Space Situational Awareness, space transparency and confidence-building measures, etc.).

Addressing potential adversary's temptation to disrupt or attack U.S. and allied space assets remains, understandably, compartmentalized. The future challenge for the U.S. will lie in the decision of how to expand collaboration without putting at risk sensitive information. It should prove helpful that Europe is awakening to the urgent need for the EU, and NATO to address the increasingly contested space environment and Japan is restructuring its space policy management in such a way as to accommodate and streamline space security priorities. This may provide a window of opportunity for the U.S. to present realistic defense-related space requirements.

It will be up to Europe and Japan, however, to integrate effectively space security into their broader foreign and security policies and to collaborate more substantively with the U.S. on issues of mutual importance (e.g., intentional disruption of space-related services, kinetic attack on space assets). Should an incident occur, there would likely be little to no time for planning/policy debates. If the U.S. and its allies are not in front of these scenarios, they will definitely be playing catch-up in a perilous environment with especially high stakes.

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# U.S. - Japan Space Security Cooperation

# 19

Scott Pace

## Contents

**Abstract**

Japan and the United States have a long history of civil space cooperation. Space security cooperation has, however, been limited by Japanese government restrictions on military uses of space. Those restrictions have been changing in recent years in response to both domestic political changes and changes in the Asia-Pacific and global security environment. This chapter reviews recent development in Japan, the current state of US-Japan space security cooperation, and where cooperation might occur in the future.

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## 19.1 Introduction

The initial period of the Space Age was characterized by the superpower competition between the United States and the Soviet Union. Japan did not see itself as a global power and it developed indigenous space capabilities in order to establish a degree of independence. While China and Japan both launched their first satellites in 1970, there was no sense of a race between Asian countries, but rather of a need to be included in the ranks of countries with space capabilities. Japan's pacifist constitution and alliance with the United States were important factors in limiting interest in gaining its own military space capabilities (Suzuki 2011).

The development of space launch systems in the 1970s and the decision to join the Space Station effort in the 1980s placed the United States at the center of Japan's international space cooperation for several decades. There was a great deal of national pride in Japan being the first non-Western country to be a developed, industrialized economy. As a result of rapid postwar economic growth through the 1980s, the development of space capabilities was seen as affordable and a necessary part of "catching up" to the United States. Japan's export-led growth created serious trade frictions with the United States, however, and this led to a series of disputes and negotiations. One of the most significant trade agreements for space was a 1990 Super 301 trade *Agreement on Satellite Procurement* that prevents Japan from protecting commercial satellite procurements from foreign competition. This agreement opened Japanese markets for US satellite manufactures and blunted the ability of Japanese manufactures to gain international market share.

The establishment of the Asia-Pacific Regional Space Agency Forum (APRSAF) and the decision to acquire its own "information-gathering satellites" in the 1990s signified Japan's recognition of the importance of regional space developments to its national interests. The Japan Aerospace Exploration Agency (JAXA) plays a major organizational role along with the support from the Japan International Cooperation Agency (JICA). APRSAF is a somewhat informal consultative body that organizes conferences and workshops on practical applications of space. Attendees come from virtually every country in the Asia-Pacific region, including China, and with the exception of the North Korea. In contrast to the regional benefits of civil space cooperation sought by APRSAF, Japan's information-gathering satellites (IGS) and ballistic missile defense programs are a direct result of security concerns poised by North Korea and, to an unspoken degree, by China.

The US space cooperation with Japan is the deepest and most extensive of any Asian country. As of 2009, seven Japanese astronauts have flown on 12 Space Shuttle missions. Japan is a founding partner, and the only Asian member, of the International Space Station (ISS) program. Japan contributed a major laboratory module (Kibo) and provides unmanned cargo resupply with its H-2 Transfer Vehicle (HTV). Unmanned science missions cover all areas of Earth, space, and planetary science. Most recently, examples include the Hayabusa asteroid sample return mission, the Kaguya lunar orbiting satellite, and the Global Precipitation Measurement (GPM) mission in which Japan will launch a US satellite.

Japan today is a leading space capable country and has "caught up" to Europe, Russia, and the United States for most practical purposes. However, the end of the superpower rivalry in space has not meant the end of regional rivalry. The rise of China, India, and South Korea, economically and militarily, has coincided with advances in their space capabilities as well. Space technologies are quintessential examples of dual-use, and advances in human spaceflight and deep space scientific exploration also have military and political significance (Moltz 2011). Looking ahead, Japan is facing new issues and choices for its space activities. With the passage of a new Space Basic Law in 2008, Japan's Self-Defense Forces have greater flexibility to develop, own, and operate satellites for military purposes. At the same time, budget constraints on new discretionary spending are more severe than ever. In this environment, a central question will be how and to what degree the United States and Japan engage in space security cooperation.

## 19.2 Japanese Policy Constraints

The unique nature of the postwar Japanese constitution, specifically Article 9 that renounces war as sovereign right of the nation, has resulted in a number of important policy constraints on Japan's military capabilities. Broad domestic political support for constraints on Japan's Self-Defense Forces has also limited the development of dual-use space capabilities. When the National Space Development Agency (a predecessor to JAXA) was created in 1969, Diet Resolutions were passed that required Japanese space activities to be "nonmilitary." This was done to underscore Japan's commitment under the 1967 Outer Space Treaty that its space activities would be exclusively for "peaceful purposes" (Aoki 2009). This was a unique interpretation among other signatories of the Outer Space Treaty who interpreted space activities as being for "peaceful purposes" if they were merely "nonaggressive."

Japan and the United States signed a series of diplomatic notes (Aoki 2009) that enabled US firms to license technologies that enabled Japan to develop larger and more capable space launch vehicles (e.g., the N series based on the US Delta launch vehicle). These license arrangements came with many restrictions on how the technology could be used and with limited insight into manufacturing processes. Japan declined US offers to participate in the development of the Space Shuttle program in the 1970s and sought instead to develop a new generation of more powerful space launch vehicles without US license restrictions. They succeeded in what became the H-2 series of launch vehicles. The lack a domestic military market has meant a relatively low flight rate compared to the United States or Russia. This H-2 has been used to send cargo to the International Space Station and launch science missions, but it has proved too expensive to be commercially competitive.

Many countries, particularly in Europe and Russia, compensate for limited domestic aerospace markets by seeking export opportunities. Unfortunately for Japanese industry, Japanese policy has been to place tight restrictions on arms exports, including most aerospace goods and services. The "Three Principles" that have been the basic policy for Japanese “arms” exports since they were declared in the Japanese Diet in 1967 ban exports to (1) communist bloc countries, (2) countries subject to arms exports embargo under the UN Security Council resolutions, and (3) countries involved in or likely to be involved in international conflicts (Ministry of Foreign Affairs of Japan 2012). The one exception was the United States due to the unique alliance relationship. As weapons system developments became more expensive and more complex, multinational cooperative programs have become more complex, but Japan’s ability to participate in them has been limited due to concerns that Japanese technology could be sent overseas in violation of the Three Principles. As a result, Japan is facing increasing difficulty in affording the acquisition of first-tier military capabilities solely on its own or with the United States as its only partner.

Notwithstanding the record of actual cooperation, there have been only a few intergovernmental agreements directly concerned with space cooperation between the United States and Japan. The most notable and complex is the intergovernmental agreement (IGA) for the International Space Station (NASA 2012). Other agreements are the previously mentioned 1969 “Exchange of Notes” which allowed for Japanese adaptation of Delta launch vehicle technology, the 1990 “Agreement on Satellite Procurement” which resulted from Super 301 trade agreement negotiations, and the 1998 “Joint Statement on Cooperation in the Use of the Global Positioning System” which has helped avoid trade frictions in one of the most visible examples of dual-use space technology, GPS. Cooperation on GPS led to close US-Japan consultations on the design of a regional satellite navigation augmentation system, the QZSS (Quasi-Zenith Satellite System), to ensure interoperability with GPS. The first QZSS satellite was launched on September 11, 2010.

While Japan continued to avoid developing specifically military space applications, the Japanese Self-Defense Forces (JSDF) have utilized space starting in the mid-1980s. For example, in 1985, the Maritime Self-Defense Force (MSDF) bought receiving equipment to obtain information provided by the US Navy’s FLEETSAT satellite. The Japanese government used what was termed the “generalization theory” in which the JSDF could use commonly available satellites or satellite with commercially equivalent capabilities. For most countries, the military has access to space capabilities that are denied to civilians. In the case of Japan’s military, they can have space capabilities as long as civilians already have access to their equivalent. A similar invocation of the “generalization theory” was used (Sawako 2009) to allow the acquisition of “information-gathering satellites” under the argument that the spatial resolution of the IGS imagery data was similar to those of US commercial remote sensing satellites (e.g., IKONOS).

## 19.3 Pressure for Change

With the end of the Cold War, it might have been expected that Japanese constraints on military space activities would have remained in place. Instead, the proliferation of ballistic missiles with the capability to reach Japan and increasing Chinese military capabilities have spurred a reexamination of Japan's space security posture. In particular, Japan began paying increasing attention to ballistic missile defense as illustrated by the chronology below:

- 1995–1996 – China "brackets" Taiwan with Dong Feng-15 missiles during the Third Taiwan Straits Crisis.
- April 1995 – The Japanese Defense Agency (JDA) commences a study of possible ballistic missile defense (BMD) architectures and costs.
- August 31, 1998 – North Korea Taepodong-1 missile flies over northern Japan.
- December 2003 – The Japanese government decides to adopt a BMD system for the defense of Japan.
- March 2007 – A Patriot PAC-3 terminal defense is deployed at Iruma Air Base. This is Japan's first ballistic missile intercept system.
- December 2007 – The JDS Kongo successfully conducts the first SM-3 missile flight test. This is Japan's first ballistic missile midcourse intercept capability.
- September 2008 – The first successful PAC-3 flight test conducted completely by Japanese personnel.
- September 2010 – JDS Kirishima successfully tests Aegis BMD upgrades.
- April 2012 – Patriot PAC-3 batteries deployed to Okinawa and around Tokyo, and Aegis BMD destroyers deployed in anticipation of North Korean Unha-3 launch attempt.

The 1998 Taepodong-1 launch and overflight of Japan was a particular shock to the Japanese public and government. It prompted Japan to acquire its own reconnaissance satellites as well as ballistic missile defenses. The first IGS was launched in 2003 and Japan today maintains a combination of electro-optical and radar imaging systems. Unlike ballistic missile defenses, the Cabinet Satellite Intelligence Center (CSIC), not the Japanese Ministry of Defense (JMOD), operates the IGS system (Kallender-Umezu 2011). In effect, the IGS system reports directly to the Prime Minister's Office.

### 19.3.1 The Space Basic Law

The most significant change in recent years to Japanese space policy was the passage of the Space Basic Law in 2008. The most important aspect being to change the 1969 Diet Resolutions regarding the use of space for "peaceful purposes" in complying with the 1967 Outer Space Treaty and other international laws. Japan now allows for dual-use and military space activities, still in compliance with Article 9 of the Japanese Constitution, as long as they are "nonaggressive" – the same interpretation as used by the United States and other spacefaring countries.

The legislation was developed by Takeo Kawamura, a leader in the Liberal Democratic Party that had dominated Japanese politics for much of the postwar era. The bill was not exclusively an LDP project but found support from the opposition Democratic Party of Japan (DPJ) and smaller Shin Komeito Party. There were common concerns within all parties with strengthening Japanese industry and security through the use of space (Yamakawa 2011). The final bill sought to:

1. Ensure a rich, secure, and safe life.
2. Contribute to enhancement of security.
3. Promote the utilization of space for diplomacy.
4. Create an energetic future by promoting R&D in forefront areas.
5. Foster strategic industries for the twenty-first century.
6. Contribute to the environment.

Under these objectives, the bill contained five chapters: (1) fundamental principles regarding space development, (2) primary responsibilities of government in space development, (3) creation of a basic space plan, (4) establishment of space development strategic headquarters, and (5) adjustment of legislation related to space activities. With regard to space security, Article 2 states that space development will be conducted in accordance with international commitments, including the Outer Space Treaty. Article 14 allows the government to take measures that would promote both national and international security.

The Strategic Headquarters for Space Policy consisted of all Japanese ministers but primarily the Minister for Space Policy, the Chief Cabinet Secretary, and the Prime Minister. A Cabinet Secretariat, headed by a Secretary-General, was set up to support the strategic headquarters. In addition to process reform, the new law also called for a Space Basic Plan to implement the new priorities. In June 2009, a Space Basic Plan was released that addressed nine program areas, divided into systems and programs (Yamakawa 2011):

Systems
A: Land and ocean observing satellite system contributing to Asian and other regions
B: Global environmental change and climate observing satellite system
C: Advanced telecommunication satellite system
D: Positioning satellite system
E: Satellite system for national security

Programs
F: Space science program
G: Human space activity program
H: Space solar power program
I: Small demonstration satellite program

Some of the areas, such as space science and human space flight, are traditional ones that JAXA has been pursuing for years. Others, such as remote sensing and telecommunication, represent areas of particular interest to Japanese industry seeking export markets. Others, such as positioning satellites and a “satellite system for national security,” have dual-use capabilities now specifically allowed for in Japanese law.

### 19.3.2 Implementation Challenges

The Japanese government is facing many difficult issues that have affected the implementation of the policy priorities called for in the Space Basic Plan. Slow economic growth, large government deficits, an aging population, the economic and military growth of China, potential instability in North Korea, and the continuing social effects of the March 11 disaster would be challenging for any Japanese government. The situation has been made more difficult by continual changes in the most senior government leadership since the DPJ came to power after the 2009 elections, displacing the long-ruling LDP.

In the next two years, there were four ministers in charge of space policy:

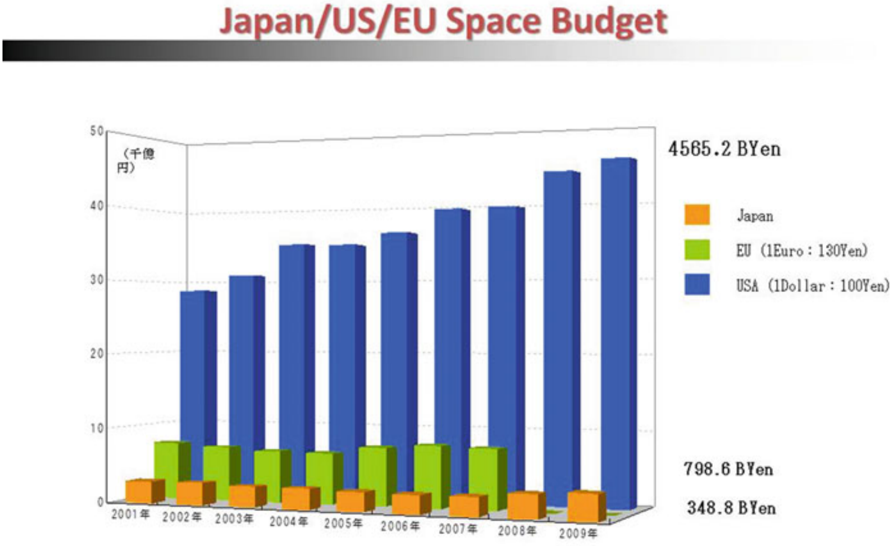
- Minister S. Maehara – July 2010–September 2010
- Minister B. Kaieda – September 2010–January 2011
- Minister K. Gemba – January 2011–August 2011
- Minister M. Furukawa – September 2011–September 2012
- Minister S. Maehara – October 2012–December 2012 (second time)

Masakazu Toyoda was the first Secretary-General for the Strategic Headquarters for Space Policy, beginning during the LDP rule under Prime Minister Taro Aso. Dr. Hiroshi Yamakawa was the second Secretary-General, serving successively under each of the four ministers listed above, all from the DPJ. On one hand, this turmoil would seem to make the implementation of a new space policy more difficult. On the other, the ministers who have held the space portfolio have each been considered talented and capable individuals who continue to have important roles in the DPJ as well as the current government. This may result in a broader awareness of space issues at the most senior levels of Japanese political leadership.

The most immediate implementation challenges to Japanese space ambitious have been overall limits on discretionary government spending. Japanese space spending is modest compared to the United States and Europe as shown in Fig. 19.1 below. It should be noted that data for Europe in 2008 and 2009 is missing in the original chart but that European space activities did not cease for those years.

As in the United States, Japanese space budgets are expected to remain flat at best in the next decade. Thus, there will not be funding for any major new initiative without reductions in existing programs. The DPJ has indicated an interest in space activities that provide more immediate benefits to Japanese security and economic interests than to pure science or exploration, the traditional interests of JAXA. Minister for Space Policy Motohisa Furukawa gave a speech in January 2012 (Furukawa 2012) that outlined what he saw as the close relationship between Japanese economic and foreign policy interests:

> For example, we can contribute to those countries in Southeast Asia that are considering the introduction of Earth observation satellites, in terms of agriculture, floods, and coastal erosion. Our country is now proposing the *Disaster Management Network for the ASEAN Region* that would strengthen disaster management in the Asia region by using satellites. We would like not only to export the equipment and technologies separately, but also to export the entire system including everything from the business program design to operation as packages from this time forward.



出典：日本航空宇宙工業会　「平成20年度宇宙産業データ ブッ

**Fig. 19.1** Japanese, U.S., and European space budgets (Yamakawa 2011)

JAXA represents the dominant majority of space-related spending in Japan, and shifting funds from traditional commitment such as the International Space Station and science program will not be easy. The International Space Station partnership is more than a science program, it is central to relations with NASA, and Japanese astronauts are popular in Japan. Similarly, the success of the Hayabusa asteroid sample return mission in 2010 resulted in congratulations from Prime Minister Kan to JAXA and three commercial films. The powerful symbolic, and thus political, value of space science and exploration was underscored by domestic public enthusiasm for visible space achievements.

Recognizing the difficulty of reallocating space resources, the Japanese government in 2012 made further reforms to consolidate control of space policies and programs at senior political levels. The Secretariat for the Strategic Headquarters for Space Policy was moved to the Cabinet Office and gained more direct budgetary authority. The former Space Activities Commission under the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) was abolished, and a space policy advisory panel of outside experts was created to advise the Cabinet Office and Cabinet Ministers (Okuno 2012).

The Space Basic Law changed Japanese national policy, but the law governing JAXA as an administrative agency remained unchanged. In February 2012, the Japanese government decided to allow JAXA to engage in dual-use and defense-related activities, and Diet legislation was introduced to approve these changes. They would take effect within 1 month after publication of the law (Kyodo 2012). JAXA continues to be under the direct supervision of MEXT, but other agencies such as the Ministry of Foreign Affairs (MOFA); the Ministry of Economy, Trade, and Industry (METI); and the Ministry of Defense (JMOD) are expected to have input to the Cabinet Office on space matters.

### 19.3.3 Relations with the United States

In general, the United States has viewed the recent changes in Japanese space policy as positive. In particular, the United States welcomed the September 2011 decision to proceed with deployment of the Quasi-Zenith Satellite System, designed to augment GPS services in the Asia-Pacific region. The QZSS will be developed, deployed, and operated under the Cabinet Office, not JAXA. As with the information-gathering satellites, Japan has chosen to place visible dual-use space programs at the level of the national government rather than operate them inside an existing ministry or agency. It is unclear how many "special cases" can or should be made for space program like the IGS and QZSS, however. There are some calls for a single space agency that would do both civil and defense-related work, but it is not clear how such an organization would work.

In recent years, there have been increasing discussions of extending security cooperation to space matters. The United States and Japan regularly hold meetings for the respective defense and foreign ministers in what are known as "2 + 2" consultations. The last meeting in 2011 issued a joint statement (Clinton et al. 2011) that highlighted four specific space topics for cooperation (emphasis added):

> The Ministers recognized recent progress to deepen our bilateral space security partnership through the U.S.-Japan Space Security Dialogue and possible future cooperation in areas such as *space situational awareness*, *a satellite navigation system, space-based maritime domain awareness* and the *utilization of dual use sensors*.

Engagement in SSA cooperation would create opportunities for closer integration of Japan with the closest US allies, such as Australia, and Canada. Cooperation on space-based enhancements to Maritime Domain Awareness cooperation would create opportunities for engagement with nations from the Indian Ocean to the Japanese home islands – an area of special importance as Indian and Chinese naval capabilities grow. Space-Based Early Warning could aid in monitoring the obvious threat from North Korea but would also provide important complimentary and integrated capabilities against Russian and Chinese missile launches.

As a specific near-term project, the concept of placing dual-use payloads on Japanese satellites has been discussed at staff levels. For example, small Overhead Persistent Infrared (OPIR) payloads could be "hosted" on QZSS satellites to enhance missile warning information. This would be consistent with the dual-use functions of QZSS and provide a capability that could be compatible with US warning systems just as QZSS itself is highly compatible with GPS. There are other, more expensive and technically advanced options such as Space-Based Infrared Systems (SBIRS) as well as simpler, less expensive ones such as Commercially Hosted Infrared Payload (CHIRP) that will be placed on communications satellites.

As might be expected in the absence of senior-level coordination, competing bureaucratic, financial, and political agendas have complicated working-level discussions, leaving deeper concerns such as interoperability with US forces, command and control, and strategic policy objectives unresolved.

Given the relatively undeveloped state of space capability within the Japanese Ministry of Defense and the Self-Defense Forces, it is likely that the Japanese Aerospace Exploration Agency (JAXA) will be the source of initial technical expertise. Given the long history of close relationships between the United States and JAXA, this may make it easier to expand the US-Japan cooperation into new areas of space security if there is political agreement to build on existing relationships first. While NASA is a civil agency, it has routine exchanges and cooperation with the Department of Defense. JAXA may look to NASA's experiences for lessons it might use in working with the JMOD in the future.

### 19.3.4 Industry Relations

A major challenge for Japan will be the state of its aerospace industry. On the one hand, Japanese technical capabilities are world class, but a relatively small, flat domestic market and policy limitations on export sales have resulted in low production volumes and high costs. Budget constraints limit the ability of the Japanese government to fund major new development programs that would help Japanese firms improve high-end systems engineering skills. At present, the liquid rocket propulsion industry is facing especially difficult decisions due to lack of follow-on work to the H-II launch vehicle and HTV cargo transfer vehicle. There have been discussions of joint work with the US industry on next-generation rocket engines, but uncertainty surrounding future US space exploration plans has blocked any major funding.

Japan has increasingly recognized the need to be able to participate in multinational weapons systems development (e.g., fighters, ballistic missile defenses), as fully indigenous development of modern systems is unaffordable. Japanese industry participation in such programs has at times been limited by Japanese arms export policies. For its part, the United States has faced international cooperation difficulties stemming from its treatment of space technologies as "munitions" for purposes of export control. Both Japan and the United States will need to discuss how to handle technology transfers to third parties as well as each other if they are to closely cooperate on dual-use space systems that improve functions such as space situational awareness and missile warning.

Japanese commercial satellite manufactures have not had the benefit of a protected domestic market due to the Super 301 Satellite Agreement requirements to be open to international competition. This has benefited Japanese firms buying satellites and related services but constrained the production volumes and competitiveness of Japanese satellite manufacturers. As a result, Japanese aerospace firms are looking to penetrate developing country markets, such as Turkey, Thailand, and Vietnam, in space applications such as remote sensing where technical performance is weighted relatively more heavily than cost.

Increasing interest in “public-private partnerships” in remote sensing may be a potential source of friction. There have been US-Japan discussions of data policies with new systems such as Japan’s Advanced Land Observation Satellite (ALOS) series. The primary US concern has been to ensure the free and open availability of data. However, it is also possible that the remote sensing satellites would be subject to the US-Japan 1990 Agreement on Satellite Procurement. Under this agreement, the procurement of satellites offering services to international commercial markets would have to be opened to foreign competition – and not reserved for Japanese companies. The 1990 Agreement is unpopular in Japan and usually thought of applying only to communications satellites, but the Office of the US Trade Representative is likely to consider it applicable to all types of non-R&D, nondefense satellites.

It can be expected that Japan will want to include trade and competitiveness issues in any broad discussion of US-Japan space cooperation. The United States is an important trading partner and could be source of support for Japanese industry. At the same time, US and Japanese policies can and do limit the ability of Japan’s space industries to operate in the same way as other sectors of the Japanese economy.

### 19.3.5 Japanese Space Cooperation Beyond the United States

Japan is already engaged in a wide range of civil space cooperation with countries in the Asia-Pacific region and around the world. In addition to development assistance and capacity building, Japan is seeking to expand export markets for its satellites and space services to compensate for the limited size of public and private demand in Japan. Beyond normal trade practices and control of sensitive technologies, it is hard to imagine any US objections to these activities. In fact, the United States is likely to be supportive of Japanese efforts to build better relations with “nontraditional” space partners like Indonesia, Vietnam, and Malaysia who are developing their own space capabilities.

The United States will likely encourage stronger dual-use space ties between Japan and other US allies such as Australia and South Korea – as long as there is a common understanding on security matters such as missile proliferation and transfers of sensitive technology. South Korea is a strong ally of the United States with a small but growing space program. Cooperation between Japan and South Korea however has been limited to modest projects. One future possibility for cooperation may be in space-based navigation and positioning. As part of its satellite program, South Korea has proposed building a regional satellite positioning and navigation system to augment Galileo and/or GPS. Such a system would seem to be duplicative with the QZSS as well as crowding already limited international spectrum for these services. This may be is an opportunity to define a common system that would be interoperable with GPS.

The two most problematic countries in the region for space activities are, of course, China and North Korea. In the case of China, the United States will likely continue to be limited to what it can do bilaterally with China in space. However, it can and should be able to work with China in the coordination of multilateral space exploration efforts. A realistic international architecture for lunar missions would be a more helpful contribution to cooperation than current efforts involving ill-defined human missions to Mars or asteroids. Such missions are beyond the capabilities of almost every country to save the United States and possibly Russia and thus do not serve as practical basis for cooperation now.

As a practical near-term step, the United States could consider tacitly accepting, if not openly supporting, efforts by Japan and Europe to engage in scientific space cooperation with China as long as there are no transfers of sensitive technology. As an example of such cooperation, the ESA Cluster mission studied the Earth's magnetosphere in conjunction with China's Double Star spacecraft. There were instrument exchanges, coordination of mission operations, and exchanges of data analyses, but no transfers of sensitive technology. Depending on US and Japanese political conditions, it is also possible to imagine a Chinese scientific experiment flying on the International Space Station if it could be sponsored by one of the existing ISS partners.

Again, assuming appropriate political conditions, it would be technically possible for a Chinese taikonaut to visit the ISS using a Soyuz vehicle. Docking a Shenzhou vehicle to the ISS would not likely be practical due to the degree of technical preparation and transparency that would be required on all sides. One has only to look at the Shuttle-MIR program that laid the basis for Russian integration into the International Space Station to appreciate the likely technical and managerial difficulties – and that program enjoyed the highest level of support from both Russia and the United States. It would be similarly impractical to consider reopening the ISS partnership to include new countries (such as China or India). All the partners, including Japan, would likely agree on this point. Thus, if there were to be human space flight cooperation with rising space powers such as China and India, it would be useful to direct expectations toward the Moon rather than the ISS.

Finally, the North Korean announcement that it would attempt a satellite launch in April 2012, despite UN sanctions, illustrates the ongoing tensions on the peninsula. Despite a failure to place a satellite in orbit, the launch did demonstrate an ongoing DPRK commitment to developing long-range ballistic missile technologies. There are no realistic prospects for space cooperation with North Korea at present. Japan and the United States will likely continue to deal with North Korean nuclear and missile threats through the six-party talks.

## 19.4 Current Developments in Japanese Space Security

The past year has seen a number of important organizational changes in Japan's space policy-making processes, organization, and management of space activities. Most of the staff functions performed by the Secretariat of the Strategic

Headquarters for Space Policy were placed in the Cabinet Office. On the surface, this may look like a demotion from working directly for the Prime Minister and other senior member of the Cabinet, but the Cabinet position has more powers to actually coordinate budgets and policy across the Japanese government. The Cabinet Office can also work on the same level as other ministries (e.g., MEXT, METI, MOFA, JMOD) and now contains a "Space Strategy Office."

Interministerial coordination is notoriously difficult within the Japanese government and space issues by their nature often cut across the responsibilities of multiple ministries. As a result, there has been a trend toward moving budget and oversight function higher up in the government. It took a major effort within the Japanese government in September 2011 to secure a commitment to complete the QZSS constellation approximately by the late 2010s. (The ambiguous phrase regarding the QZSS schedule is a direct translation of the Cabinet decision. Personal communications with Japanese officials confirm that the ambiguity is intentional.) This resulted in yet another "special" organization like the IGS.

Many Japanese Diet members would like there to be a single, accountable, space agency, but it is rare to find members with an appreciation for the problems that occur in mixing civil and national security space functions. Perhaps more importantly, the desire for a single space agency to consolidate all space activities is seen as a way to avoid interministerial negotiations. Unfortunately, a single space agency would pull "space" away from the users in the ministries and would be especially problematic for international cooperation if civil and national security functions were mixed. Nonetheless, since the interministerial process is weak and there seems to be an aversion to creating one, there are strong bureaucratic arguments for consolidating budgets and oversight of dual-use space activities at the Cabinet Affairs level, over the objections of JAXA.

JAXA is an administrative entity and its members are not technically government employees. Therefore, there must be a ministry sponsor to provide government oversight. Japanese law says there can be only one sponsor, but it is unclear at this writing whether MEXT will continue to be the sponsor or whether JAXA will report effectively to group of ministries in the Space Strategy Office at the Cabinet Affairs level. Legislation was introduced into the Diet in early 2012 to authorize JAXA's support for dual-use space activities and clarify its reporting relationships. The old Space Activities Commission that had coordinated space activities before the creation of JAXA would also be abolished.

In April 2012, the Diet approved the national space budget as submitted by the government in January. Overall, the Japanese space budget declined by 2.3 % from the previous year. Assuming an exchange rate of 100 yen to one US dollar, the national budget has dropped below $3 billion dollars for the first time in more than 5 years. JAXA continues to comprise about 59 % of the national space budget, while 21 % goes to the Cabinet Secretariat for the IGS satellites, and the rest goes to smaller space efforts across multiple ministries. The Prime Minister's top priority of expanding QZSS was funded primarily thru METI and the Cabinet Office, not JAXA. Together, the Cabinet Secretariat and the Cabinet Office account for 25 % of the national space budget in Japanese fiscal year 2012.

In conjunction with the new budget, the Ministry of Foreign Affairs created a space policy office to focus on dual-use issues, e.g., an international space code of conduct, Space Situational Awareness, international space cooperation, and space security ties with the United States. A senior JAXA official, Yasushi Horikawa, is the newest chairman of the UN Committee on the Peaceful Uses of Outer Space (COPUOS). Guidelines to ensure the long-term sustainability of the space environment and mitigate the threat of orbital debris will be a major focus of COPUOS and thus of Japanese diplomatic attentions.

It is possible that the Cabinet Office can coordinate top-level space policy decisions, but the real difficulties would arise during implementation. In the United States, this would be akin to White House offices doing program management functions. It was widely recognized that the ministries do implementation, but there continues to be uncertainty as to what budget coordination power the Cabinet Office will really have across ministries.

## 19.5 A Strategic Framework for Space

Japan's passage of the 2008 Space Basic Law opened a potential new era for US-Japan cooperation in addressing shared strategic interests. In particular, there are new strategic threats emerging from China and North Korea primarily in the military sense but also in economic and regional political arenas. National security space is still a politically sensitive term in Japan, but it has come to be understood as including the protection of domestic infrastructure and the ability to respond to and manage natural and man-made disasters (e.g., the events of March 11).

The United States and Japan have taken steps to lay the groundwork for deeper and expanded cooperation in space-based systems as part of efforts to increase their capabilities in support of regional and national strategic interests. In doing so, national security space decisions are part of the larger strategic relationship between the United States and Japan. The Space Basic Law has opened the door for Japan to move forward with new authorities and agencies to address new dimensions of national security.

There is a shared commitment, at least in theory, for expanded cooperation in national security and strategic space activities. The major objective now is to move beyond words and create tangible programs and benefits. The challenges are many as traditional established channels for collaboration in space are not fully adequate. They tend to take narrow, parochial views of their immediate organizations and lack a larger perspective of national and regional strategic interests. There is a tendency at lower levels of the US and Japanese bureaucracies to treat "cooperation" as acquisition exercises, rather than as elements of a coherent strategy. Both governments have been distracted by more immediate political crisis, and as a result, individual offices have at times been free to pursue separate agendas or do nothing at all.

In light of changing global conditions, it may be desirable to create a more comprehensive framework for US-Japan space cooperation, to include civil and security space activities. This view is not new but can be found in think tank reports (Campbell et al. 2003) almost a decade ago:

> A new framework should replace the *1969 Exchange of Notes* and the *1990 Agreement on Satellite Procurement*, and encompass all recent bilateral activity, such as the *1998 Joint Statement on Cooperation in the Use of the Global Positioning Systems* (GPS). Recent bilateral activity has been piecemeal rather than comprehensive, and a new agreement should fill in the gaps. . . .

Among the identified gaps were the need to strengthen institutional ties in space security, commitment to common standards in dual-use programs like the QZSS, export control reform, and trade promotion and to strengthen space ties at the most senior levels of government, such as between the US National Security Council and the Office of Science and Technology Policy and the Japanese Strategic Headquarters for Space Policy and the Cabinet Office. Some of the recommendations of the 2003 CSIS report have been implemented in the passage of the Basic Space Law while other changes aimed at improving regional security ties were not.

Japan's foreign policy-makers recognize that space issues are important to their diplomatic agenda. In a wide-ranging speech on international affairs, Japanese Foreign Minister Koichiro Gemba highlighted space as an area for international cooperation (Gemba 2012):

> The second new area of international cooperation is outer space. Recently, outer space has become remarkably congested, and you might often hear the news of "space debris" or destruction of satellites. The diplomatic and security significance of outer space has been increasing in recent years. Japan's outer space diplomacy has three major pillars.
>
> The first is to promote efforts to establish international norms. As I previously noted, Japan will actively participate in discussions with the United States, the European Union, and Australia on drawing up an international code of conduct. . . I, myself, served as the Minister for Space Policy in the past. Japan will be actively involved in discussion to set guidelines for securing long-term sustainability of outer space activities.
>
> The second pillar is to promote further international cooperation on outer space. In this field, from a development perspective, I intend to actively support emerging countries in particular, through ODA (official development assistance) projects, in addressing disaster management, climate change, and other global challenges. Between Japan and the United States, negotiations on a Japan-US Outer Space Framework Agreement have just started, which aims to facilitate civilian and commercial cooperation between the two countries. This process was initiated based on my discussion with Secretary Clinton last September in which we both agreed to launch our negotiation.
>
> The third pillar is to advance outer space policies as part of national security measures. Japan will conduct further discussion with the United States on space security cooperation, such as space situational awareness, a satellite navigation system, space-based maritime domain awareness and the utilization of dual-use sensors. As the Japanese government is planning to review the existing apparatus of government agencies dealing with space policies, the Ministry of Foreign Affairs will play an active role in that process.

Ironically, a potential area of friction may be human space flight as some in both countries may argue that limited resources should be directed toward projects with more immediate commercial or security benefits. This would likely be short sighted as expanding civil space cooperation, to include the most symbolic and visible forms of space exploration, will be an important element of building better relations with other spacefaring nations in the Asia-Pacific and globally. Japan is the most important and senior US space partner in Asia, and disruption of cooperation in human space flight, even if unmanned scientific cooperation were unaffected, would be taken as a sign of a weakening relationship.

Unlike Europe, there are few established frameworks for peaceful space cooperation across Asia. In fact, the region can be characterized as containing several “hostile dyads” such as India-China, North Korea-South Korea, and China and its neighbors around the South China Sea. At the same time, this provides an opportunity for creating a new, long-term geopolitical rationale for a program of human space exploration. Asian space agencies have shown a common interest in lunar missions as the logical next step beyond low Earth orbit. Such missions are seen as ambitious but achievable and thus more practical than missions to Mars and more distant locations. A program of peaceful, multilateral exploration of the Moon would be a symbolic and practical means of creating a framework for peaceful space cooperation in concert with dual-use discussions of space-related transparency and confidence building measures (TCBMs).

Expanding civil and dual-use space cooperation could allow Japan to increase the level and effectiveness of its contributions to regional and global security partnerships as well as its support to multinational peacekeeping, humanitarian assistance, and disaster relief operations. Japan should be the partner of choice for space cooperation in the Asia-Pacific region due to its relationship with the United States and its capabilities. That said, political and policy changes in Japan are often slow, and the United States will also need to make its own decisions about space cooperation with countries in the region, notably Australia, India, South Korea, and China, if a common approach with Japan is not possible.

## 19.6 Conclusions

Secretary of State Hillary Clinton discussed the importance of the Asia-Pacific region to the United States in the November 2011 issue of *Foreign Policy*. The article was the basis for numerous press stories about a US “pivot” toward Asia after a decade of conflict in Afghanistan and Iraq. But perhaps the most useful statement was an obvious one that “The Asia-Pacific has become a key driver of global politics” (Clinton 2011). Saying that Asia is important to the United States is not the same as saying what vision the United States has for the region. Such a vision would have challenges similar to those for Asia-Pacific space cooperation, i.e., how to ensure stability with existing friends and allies while integrating China into a broader political framework. As one observer (Green 2012) of the US statement wrote: “Without that inclusive vision, the Chinese have chosen to interpret the pivot as being primarily about containing them.” The same risk is present for visions of space cooperation that fail to address the role of China in political and military as well as scientific and commercial space activities.

The United States and Japan should engage in a comprehensive “strategic dialogue” in which space would be one important area as opposed to a dialogue solely focused on space. Other likely topics could and should include missile proliferation, nuclear proliferation, and cybersecurity. The reason for including "space" as one of several important topics is to ensure a comprehensive treatment of all areas of space cooperation, including civil, commercial, military, and intelligence. Existing organizational structures within the Japanese government make it extremely difficult to take a "whole-of-government" approach to an issue area like space. Having space as part of a "dual-use" dialogue from the beginning may make it easier to take an integrated approach to space in line with the intent of changes in Japan's Basic Space Law. Civil space cooperation could be discussed along with regional security concerns so that regional economic development using space technology would help advance common security and stability interests.

Japan will likely continue to see the United States as its most central and important partner in space cooperation. In particular, this will mean maintaining its role in the International Space Station. However, Japan's economic and security interests will require greater engagement in dual-use applications of space technology in the Asia-Pacific region. This may include promoting applications of the QZSS in conjunction with GPS and providing turnkey remote sensing and communications satellite systems to developing countries. These latter economic activities have the potential to bring Japan into further economic and political competition with China who is also seeking to use space cooperation to advance its own foreign policy interests. Thus, it will be important for Japan to develop a common understanding with the United States on a broad range of space matters, to include civil, commercial, and security issues.

After a creating a joint strategic vision for space, a common US-Japan roadmap on dual-use space cooperation will be required. Such a roadmap would take account of decisions already in work, such as legislation before the Diet and existing cooperative programs, and address the details of creating a "whole-of-government" approach to space discussion that encompasses the traditionally separate channels of NASA-JAXA and the "2 + 2" meetings. A near-term product should be a common plan for cooperation, just as the Space Basic Law led to the Space Basic Plan. Cooperation can be both diplomatic and programmatic, ranging from coordination on an international code of conduct for space and outreach to developing countries to sharing of space situational awareness data and fostering international broader engagement in space exploration, both human and robotic.

The Asia-Pacific region will be a crucial area of concern for future US administrations, whether Democratic or Republican. In developing and implementing a regional strategy in a global context, resource constraints will continue to be major concerns for the United States, Japan, and other allies. Pressures on discretionary resources can be expected to increase such as multilateral actions to coordinate and share costs will be necessary. Those pressures will also increase demands for greater accountability for expected economic, security, and political benefits to come from regional engagement.

Similarly, resource pressures and concern with economic and security competitions will also be present in any discussion of Asia-Pacific space cooperation. If the United States and Japan are to find a common approach to regional space cooperation, they will need to deal with all aspects of space – whether civil, commercial, or security-related. If their common approach is to be successful, the United States, Japan, and their friends and allies, will need a common vision for the peaceful and stable development of the Asia-Pacific region in which space cooperation contributes to that vision.

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# Space Security in Russia

# 20

Christophe Venet

## Contents

## Abstract

The post-Soviet Russia is no longer a military space superpower and strives to adjust its military space policies to a new geopolitical environment. Since the "lost decade" of the 1990s, when Russia failed to maintain many of its military space capabilities, the country has sought to rebuild its military space power. Driven by political considerations, such as the need to regain its status as a respected global power, as well as pragmatic reasons, epitomized by an increased reliance on space assets in modern warfare, Russia launched in the 2000s ambitious military space initiatives. It strengthened its foundations by reorganizing its space industry, as well as its military institutional architecture for space and its ground infrastructure.

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## 20.1 Introduction

The Soviet Union was a pioneer in space and led, together with the USA, the space game for several decades. This heritage is both an asset and a burden for Russia's current space policy. On the one hand, Russia is still benefiting from the capabilities acquired during Soviet time, particularly in the crucial field of launchers. On the other hand, the hypertrophied and inefficient space industrial complex was severely harmed after the collapse of the Soviet Union, and in the 1990s, Russia's presence on the space scene sharply decreased. The subsequent efforts to rebuild a coherent and credible Russian space policy since the early 2000s also suffered from inherited weaknesses.

More generally, Russia is facing a structural dilemma: opting for the safe option by capitalizing on existing programs which were often developed in the Soviet era, or launching new projects from scratch, a more risky but also more promising endeavor. This dilemma illustrates the governing principles of Russia's space security policies today. On the one hand, there is a firm political will to implement a radical change of course to leave the Soviet heritage behind. On the other hand, there are clear elements of continuity between the Soviet and Russian space security policies.

While the Soviet Union was a military superpower in space, Russia's current positioning in the military space hierarchy seems more ambiguous. As a consequence of the "lost decade" in the 1990s, it clearly lags behind the USA quantitatively and qualitatively, (Facon and Sourbès-Verger 2007a, pp 37–38) and it does not seem to be capable and willing to close the gap in the near future. At the same time, however, Russia still has unique capabilities in certain areas (e.g., early warning satellites), and it is in the course of rebuilding its GLONASS satellite navigation constellation.

To understand Russia's current space security policies, it is necessary to put the issue in a broader political perspective. Not only is the Soviet legacy relevant in that respect, but so are the ups and downs of Russia's internal and external situation after 1991. The Russian space sector suffered extensively from the political turmoil in the 1990s (Arbatov 2011), but space was elevated as a symbol of the country's comeback on the international scene in the 2000s and later as an important tool for Russia's economic and industrial modernization (Facon and Sourbès-Verger 2007b). However, as one of the experts on Russia stated, "Russia's future, in essence, remains a paradox, a tension between an increasingly ambitious drive to restore Russia's standing in the world and the reality of structural weaknesses that ineluctably diminishes its ability to do so" (Roi 2010). This statement perfectly fits the military space sector.

Russia gradually started to rebuild its military space power in the 2000s. This paper explores the various aspects of this transformation. It first sketches the overall political context in which to consider Russia's space security policies, showing that military space regained, in recent years, its strategic status. It then focuses on the foundations of Russia's military space power, which are necessary to support Russia's space security policies. Indeed, Russia reshuffled its military space institutional architecture, reorganized its space industry, and modernized its ground infrastructure. Finally, Russia's policies in various fields of space security are analyzed. This paper adopts the classical distinction between space militarization (or space for security, the use of space assets to support military actions on Earth, which is already taking place) and space weaponization (or security for space, the potential conflict in space using space weapons, which is still hypothetical). While both aspects will be considered separately for the purpose of the analysis, it is important to remember that space militarization and space weaponization are functionally linked, as military space activities should be considered on a single threat continuum.[1] As for the former, Russia adopted a rather pragmatic approach in a clear shift from Soviet policies. As for the latter, Russia's positions are still largely influenced by the US strategic posture, a sign of some continuity with the Soviet era.

## 20.2 Political Context

The state of the Russian space sector, and more particularly of its military branch, has been closely linked to Russia's political fate in the last 20 years. After a near collapse in the 1990s, Russia's space capabilities were expected to become a central element of Russia's renewed ambitions in the 2000s.

After the end of the Soviet Union in 1991, Russia went through turbulent times, both internally and on the international scene. At home, the country was plagued by political instability, by ethnic conflicts in the North Caucasus, and by the consequences of the harsh transition from central planning to a market economy. The Russian GDP diminished sharply between 1991 and 1996, and the 1998 financial crisis had a strong negative impact on the country (International Monetary Fund). At the international level, Russia lost the status of a superpower to become a "weak and inward-looking nation" (Tsygankov 2011) in the 1990s. One of the main pillars of its foreign policy throughout this decade was an attempt "to integrate into, and then with, the West" (Trenin 2009).

In the 1990s, Russia's space policies and capabilities reflected these trends, manifested by the loss of political interest for space matters during the Yeltsin presidency (Facon and Sourbès-Verger 2007b). Overall, Russian space assets decreased considerably during the decade, and in 2004 the US space budget was 20 times larger than that of Russia (Arbatov 2011). On the military side, Russia virtually lost all of its capabilities in space, following the sharp decline of defense and space budgets, the dismantling of scientific centers, and the stopping of any sort of industrial cooperation. In the beginning of the 2000s, Russia only had a few outdated military spacecraft in orbit and its early warning, navigation and communication constellations were incomplete (Arbatov 2011, pp. 441–442). Russia's space power was only saved by the commercialization of its launchers, mainly through joint ventures with the West (Facon and Sourbès-Verger 2007a, p. 8). This dependency on the West also extended to the purely military realm, as Russian

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[1] On these aspects, see DeBlois et al. (2004), Mueller (2002)

combat aircraft had to rely on the US satellite navigation system, and the Russian Northern Fleet was getting data from the Canadian Radarsat-1 satellite (Arbatov 2011, p. 442). More fundamentally, Russia lost its ability to conduct long-term research and development (R&D) activities in military space after the collapse of the Soviet Union (Podvig 2004).

In the 2000s, however, Russia's overall economic situation improved sharply, with a yearly growth rate of around 7 % starting in 2003. Although the crisis strongly hit the country, leading to a negative growth rate of −8.7 % in 2009, the Russian economy quickly recovered in 2010 and 2011 (de Montluc 2010). On the international scene, Russia entered a phase of power affirmation, with a noticeable hardening of its foreign policy (de Montluc 2010, p. 16). Putin's ambition was for Russia to behave like an independent great power (Trenin 2009; Tsygankov 2011). At the domestic level, the return of the state became the dominant motto, in both the political and economic spheres. In particular, a new industrial strategy articulated in 2005 identified key sectors in which the state should heavily intervene, including the aerospace industry (de Montluc 2010).

These economic and political trends also impacted the space sector. Since 2001, Russian political authorities started again to place an emphasis on space as a strategic sector (de Montluc 2010, p. 19). Space was to play a central contributing role in Putin's political project of Russia's rebirth as a great power (Facon and Sourbès-Verger 2007a, p. 11). Space was now conceived as a tool for prestige, in the classical Soviet understanding, but also as a means to boost Russia in the postmodern era. The space industry, as a provider of highly innovative technologies, was to become one of the drivers of Russia's economic modernization course (de Montluc 2010, pp. 15–24). This approach demonstrates a pragmatic turn in the Russian space policy: the development of space assets is a symbol of power, but it should also be done in a rational and utilitarian perspective, taking into account the existing resources (Facon and Sourbès-Verger 2007a, p. 8). To implement these ambitious objectives, Russia issued three major space policy documents in the 2000s: the specific *Federal Program on Global Navigation Systems (GLONASS) for 2002–2011* and *Federal Special Program for the Development of Russia's Cosmodromes (DRC) for 2006–2015*, and the more general *Federal Space Program (FSP)*. The latter was approved in 2005 and is running through 2015, laying down Russia's broad objectives in space, including in the security field (Government of the Russian Federation 2005). These stated ambitions were accompanied by a steady and sharp increase in the Russian space budget de Montluc (2010) Even at the peak of the crisis, in 2008–2009, the space budget continued to rise significantly (Venet 2011).

With this perspective, military space became a priority again under Putin (Facon and Sourbès-Verger 2007a, p. 25). The major objective was to rebuild military space capabilities after years of steady decline (Facon and Sourbès-Verger 2007b, p. 54). By doing so, Russia sought strategic autonomy, in particular by reducing its dependency on the West, both technologically and in terms of access to military-relevant data. The renewed focus on military space also corresponds to Russia's political ambitions on the world stage. In the classical symbolic perspective, military space capabilities are perceived by Russian leaders as an indispensable element of a great power's portfolio. Beyond the official discourse, however, Russia's approach to military space activities is not simply power based but also pragmatic. Military space assets should not only support modern warfare but also offer technological and commercial perspectives by fully integrating the dual-use nature of space. Similarly, Russia's space security should be guaranteed but through diplomatic activity rather than an arms race.

Overall, military space regained in the 1990s, at least in the official discourse, a strategic and symbolic value it had enjoyed during the Soviet era. At the same time, a more utilitarian influx was given to space policy, as reflected in the FSP. Despite the stated ambitions, however, some uncertainty is still floating over the future of military space in Russia, given "the relative modesty of Russia's economic potential, its dependency on raw material and its technological backwardness" (Trenin 2009).

## 20.3 The Foundations of Russia's Space Security

As a consequence of the renewed strategic and political relevance of military space, Russia put a strong emphasis on rebuilding solid foundations to support its space security policies. Specifically, it launched a broad reorganization of its space industry, it streamlined its military space institutional architecture, and it rationalized and modernized its ground infrastructure.

### 20.3.1 Industrial Architecture

In line with the overall policy of heavy state involvement in strategic sectors of the Russian economy, a restructuring of the Russian space industry was launched in the 2000s. Given the strong ties between the space and defense industrial complexes, this process will have strong implications for the military space sector.

The main objectives of the process were to enhance the industry's competitiveness on global markets by reducing overcapacities and rationalizing management procedures. The *Federal Program on Reform and Development of the Military-Industrial Complex* was adopted in October 2001, and the *Strategy for the Development of the Space Industry* was approved by the Russian government in July 2006 (Nardon and Kastoueva-Jean 2007). The goal of this process is to reduce the number of industrial entities by creating a dozen of integrated state-owned companies. The underlying rationale is that supply chains would be optimized and competition for each product group would be reduced (Makarov and Payson 2009). This increased involvement of the state also had consequences for military space. After having focused on the export market for a decade, the Russian space and defense industries were invited by the government to reorient their production towards national armed forces. Similarly, both sectors were subordinated to the newly created Military-Industrial Commission (*Voenno-promychlennaïa komissiia* or VPK) in 2006 (Facon and Sourbès-Verger 2007b). Overall, these efforts brought mixed results, and a series of recent spectacular failures – including the loss of two military satellites (the geodesy satellite *Geo-IK* in February 2011 and the dual-use communications satellite *Meridian* in December 2011) – led then-President Medvedev to call for another batch of radical reforms in the space sector (Quénelle 2012).

### 20.3.2 Institutional Architecture

The institutional architecture of the military space sector in Russia was likewise affected by the political evolution of the country in the last 20 years. In the 1990s, the Russian Space Forces underwent a series of reforms and counterreforms, mirroring the conflicting views on the new international environment within the Russian armed forces. In the 2000s, the institutional setup was streamlined and centralized and marked the return of the state in military space affairs.

The military space forces (*Voenno-kosmicheskie Voiska* or VKS) were created in 1992, based on the previous Soviet architecture for military space. In 1997, the VKS were merged with the strategic missile forces (*Raketnye Voiska Strategicheskogo Naznacheniia* or RVSN) and the space and missile defense forces (*Voiska Raketno-kosmicheskoj Oborony* or VRKO). This reflected the internal tensions between those seeking a strategic parity with the USA and those focusing on reforming the conventional forces. The fusion of the three bodies translated the views of the former, as it was supposed to increase the credibility of Russia's nuclear deterrence. However, the lack of a common organizational culture between the three branches and the increasingly important role played by space assets in support of Russia's armed forces led in 2001 to the recreation of autonomous space forces (*Kosmicheskie Voiska* or KV). The KV were in charge of the military spaceports (Plesetsk and Svobodny), the ground control centers, the ground radar sites, and the A-135 antiballistic missile system protecting Moscow (Facon and Sourbès-Verger 2007a, pp. 27–30). In December 2011, the KV were replaced by the newly created Aerospace Defence Forces (*Voiska Vozdushno-kosmicheskoj Oborony* or VVKO), which now encompass a wide range of functions. The VVKO's responsibilities are to detect ballistic missile launches, to intercept ballistic missile warheads, to monitor space objects and identify threats in and from space, to carry out spacecraft launches, and to maintain military satellites and their launch infrastructure in order (Ministry of Defence of the Russian Federation). The VVKO have four main components: the Russian Space Command, the Air and Missile Defence Command, the Plesetsk Cosmodrome, and the arsenal (Ministry of Defence of the Russian Federation). This additional reorganization was guided by "the necessity of a unified command and force, capable of operating in air and space combat trials, as nowadays, the race to attain strategic advantages in space became a prerequisite to ensure national security and interest in military, economic or social spheres" (Ministry of Defence of the Russian Federation). This shows that military space definitely regained its strategic status in Russia.

### 20.3.3 Ground Infrastructure

Efficient ground infrastructure is one of the most essential enablers of military space power. This concerns both the cosmodromes and the satellite control and space surveillance networks. Russia is seeking to modernize and rationalize these assets, driven by the need to ensure strategic autonomy to its military space forces. Indeed, after the collapse of the Soviet Union, many ground-based assets were located outside the territory of Russia, in former Soviet republics. As a result, a major driver of Russian military space policy in the past two decades was to reduce and mitigate these strategic dependencies.

#### 20.3.3.1 Launch Infrastructure

In the beginning of the 1990s, Russia's major cosmodrome was Baikonur, in Kazakhstan. The launch center was operated by the Russian Military Space Forces, and the site was used both to launch military spacecraft and to test ballistic missiles. An agreement was concluded between Russia and Kazakhstan in 2004 to extend the Russian lease until 2050, including for military purposes (Podvig and Zhang 2008, p. 16). However, Russia's concerns over its strategic dependency on an asset based in a foreign country were reinforced in recent years by a series of tensions between Russia and Kazakhstan. In particular, disputes over drop zones of rocket stages over Kazakh territory led to several launch delays (de Selding 2012).

As a consequence, Russia launched an effort to move all its military space activities back on Russian territory. As a first step, the Russian military space forces progressively handed over all the facilities and activities of the Baikonur Cosmodrome to the civilian Federal Space Agency, Roskosmos (Oberg 2011). Furthermore, Russia reinforced the military role of the other cosmodromes located on its territory. The Plesetsk Cosmodrome in Northern Russia is undergoing significant infrastructure enhancement to become Russia's major military spaceport. The site's location, at 63° north and 41° east, is imposing much stricter constraints than Baikonur in terms of accessible orbits and maximum payload weights (Podvig and Zhang 2008, p. 18). To remedy this deficiency, a new launch pad is being constructed in Plesetsk to launch the future generation Angara rocket. This combination will enable to launch military payloads into all operational orbits (Oberg 2011). In addition to the modernization of Plesetsk, the Russian Space Forces requested in 1992 a new space launch site to be developed on Russian territory. The rationale for this demand remained the same: considering the uncertain political and economic future of Baikonur, Russia should ensure an independent access to space. The site of Svobodny in Siberia, a former strategic missile base, was initially chosen. However, due to the lack of funding, the construction of the Svobodny Cosmodrome was abandoned in 2006–2007. Despite this decision, the strategic necessity to have a spaceport on Russian territory enabling launch performances similar to those of Baikonur remained valid. For this reason, the Russian government decided in 2007 to develop a new launch site in the Amur region, called Vostochny. The new cosmodrome, which will also support military launches, is to be operational by 2020 (Russian Space Web 2012a).

It has to be noted that the issue of strategic autonomy also applies to the launch vehicles. At least two of the rockets used by the Russian military to orbit their payloads are built in Ukraine (the Tsyklon and Zenit launchers). Together with environmental concerns linked to the use of toxic propellant for the Kosmos-3M and Rockot launchers (Russian Space Web 2012b), this latent dependency led to the development of a new launcher, developed and built in Russia, the Angara rocket. The new rocket will feature a modular design, able to orbit a wide range of payloads (2–23 t in low Earth orbit or LEO), including military spacecraft (Russian Space Web 2012c).

#### 20.3.3.2 Satellite Control and Space Surveillance

The Soviet Union built an extensive network of ground control facilities, receiving stations, and satellite tracking facilities. After the breakup of the Soviet Union, Russia lost control of some of its control and measurement complexes (*Otdelni Komando-izmeritelnii Komplex* or OKIK), as three of them were located in Ukraine, one in Kazakhstan, and one in Uzbekistan. The latter one was the newest addition to the network and included laser measurement systems. Russia still has ten operational stations scattered on its territory. Most of these OKIKs are managed by the central control unit of the VVKO, the Main Space Systems Center (*Glavnii Ispitatelnii Tsentr Ispitanii i Upravleniya Kosmicheskimi Sredstvami* or GITsIU KS), located in Krasnoznamensk, near Moscow. These stations are used to control and receive data from both civilian and military spacecraft. In addition to these dual-use facilities, some military systems are managed completely separately, such as the early warning satellites which have their own control center in Kurilovo, and the US-PU naval intelligence spacecraft managed directly by the Russian navy (Podvig and Zhang 2008, p. 21).

The Russian space surveillance and tracking system is a crucial part of Russia's military space policy. It is an integral component of Russia's early warning system, and it provides space surveillance capabilities to Russia that are second only to those of the USA. However, the network was affected by the collapse of the Soviet Union, as many radar stations that were part of the network are now located outside of Russia's territory. This is also true for two of the most modern radar stations (*Daryal* radar) built in Azerbaijan and in Belarus. As a result, Russia had to rely on older radars, some of which were built in the 1970s, and to negotiate the use of radars located outside Russia with the host countries (Azerbaijan, Belarus, Kazakhstan, Ukraine) in the beginning of the 1990s (Podvig 2004). Today, in addition to these foreign assets, Russia mainly relies on seven radars located on its territory to track space objects. It is also constructing three more radars and planning an additional one. In addition to these dedicated systems, Russia is also using the Moscow missile defense system radar Don-2M and the Dunay-3U radar near Moscow to provide early warning and space surveillance data (Russianforces 2012).

The Russian space surveillance system also raises the question of strategic autonomy, as the most advanced of its optical observation stations (*Okno*) is located in Tajikistan. Moreover, the space surveillance network relies on the early warning radars, and on the *Krona* system, composed of dedicated X-band surveillance radars. Two such systems are deployed, one in Zelenchukskaya in the North Caucasus and one in Nakhodka, in the Far East (Russianforces 2012). All in all, despite some remaining weaknesses, Russia has substantial space surveillance and tracking capabilities, a fundamental asset both for operational military purposes and space security policy elaboration.

## 20.4 Russian Military Space Policies

After the collapse of the Soviet Union and the difficult decade of the 1990s, Russia intended to rebuild its military space power. A clear political will to do so emerged at the highest level, accompanied by an institutional and industrial reorganization of the space sector, as well as strengthening and modernization of its foundations. It is a major challenge as Russia's military space policies need to adapt to the new geopolitical landscape of the twenty-first century. In the field of "space for security," Russia adopted a pragmatic approach. It sought to match its military spacecraft constellation with its strategic priorities, focusing on the Russian territory and the "near abroad." This marks a clear departure from Soviet policies, which had a more global scope. In the area of "security for space," however, continuity with Soviet practices seems to persist. Russia continues to seek global strategic parity with the USA through a skilful diplomacy based on self-restraint and ambitious diplomatic initiatives.

### 20.4.1 Space for Security

In terms of military space capabilities, Russia is still, after the USA, the second largest power. However, it cannot afford to be a global military space player anymore. Two factors explain this. First, its level of resources is not sufficient to conduct a high number of military launches and to maintain extensive constellations of military spacecraft in orbit for each military purpose (i.e., communications, navigation, surveillance, ocean surveillance, early warning, signals intelligence, geodesy). Second, the geopolitical environment changed after 1991, and Russia's foreign policy objectives differ from the former Soviet foreign policy. Russia adopted a pragmatic approach, and military capabilities are to be developed only to respond to certain needs and in accordance with existing resources. However, despite Russia's efforts to rebuild credible military space capabilities, there remain some important weaknesses as exposed, for example, during the 2008 war with Georgia.

Russia chose to align its military space capabilities with its new foreign policy objectives. Besides Moscow's desire to regain its status as a global strategic power, Russia mainly aims at strengthening its position as a regional power (Tsygankov 2011). This means, in concrete terms, that Russia's international efforts concentrate on the Community of Independent States (CIS) and on the "near abroad" (Trenin 2009). Accordingly, in the military space field, Russia's objective is not to imitate the USA by becoming a global power focusing on force projection but rather to focus on its own territory and neighboring countries (Facon and Sourbès-Verger 2007c, p. 6). The military space assets were conceived in view of this. While being developed as a global system, the main purpose of the GLONASS satellite navigation constellation is to cover the Russian territory. In the field of satellite communications, Russia has a couple of GEO (geostationary Earth orbit) communications and data-relay spacecraft but rather focuses on spacecraft in HEO (highly elliptical orbit, or *Molniya* orbit). The Molniya orbits enable a better coverage of Russia's northern territories. Similarly, unlike in the Soviet era, Russia has only limited naval projection capabilities, (Arbatov 2011) and the last ocean surveillance satellite was launched in 2006 (Lardier 2011).

In addition to focusing on its "near abroad," Russia recently developed an increasing strategic interest in the Arctic region. This is linked to economic considerations (presence of huge oil and gas reserves, growing potential of the northern route for shipping, extension of the exclusive economic zone), ecological concerns, and also security aspects (Baev 2012; Roi 2010). Russia's space architecture is also geared to support this new item on the country's foreign policy agenda. In 2008, President Putin approved the *Arktika* satellite constellation. With a budget of $1.23 billion and five satellites to be built (two *Arktika M* satellites with optical monitoring systems, one *Arktika R* radar satellite for the polar nights, and two *Arktika MS* telecommunications satellites), this is the biggest Earth observation (EO) project in Russia of recent years (Robinson and Venet 2010).

In terms of capabilities, Russia is focusing on few strategic areas. In addition, the dual-use approach is much more integrated in military space planning than it was in the Soviet Union, when a strict separation between civilian and military space activities prevailed.

As for specific capabilities, the most important effort is dedicated to maintaining a comprehensive early warning system. This capability is crucial for the credibility of Russia's nuclear deterrence, (Arbatov 2011) which is still the major pillar of Russia's national security policy (Baev 2012, p. 10). The early warning satellite constellation was severely hit by the crisis in the 1990s, as funding issues led to capability gaps of up to 8 months. This was particularly worrisome for global nuclear stability, as it could have led to misinterpretations and false alarms (Moltz 2009). The space component of the Russian early warning system was reconstituted since that time, and Russia has four spacecraft on HEO and one on GEO as of September 2012. The system, however, still lacks global detection capabilities, as it was designed only to observe ballistic missile launches from the USA and not from other regions or from the sea (Russianforces 2012).

A second most important area is satellite navigation, an application of dual-use nature. Besides the *Tsiklon*/*Parus* navigation system used for maritime purposes, the major program in this field is GLONASS (*Globalnaya Navigatsionnaya Sputnikovaya Sistema*). It was launched in 1982 for purely military purposes as a counterpart to the US GPS (Global Positioning System) and reached initial operational capabilities in 1989. The satellite navigation capability was virtually lost in the 1990s, as Russia was unable to maintain enough satellites in orbit, but a new impetus was given to GLONASS in the 2000s. Launches of the improved GLONASS-M satellites resumed in 2004, and the system is now fully operational (Podvig and Zhang 2008, p. 13). GLONASS is a typical example of Russia's new approach to space, where technological development and socioeconomic benefit considerations prevail over purely military aspects (Facon and Sourbès-Verger 2007b).

Military Earth observation (EO) has a crucial support function for the military, but Russia is facing difficulties in this field. Soviet practices focused on a huge number of launches, putting EO satellites with a very short lifetime in orbit. Despite stated objectives to abandon this costly approach, Russia is still relying on satellites with a very short operational life (between 60 and 130 days) (Lardier 2011). In addition, it has no high-resolution capabilities in optical EO and no radar capabilities at all. Russia plans to also rely on civilian spacecraft for its military needs, demonstrating again a dual-use approach. However, despite ambitious plans in this field, only few EO and meteorology satellites have been launched to date (Robinson and Venet 2010).

In addition to these three areas, Russia maintains basic capabilities in military satellite communications, through 3 GEO *Raduga/Globus* satellites, 4 HEO *Meridian* spacecraft, 9 *Strela/Rodnik* store-dump military communications satellites, and one *Garpun* data-relay spacecraft (Lardier 2011). Russia is also trying to maintain capabilities in electronic intelligence and geodesy by planning to launch new spacecraft in the coming years.

Despite these efforts to revitalize its military space capabilities, Russia still faces difficulties. The latent capability gaps (lack of high-resolution optical and radar satellites, no global coverage for early warning, limited operational life of spacecraft) were highlighted during the 2008 war with Georgia, as referenced above. GLONASS was not yet operational at that time, and the GPS signal was unavailable over Georgia during the conflict. As a consequence, the Russian command chain had no situational awareness, and satellite targeting could not be used for artillery or precision-guided munitions. In addition, space-based intelligence was deficient, and satellite communications were also not usable. All in all, the war highlighted the general failure of the command and control system, which was supposed to rely on space assets (McDermott 2009; Cohen and Hamilton 2011). After the war, Russian military and political decision-makers pushed for the modernization of the space forces and accelerated in particular the fielding of GLONASS. Finally, the Russian military space forces are plagued with structural issues that are common in the Russian space sector: uncertain funding and discrepancy between ambitious plans and meager realizations. Overall, Russia's military uses of space are still in a transition phase, aiming at refocusing on core activities and modernizing existing assets.

### 20.4.2 Security for Space

In the field of "security for space," Russia's policy is clearly inherited from the Soviet Union. Russia is still obsessed with the US threat to its nuclear deterrence, and it developed a response based on self-restraint with regard to the issue of space weapons and on diplomatic initiatives to prevent an arms race in outer space.

Russia's perspective on international relations is still influenced by the nineteenth century so-called Great Game of power influence. More specifically, Russian elites identify the (potential or actual) US global hegemony as the major threat to their security and keep calling for a multipolar world order to balance against the threat (Trenin 2009). This perception, inherited from the Cold War thinking, is not reciprocal, as the USA now focuses more on the Asia-Pacific region and no longer considers Russia as an equal strategic partner (Trenin 2011). Moscow's approach is reflected in the Russian military doctrine released in 2010, which identifies the USA and NATO (North Atlantic Treaty Organization) as potential enemies. Russia's threat assessment is focusing in particular on the credibility of its nuclear deterrent, as the USA is thought to possess (or develop) capabilities able to neutralize Russia's strategic nuclear forces. (Śmigielski 2010)

The Russian space security policy stems from this fear. The main security threat in space from Russia's point of view would be a US first strike against its nuclear forces using space-based weapons (Mizin 2007). Accordingly, Russia is strongly opposed to US plans for ballistic missile defense (BMD). This would not represent a direct threat to Russian strategic missiles but would open a door towards space-based weapons integrated into a BMD architecture. This, in turn, could constitute a vital threat to Russia's strategic missile forces. In addition, BMD missiles could easily be used as antisatellite (ASAT) weapons, thus threatening Russian military spacecraft in LEO (Dvorkin 2007).

To counter this threat, Russia is pursuing a strategy of self-restraint in the development of ASAT weapons. Part of this rationale is derived from budgetary considerations, as well as the learning curve inherited from the Cold War. In those days, the Soviet Union and the USA quickly understood the benefits of the status quo in space to preserve a stable strategic balance. After the development and testing of kinetic and laser ASATs in the 1960s–1970s (Stares 1985), the Soviet Union announced a unilateral moratorium on ASAT testing in 1983. In line with this decision, it refrained from launching military space stations in the 1980s, and President Yeltsin ordered to withdraw the IS-M ASAT weapon from operational service in 1993 (Dvorkin 2009). Russia pursued this strategy of self-restraint (Mizin 2007; RiaNovosti 2010) but, nevertheless, warned that any move to weaponize outer space by another nation would be followed by similar measures from Russia (Associated Press 2007). Russia would probably focus on asymmetric means to counter any US move to weaponize outer space, as the development of symmetric capabilities is out of its financial reach (Dvorkin 2009). This means that Russia would not make the same mistake as the Soviet Union to compete with the USA in the development of space-based weapons but rather keep dormant technological capabilities to develop and operate terrestrial ASAT weapons.

The second pillar of Russia's space security strategy consists of diplomatic initiatives aimed at preventing an arms race in outer space. The Soviet Union was a proponent of a stable and open space environment, starting with the cosponsored Partial Test Ban Treaty (PTBT) of 1963 and the Outer Space Treaty of 1967. Soviet delegates were also active at the Conference on Disarmament (CD) to promote the discussion on the Prevention of an Arms Race in Outer Space (PAROS), and the Soviet Union proposed several draft treaties on the issue throughout the 1980s, as well as the creation of a world organization that would monitor the exchange of "peaceful" space technologies in 1986 (Mizin 2007).

Russia is building on this diplomatic heritage. It proposed, together with China, a draft "Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects" (PPWT) in 2008. Prior to this proposal, both countries submitted a draft outline for a treaty in 2002, as well as two non-papers on the issue in 2004. Russia's cooperation with China on this matter is guided by the perceived need for both spacefaring nations to balance against the USA in space (Perfilyev 2010). From the Russian point of view, the rationale for the PPWT is to close existing gaps in international space law. Russia equals space weapons to weapons of mass destruction (WMD) and argues that their deployment could have similar destabilizing effect on the global strategic balance (Vasiliev 2008). The PPWT is, however, heavily criticized in its current form by other countries, including the USA, as having three inherent weaknesses. First, it does not capture terrestrially based ASAT weapons. Second, the interpretation of a "threat or use of force against outer space objects" is vague and open to various interpretations. Finally, no definition of "space weapon" is given, and no verification mechanism is proposed (Hitchens 2008). Confronted with a deadlock, Russia seems to have adopted a flexible and pragmatic diplomatic approach and also supports another initiative in the field of space security, the UN-sponsored Group of Governmental Experts (GGE) on Transparency and Confidence-Building Measures (TCBM) in outer space. The Russian delegate, V. Vasiliev, was unanimously designated as chairman of the GGE. The GGE has a 2-year mandate to provide recommendations for space-related TCBMs (Ministry of Foreign Affairs of the Russian Federation 2012). While TCBMs may not be legally binding, as opposed to a treaty, they could, nevertheless, be considered a first step towards an international legal framework governing activities in outer space and thus contributing to a more stable and sustainable environment. By supporting such an approach, Russia showed its willingness to cooperate with other major spacefaring nations on space security issues and adopted a more pragmatic, and potentially more fruitful, approach than, for example, China.

## 20.5 Conclusions

The Soviet Union was once a superpower in military space, but Russia now struggles to adapt its military space policies to the new geopolitical environment. After the "lost decade" of the 1990s, where it lost many of its military capabilities in space, it has sought to rebuild its military space power. Driven by political considerations (i.e., the need to regain its lost status as a respected global power) and pragmatic reasons (i.e., an increased reliance on space assets in modern warfare), Russia launched in the 2000s ambitious military space initiatives. It strengthened its foundations by reorganizing its space industry, its military institutional architecture in space, and its ground infrastructure.

Despite the strong political will displayed by Moscow's high-level decision-makers, these efforts still suffer from the Soviet legacy. In the field of "space for security," Russia still largely relies on assets developed during the Soviet era and has shortcomings in many operational space capabilities (as demonstrated, e.g., during the war with Georgia in 2008). In the area of "security for space," Russia is still applying the Cold War thinking, focusing on the perceived threat represented by the USA and seeking to balance against its hegemony. While this approach contributed to the remarkable stability of the space environment during the Cold War, it cannot be applied to the space environment of the twenty-first century, which is characterized by an increasing number of actors with military ambitions in space and by competitiveness that could potentially lead to regional space races (e.g., in Asia).[2]

Overall, Russia remains the second biggest military space actor, but its future prospects remain uncertain: Russia proved that it is able to adopt a pragmatic and efficient approach to security issues in space, but it has been, for the past two decades, hobbled by funding issues, program delays, and technical failures.

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# Space and Security in Europe

# 21

Geraldine Naja and Charlotte Mathieu

## Contents

**Abstract**

The relation between space and security has always been quite different in Europe as compared to that in other spacefaring nations. This situation has evolved in the past decade with the progress of a European security and defense policy and the new competences of the European Union over security and space matters, as well as with the growing reliance of European economy and society on space for many critical services and policies. The article gives an overview of the recent evolution of "space and security" in Europe. It highlights the political and institutional developments, describes Europe's specific approach to security and to "space for security," and introduces the main European space activities for security. It finally reviews Europe's current efforts to safeguard space sustainability and to protect its space assets from man-made and natural hazards.

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## 21.1 Introduction

The relation between space and security has always been quite different in Europe as compared to that in other spacefaring nations. Contrary to most of them, the development of space activities in Europe has been mainly driven by civilian applications, which also means that space is relatively less used for security and defense purposes, despite the unique capabilities it offers. This situation has evolved in the past decade with the progress made in the European Security and Defence Policy (ESDP) and the new competences of the European Union (EU) over security and space matters. Space is called to support more and more European security actors in addressing all their security challenges. Furthermore, space is now fully integrated in the economy, and society is now relying on space for many critical services and policies. European citizens have thus become dependent on space infrastructures and services; hence they need to protect these and to ensure the sustainability of the space environment in order to maintain and to further develop all the benefits they derive from space. Europe has taken a leading role in political initiatives and technical activities to address this rising problem.

The present article gives an overview of the recent evolution of “space and security” in Europe. It highlights the political and institutional developments, describes Europe’s specific approach to security and to “space for security,” and introduces the main European space activities for security. It finally reviews Europe’s current efforts to safeguard space sustainability and to protect its space assets from man-made and natural hazards.

## 21.2 Security and Defense in European Space Activities

Space-based systems offer unique capabilities to serve the needs of security and defense actors. They have demonstrated in particular their distinctive advantages for the collection of data; for its distribution in a secure, unrestrained, and instantaneous way; and for global positioning, navigation, and timing. Space-based assets and services can help security actors to address the full spectrum of challenges they are facing, including border surveillance, maritime surveillance, critical infrastructure protection, crisis management, security operations, monitoring of climate change and its consequences, international treaty enforcement and monitoring, and the fight against proliferation of weapons of mass destruction (WMD), illegal activities, organized crime, and terrorism. They can support humanitarian and military operations, in particular through their distinctive ability to collect information anywhere in the world and to distribute it instantaneously anywhere else. Space assets provide unique intelligence, surveillance, reconnaissance, early warning, and communication capabilities and have become key enablers of military capabilities and force multipliers that significantly increase the effectiveness of forces.

The significant contribution of space to security and defense has motivated the large investments in this field made by most space powers and has granted space high political visibility in these countries. As a result, security and defense have been, and continue to be, the main drivers for space undertakings in most spacefaring nations. Space capabilities have been, and remain, an attribute of prestige and power for most nations. During the Cold War, space was an arena for competition between the USA and the USSR as each nation was trying to demonstrate its scientific and technical superiority. This dimension persists today as demonstrated, for instance, by the more recent development of the Chinese space activities. The development of space capabilities is also strongly linked to the development of military capabilities, since space and defense use the same technologies produced by the same industry, as illustrated by launchers and missiles.

In contrast, space activities at European level have been mainly motivated by science and civilian applications, together with the will for an autonomous access to space. The investment in space for security and defense and its use in that context therefore remain limited compared to the other space powers. Beyond the direct impact on the capabilities available to security and defense actors, this situation also impacts the European space industry. The latter cannot in fact benefit, like its competitors, from a large captive market and has to rely on its performance on the commercial market to maintain core capacities.

In addition, space programs for security and defense in Europe still remain to a great extent in the national realm, as they are mostly handled by member states at national or multilateral levels and do not benefit from European integration. This is still typically the case of the military space programs that are undertaken by a few European member states.

### 21.2.1 The Development of Space for Security and Defense in Europe

This situation has gradually evolved over the past decade both in European member states and at European level. Space is more and more used for security and defense, and the European dimension of space and security is growing. At European level, this recent evolution has come with the development of European security and defense policies and activities and with stronger EU competences over both space and security matters. First, since the 1990s, a European Security and Defence sector has gradually emerged. The initial European Security and Defence Policy (ESDP) was reinforced into a Common Security and Defence Policy (CSDP) with the entry into force of the Lisbon Treaty in 2009 and is now supported by new structures. The Lisbon Treaty abolished the "pillar structure" of the EU, established a single High Representative of the Union for Foreign Affairs and Security Policy, who is also the vice president of the EC and chairs the Foreign Affairs Council and the European Defence Agency's (EDA) Board. The treaty also created a permanent president of the European Council, who represents the EU in the world in the field of foreign and security policy. In addition it established the European External Action Service (EEAS) to support the High Representative and which should ensure the coherence of the foreign policies and a reinforced involvement of the EU in security affairs. The scope of potential EU missions, the Petersberg tasks, was furthermore extended.

Moreover, the "European Security Strategy" (EU Council 2003), established in 2003, identified the global challenges and key threats to be addressed and called for a more coherent, capable, and active Europe in providing appropriate policy responses and shaping future evolutions. As reflected 5 years later in the "Report on the Implementation of the ESS" (EU Council 2008a), the threats are changing, and this evolution has called for an expanded definition of security. These developments have led Europe to adopt a so-called "comprehensive" approach to security. Pursuing this new ambition and these new objectives require adequate European capabilities, including space-based ones, based on the integration of civil and military assets.

In 2007, the Ministers of the 29 member states of the European Union (EU) and the European Space Agency (ESA) had already defined meeting Europe's security and defense needs as one of the strategic objectives of the European Space Policy (Space Council 2007). Space was to be further used for Europe's security and defense. The importance of space for security was further emphasized in the Resolution of the European Parliament in 2008 (European Parliament 2008) and has been repeatedly stressed by the Ministers in the resolutions of the subsequent Space Councils, which called for the further use and integration of space assets to support security actors in their missions and for the development of new appropriate capabilities.

In parallel with the growth of its security dimension, the European Union has gained new competence in space matters, in addition to its member states' own competences, with the entry into force of the Lisbon Treaty in 2009. Space is now on the European political agenda at the highest levels. All these elements should significantly contribute to the further advancement of space for security in Europe.

### 21.2.2 A Growing Number of European Institutional Actors in Space and Security and the Need for Coordination and Adaptation

These recent evolutions have also brought a substantial increase in the number of European actors involved in space and security. All these stakeholders are of diverse natures, have different roles and responsibilities, and also have different constituencies and decision-making processes. This certainly adds complexity, but on the other hand, it should ensure that space is used to its full potential for security purposes and in support of the largest number of European policies in a user-driven approach. These actors include the European Commission, the EU Council General Secretariat (CGS), the European External Action Service (EEAS), ESA, EDA, and the EU Satellite Centre (EUSC). This multiplicity and variety of actors, the complexity of their interactions, and the importance and the breadth of associated challenges have called for appropriate coordination. The Fourth Space Council of May 2007 (Space Council 2007) therefore called for the creation of a “Structured Dialogue on Space and Security” which today gathers all the European organizations mentioned above. This forum guarantees coordination and stimulates policy-level dialogue on all space and security issues, orienting actions which can subsequently be taken through the formal decision-making processes of each actor or joint processes such as the Space Council. This increased dialogue between the space and defense communities has contributed to further develop the security dimension of the European space policy and to better support Europe’s security and defense needs.

At the same time, it has required the evolution of the existing institutions and agencies concerned. These organizations have strengthened their expertise and gained new ones and have set up the proper structures and tools to successfully conduct these efforts. For instance, ESA is now managing programs with a security dimension. ESA has historically managed mainly scientific and civilian programs, funded through civilian budgets, but the agency is not limited by its Convention to civilian activities. Its convention refers to “peaceful purposes.” In March 2004, the ESA Council actually took note of the “Position Paper on ESA and the Defence Sector” (ESA 2004). On this occasion, ESA has declared that the agency has the potential to make contributions to the space component of ESDP, acknowledging that the defense sector is becoming a crucial issue in the European space policy (“Space has a security dimension and security has a space dimension”) and outlines that the reference to “peaceful purposes” in Article II of the ESA Convention cannot be interpreted as restricting ESA’s capacity to conduct activities of dual use as long as they are not aggressive. Actually ESA is gradually opening to defense communities and is now managing programs with a defense and/or security component, such as Galileo, GMES, and the preparatory program on SSA. These programs will also have military users, and ESA now receives limited funding from a Ministry of Defence. ESA has consequently adapted its procedures and ways of functioning, as illustrated to the security procedures put in place at ESTEC for ESA to manage the Galileo development program and by the creation of ESA’s Security Office, in charge of the physical security of ESA centers and assets and of the accreditation of the relevant ESA staff.

Last, in view of exploiting synergies and maximizing complementarity, these organizations have also developed proper frameworks for cooperating on specific research activities and programs. The “European Framework Cooperation for defence, civilian security and space-related research” (EFC), established in 2009, is an example of such mechanisms through which the EC, EDA, and ESA coordinate their research activities to ensure the exploitation of synergies and an optimal use of the resources. These organizations have also established bilateral framework agreements and associated security agreements to facilitate their programmatic cooperation, as illustrated by the Administrative Arrangement signed between ESA and EDA in June 2011 and its associated Security Arrangement established in November 2012. Building on their specific complementary roles and activities, ESA and EDA are cooperating on a variety of subjects including intelligence, surveillance, and reconnaissance (ISR), civil–military synergies in Earth observation, satellite services for UAS missions, and mobile satellite communications. This cooperation includes an increasing number of activities in different fields and with different setups building on their complementarity and exploiting synergies between civil and military needs.

A first example concerns space-based services for UAS command and control, for which a joint demonstration mission was initiated last January. This joint mission follows two parallel feasibility studies on satellites support to UAS integration in the European airspace that was conducted by each agency, respectively, and is the first project jointly funded and managed by both agencies. In Earth observation, parallel studies on ground segment systems of systems for security services are ongoing. As recommended by the taskforce on civil–military synergies, these studies investigate how security and defense services could be created in a comprehensive approach by networking existing ground segments; while the ESA study focuses on civil security services, the EDA study focuses on defense services. ESA has also recently contributed with its Concurrent Design Facility to an EDA study on ISR (intelligence, surveillance, and reconnaissance) capability in support of CSDP. This innovative cooperation was a very concrete example of an integrated approach to ISR. In the near future, cooperation could be strengthened in those fields and further developed in the field of telecommunications, in particular for mobile/tactical communications. Finally, EDA and ESA have worked together with the European Commission for over 3 years on critical space technologies for European non-dependence.

### 21.2.3 A Special Focus on Civil–Military Synergies Reflecting Europe's Unique Approach to a Broad Concept of Security

In the development of European capabilities, a special emphasis has been put on exploiting civil–military synergies to the benefit of all security and defense actors. In the space domain, the European Space Policy of 2007 already called for "[improving] coordination between defence and civilian space programmes, pursuing in particular the synergies in the domain of security" (Space Council 2007). It seems indeed crucial to improve coordination and ensure coherence of all relevant activities given the existing commonalities of technologies, infrastructure, and industrial base between civil and military space applications and the constrained funding of space and security in Europe. A common approach and the exploitation of all possible civil–military synergies at all levels are essential to avoid duplication of capabilities and to maximize the use of the resources available, especially in the current economic and financial crisis.

Most space technologies are fundamentally dual use. While the uses to which they are put and the operational context may differ, the technologies, the expertise, and much of the tools as well as the ground and space infrastructures are common to both areas. Security and defense services do come with certain constraints, but only a limited number of technical areas are specific to these applications. Space for security and defense in Europe has built and will continue building on the large experience gained with civilian applications and systems. Last but not least, the effectiveness of the implementation of coordinated European actions will depend on the ability to achieve maximum synergy within a coherent European effort among intergovernmental and communitarian actors but also with national actors, who remain the main players in this field.

Building on the various space programs successfully developed for civilian applications in Europe, a number of European activities are now addressing security and defense needs. As a first step, space systems developed for civil applications have been increasingly used by security and defense users. Many infrastructure developed in a civil framework have found defense applications, in the fields of launchers, meteorology, telecommunications, imagery, oceanography, navigation, environmental monitoring, and investigation of the gravitational field. They are now used by security and defense actors but without that usage having constrained or determined their initial development specifications.

An example is the Charter for Space and Major Disasters. Founded initially by ESA, CNES, and the Canadian Space Agency in 1999, this unique international collaboration among space agencies supports relief efforts with space-based data and information in the event of emergencies caused by major disasters. It aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters, and it is since September 2012 opened to all national disaster management authorities worldwide. Imagery is delivered at no cost to users but only in the immediate response phase. The Charter is open to all space agencies and space operators in the world, on a voluntary basis, with no exchange of funds and has now 14 members who have committed civilian (and more recently dual-use) resources. To date, requests have covered natural disasters such as floods, hurricanes or forest fires, earthquakes, and volcanoes or landslides and technological disasters such as oil spills and industrial accidents. The Charter has been activated for more than 360 disasters (as at the end of 2012) in over 120 countries since its inception in 2000.

Then, new space programs integrating security and defense requirements have been launched. With a view to deriving maximum benefits from the convergence of civil and defense needs, a number of major applications programs recently deployed have been designed from the outset in a dual-use perspective. Dual-use systems have been developed at national level to serve both civilian and military applications, like the Italian radar COSMO-SkyMed and the French optical system Pleiades. This trend is even more visible at European level: the two EU flagship programs, Galileo and GMES, are civilian programs, developed in a civilian framework, but will also serve security and defense users, which has been taken into account in their development and implementation. The GMES emergency management service now provides civil protection and humanitarian actors with worldwide coverage and rapid 24/7 reactivity, providing products including reference maps, flood risk analysis and mapping, forest fire monitoring, landslide monitoring, and forecasting earthquake damage assessment and support of assistance effort during humanitarian crisis. The service should be expanded beyond the emergency response phase to cover the entire crisis cycle. The GMES security service will have the potential to provide intelligence and early warning information to the EEAS, border and maritime surveillance actors, and member states. A series of crisis indicators should measure consequences and trigger alerts in case of fighting for natural resources, population pressure, land degradation, and illegal activities. Other products should be dedicated to monitoring and analysis of migrations, including border crossing activities and smuggling, monitoring nuclear facilities and other treaty-related infrastructures, and detection of changes related to critical assets. The service may also contribute to support the planning for EU intervention and citizens repatriation during crises and post-crisis reconstruction. The development of GMES will substantially support the potential of Europe to act as a global player in the areas of international politics, climate change adaptation, environmental protection, and humanitarian assistance.

The unique European approach to security is also reflected in ESA's GIANUS initiative on Space for Crisis Management. During the Seventh Space Council in November 2010, EU and ESA Ministers acknowledged "the reinforced EU engagement in security and defence matters embedded in the Lisbon Treaty and the setting-up of the European External Action Service (EEAS) and the significance of crisis management as a key element of the EU and its Member States' actions both in Europe and globally" and "therefore invite[d] the European Commission, the EU Council, assisted by EDA, together with Member States and ESA, to explore ways to support current and future capability needs for crisis management through cost-effective access to robust, secure and reactive space assets and services (integrating global satellite communications, Earth observation, positioning and timing), taking full advantage of dual-use synergies as appropriate" (Space Council 2010).

Following this call for strengthening Europe's response capacity, ESA launched several studies which underlined the unique capabilities offered by space systems for crisis response, but also their limitations and therefore the need to integrate them with non-space systems. The studies demonstrated that the sustainability of existing systems must be ensured for the continuity of existing services that are critical to crisis management actors and for the transition of pre-operational services towards fully operational ones. They also showed that the completion of ongoing developments (including Galileo) is key to a number of new planned services and that a number of additional services based on existing systems could be delivered in the short-term with satisfactory level of performance, requiring further service developments but also actions addressing political and organizational issues. The studies concluded that strengthening the European response capacity in the future would require new systems and therefore new infrastructure developments. But for capacity and cost reasons, these new systems would have to be shared with other applications/users. Should some of these systems be available at horizon 2025, new technological developments would have to be initiated in the short term.

The development of new activities in the framework of the structured dialogue has also strengthened the cooperation between all European organizations involved in space and security. For instance, the development of the Galileo PRS or the

GMES security services required coordination between all these organizations. ESA and EDA have remarkably reinforced their cooperation in the past years, with the objective to explore the added value and contribution of space assets to the development of European capabilities in the area of crisis management and the Common Security and Defence Policy. Building on their specific complementary roles and activities, ESA and EDA are cooperating on a variety of subjects including intelligence, surveillance, and reconnaissance (ISR), civil–military synergies in Earth observation, satellite services for UAS missions, and mobile satellite communications. ESA and EDA have also cooperated with the EU CGS and the EC on Space Situational Awareness (SSA).

The development of space for security in Europe came indeed with a growing concern for the security of space assets and more generally for the sustainability of the space environment, which has become more and more critical to European society as a whole.

## 21.3 Security in Space: Europe's Efforts to Protect Its Space Assets and to Safeguard Space Sustainability

The European citizens have grown more and more dependent on the services delivered by space systems, and this trend will continue in the future. Space-based services have become indispensable in their daily life, much more than most of them are actually aware of. The increasing use of space for security and defense makes this reliance on space even more acute. Space systems have thus become critical infrastructure; they are essential for the functioning of the European society and economy and are therefore a source of vulnerabilities. Europe must ensure the protection of these key assets and its ability to maintain the services they offer. It requires guaranteeing the sustainability of the space environment and the protection of its space systems and their associated ground infrastructure from both man-made and natural hazards. Europe operates almost 20 % of the active satellites in orbit and is the 4th largest contributor to the space debris population. The strategic dimension of space also calls for European autonomy in a number of areas in order to guarantee the continuity of the benefits it derives from its space activities.

First, the sustainability of the space environment is today challenged by the growing number of actors in space: 10 countries are now able to launch satellites, and 55 public entities are operating satellites in addition to numerous private entities that are operating commercial ones. Space sustainability is also threatened by the increasing orbits' congestion and use of scarce resources like orbital slots or frequencies, with 1,300 operational satellites today including more than 400 in geostationary orbit, and by the alarming proliferation of space debris. After about 5,000 launches since 1957 and 240 satellite explosions in orbit, there are currently 22,000 man-made objects monitored by the US Space Surveillance Network, 60 % of which are debris. In fact about only 5 % of the overall debris population is catalogued, and debris from 1 to 10 cm are not catalogued even though they can cause a complete satellite loss or a fatal accident on the ISS due to their speed. In the last years, 3,000 additional debris were created with the Chinese ASAT test in 2007 and 1,500 additional debris in 2009 with the collision between the Iridium and Cosmos satellites.

Space sustainability has become a concern shared globally, which will require international solutions. This challenge has triggered several political initiatives and related technical proposals. Europe and its member states are at the forefront of these issues and play a leading role both at political and programmatic levels. Europe has addressed the question of space sustainability primarily through a proposal for an International Code of Conduct for Outer Space Activities. The objective of this EU initiative is to improve security in space through a pragmatic and incremental process, based on the development of transparency and confidence-building measures (TCBMs), as a means to achieve enhanced safety and security in outer space and to limit the creation of space debris.

The first draft Code of Conduct was adopted by the EU Council in December 2008 (EU Council 2008b), and after a first round of discussions with the main spacefaring nations, a revised version was adopted in September 2010 (EU Council 2010). On the basis of this new text, the EU Council gave mandate to the EU High Representative to carry out further and wider consultations. The EEAS is leading this process and has consulted with a number of countries to discuss this proposal in 2011. The EU Political and Security Committee (PSC) agreed in September 2011 to discuss the EU initiative multilaterally by convening a multilateral expert meeting in June 2012. The EU presented an updated text which will require further multilateral discussions. The next meeting is planned in early 2013. This ongoing process should lead to a final version of the Code which would then be open to endorsement by all states on a voluntary basis at an ad hoc high-level diplomatic conference. The Code could also be negotiated or put to a vote at the UN General Assembly.

Europe is also an active player, through its member states, in the two other major ongoing international initiatives addressing space sustainability: the working group on Long-term Sustainability of Space Activities (LTSSA) of the Scientific and Technical Subcommittee of the UN COPUOS and the Group of Governmental Experts (GGE) on TCBMs in Outer Space.

The UNCOPUOS working group was established to draft recommendations, which could then lead to a specific resolution of the UN General Assembly in 2014. These recommendations will be based on the bottom-up work of experts grouped around four themes: sustainable space utilization supporting sustainable development on Earth, space debris, space operations and tools to support collaborative space situational awareness, space weather, and regulatory regimes and guidance for actors in the space arena. Three of these expert groups are chaired or cochaired by European experts.

The Group of Governmental Experts (GGE) on TCBMs in Outer Space is another initiative of the UN General Assembly First Committee, which is in charge of security and disarmament issues. It was set up in 2011 to prepare recommendations on TCBMS that could help ensure strategic stability in the space domain by mid-2013. This group is made up of 15 international experts, including 4 European ones.

On the specific issue of space debris, Europe and its member states have also been active since the 1990s as part of the Inter-Agency Space Debris Coordination Committee (IADC), which developed "Space Debris Mitigation Guidelines" (IADC 2007). Experts from ASI, CNES, DLR, BNSC/UKSA, and ESA contributed to the definition of mitigation guidelines that aim at limiting the debris released during normal space operations, minimizing the potential for on-orbit breakups and collisions and removing nonoperational space objects from populated regions. Based on these inputs, the UNCOPUOS adopted its "Space Debris Mitigation Guidelines" in 2007 (COPUOS 2010).

These initiatives are supported by the development of technologies and systems, in particular to address the challenges associated to space debris. A first necessity is the further development of space surveillance and tracking capabilities. EU member states own valuable assets which could be part of a European SSA system. These include radar sensors, telescopes, space weather sensors, secure data communications networks, storage and computation, as well as human expertise. There is already today some resources and data sharing among member states, as illustrated by the French–German cooperation on the exploitation of data from the French GRAVES surveillance radar and the German TIRA tracking radar and the pre-operational validation of the ESA optical space debris telescope at Tenerife, the Spanish telescopes of La Sagra, and the Swiss ZIMLAT telescope at Zimmerwald.

However, these systems have significant shortcomings: many sensors need to be upgraded to become operational, while others have very limited operational availability despite high technical performance. Europe, therefore, depends on the USA for information on objects in orbit and potential risks of collision and is lacking an autonomous source of timely and accurate information on objects in orbit. This deficiency has led to the launch of the Space Situational Awareness (SSA) Preparatory Programme in ESA in 2008, which aims at providing Europe with the ability to autonomously detect, predict, and assess the risks due to space objects and in-orbit explosions, as well as space objects reentries. This preparatory program includes the development of two breadboard surveillance radars to test methods for finding orbital debris. A monostatic radar was deployed near Santorcaz, Spain, in October 2012, and a bistatic radar will be deployed in Dreux and Palaiseau, France. As part of broader space situational awareness activities, Europe is also developing its ability in monitoring threats from space, including space weather and near-Earth objects (NEOs). At ESA Council at ministerial level in November 2012, the next phases of this program were launched with a stronger focus on space weather and NEO activities. The European Commission is now working in parallel on a decision for the setting up and operations of space surveillance and tracking services at European level.

Other complementary European initiatives address space debris mitigation and remediation. Space environmental protection is one of the priorities of ESA's new Clean Space initiative, part of which aims at limiting the number of debris released by future European space missions and at investigating active debris removal techniques.

To protect space systems, not only the space environment should be protected but also the ground infrastructure necessary to the operations of these systems, which can be, and have been, targeted by physical and cyber attacks. Cyber attacks of space systems can range from access to the satellite control while in operations to malicious software implanted during the satellite development. Data and information collected or distributed by space systems also need to be protected. The protection of the ground infrastructure has become a growing source of concern for satellite operators and owners also in Europe. All European stakeholders are facing common threats and are therefore working together to address these issues, as illustrated by the recent initiative of the EC, EDA, and ESA to coordinate their respective research activities in the field of cyber security. ESA is, in particular, investigating means to protect itself as an institution and R&D agency, to protect its data and information, to protect its own missions, to ensure the security of the satellites it develops for third parties, and to support the security needs of commercial SATCOM operators through technology development.

The growing dependence on space systems in Europe also calls for guaranteeing a certain level of autonomy and for reducing technological dependence from outside Europe. To keep the autonomy of decision and action, Europe needs an autonomous access to space and its own space systems. It should also limit its dependence on non-European suppliers for critical space technologies and components, which means mastering the most strategic technologies and maintaining a European supply sources in a cost-effective manner. This requires mechanisms to define these technologies and targeted efforts supported by an adequate industrial policy. Since 2008, the EC, ESA, and EDA have worked on joint effort to define and to develop critical space technologies in Europe, with the objective to ensure that Europe can rely on a technical and industrial capacity for accessing space, in particular in the area of the manufacturing of satellites and launchers.

## 21.4 Conclusions

The topics of “space for security,” “security in space,” and “security of space” have become critical topics in Europe over the last decade. Security has become a key parameter for space activities in Europe, next to their socioeconomic dimension, and this trend is likely to expand. Thus it can be expected that space activities related to security and defense will grow also at European level, eventually reaching an importance commensurate with Europe’s capabilities, ambitions, and assets in space overall.

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# External View of Space Security in Europe

# 22

Agnieszka Lukaszczyk

## Contents

**Abstract**

The international community has long agreed that the space environment is becoming more crowded with more actors and more objects launched into space while the space environment is very fragile and needs protection. The long sustainability of the outer space will assure a long-term utilization of space infrastructure for benefits of humankind. It is in the interest of all actors to behave responsibly as anyone's assets can be affected by debris, space weather, and man-made threats. As a spacefaring actor, Europe is as affected by various threats and predicaments of space security nature. This chapter assesses Europe's involvement and approach towards space security affairs.

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## 22.1 Introduction

Space security has become an increasingly important issue, with the international community witnessing a number of debris-generating events in the low earth orbit. The long-term sustainability of the outer space, however, also faces various risks. Ensuring that the space environment is safe and stable should be of high importance to the global community and thus Europe. With more actors active in space activities, and thus more objects in space, some rules of the road will need to be established in order to protect the space assets so that they could benefit the humankind in a sustainable way. Space environment is very fragile and it is not a question of whether we should protect it, but rather how we should do it.

For a long time it has been assumed that only the rich and developed countries such as the United States, the Soviet Union (and later Russia), and to some extent Europe could have access to space and benefit from it. However, in recent years space activities have rapidly increased with government and private space operators having assets in space. Today, not only the developed world is participating in space activities. There are currently nine states with launching capabilities, and more than fifty countries and international organizations own or operate satellites of various sizes. In addition, private companies, universities, and institutions own and launch small/cube/nano satellites, which, to a certain extent, make them space actors as well. Space programs and other related technologies are now becoming part of national strategies and policies of many emerging space states, which strive to strengthen their international standing, security, and economic benefits. Currently it is estimated that there are about 1,000 operational satellites in orbit,[1] 22,000 objects larger than 10 cm (40 % are satellites that are no longer operational and 55 % are fragments of other objects). More than that, there are around 45,000 objects between 1 and 10 cm and estimated several million of pieces below 1 cm.

Since space does not belong to anyone, in theory everyone should have free access to it and it should be used for the benefit of all humankind. At the beginning of the space age, this notion was only theoretical as in reality only two countries had access to space and derived benefits from it. The situation is, however, very different today. Currently there are attempts to not only utilize space for military, commercial, and scientific reasons but also purely for leisure purposes. Space tourism has been on the agenda for some years and is slowly becoming a reality.

On one hand it is exciting that space is finally becoming relatively reachable for more and more people, companies, and states. However, alongside the benefits there are costs that should not be neglected, as they bring many potential threats. There is an urgent need to guarantee sustainability of space activities. More actors in space translate into increased crowding in key orbits as well as growing number of debris in space. Accordingly, raising awareness of benefits of space activities is

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[1] UCS Satellite Database

very important. New space actors – public or private – should not only be encouraged to participate in space activities, but they should also be educated on how to become a responsible actor. Capacity building in this context is crucial because the space environment is unique in the sense that a mistake of one actor affects all actors. A 10 cm or larger piece of debris can seriously damage, even destroy, a satellite. Potential consequences can be hazardous and very expensive, thus, it is in everyone's interest that new space players have a good understanding of space environment as well as proper policies in place.

The panorama of space security has changed significantly since the end of 2008. A number of encouraging steps have been taken, spurred on by the fright caused by the collision in February 2009 between the Cosmos 2251 and Iridium 33 satellites. As a result, a number of unilateral and international initiatives on space security, including those listed below, have emerged and the global spacefaring community now has an unprecedented opportunity to make great progress towards space stability.

### 22.1.1 Movement to Treaties and Agreements

A draft Code of Conduct was adopted by the European Union (EU) in December 2008 and revised in 2010 and 2012, respectively. The UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) approved the establishment of a working group to develop best practices guidelines for space operations to be completed in early 2010. In May 2009, the Conference on Disarmament (CD) adopted a program of work that provided for substantive discussions dealing with issues related to the "Prevention of an Arms Race in Outer Space" (PAROS) and establishment of a working group to address its issues. Nevertheless, objections by the government of Pakistan to the Program of Work on subjects unrelated to space issues later halted formal consideration of space issues within the CD.

The international space community is now considering several other proposals, including the February 2008 Chinese/Russian draft *Treaty on the Prevention of the Placement of Weapons in Outer Space* (PPWT), a 2009 working paper by the Canadian government on the Merits of Certain Draft Transparency and Confidence-Building Measures and Treaty Proposals for Space Security, as well as a *Treaty Banning the Testing and Use of Destructive Methods Against Space Objects* proposed by the Henry L. Stimson Center.

### 22.1.2 Shift in the US Government Priorities

The Obama administration committed itself to making changes in its approach to space security. It undertook a review of national space policies beginning in the summer of 2009 and intends to put a greater emphasis on international cooperative mechanisms than the Bush administration. The US Under Secretary of Defense for Policy, Michèle Flournoy, wrote: "First, U.S. strategy must be grounded in a common sense pragmatism rather than ideology. U.S. national security strategy must be based on a clear-eyed assessment of the challenges and opportunities of the new security environment as well as realistic objectives derived from our national interests." Current US government openly supports Transparency and Confidence-Building Measures (TCBMs) initiatives, which involve, for example, its active participation in the Group of Governmental Experts (GGE) on space. It also reaffirms US support for the Inter-Agency Space Debris Committee (IADC)-generated Best Practices Guidelines initiative.

Another aspect of this increased interest in international space policy has to do with the US interest in freedom of commerce. The United States supports "free and fair access to global commons." The US government plans to expand current transatlantic discussions on technical standards internationally. To this end, it is expressing a commitment to develop unified global standards for space activities, reflecting the reality of increased interdependence among space activities.

### 22.1.3 Weapons: Tests but No Space Weapons Observed

Despite recent tests, no space weapon system is operational. As opposed to "traditional" arms control negotiations, which deal with weapons that are already deployed (and are encompassed in most existing treaties), the space community continues to engage in discussions aimed at "preventive" arms control, that is, dealing with weapons that are not yet deployed, and for cases in which the technology is not even ready.

## 22.2 The Role of Europe in Space Security: An Overview

The dynamics of space activities has changed since the end of the Cold War, and many new space actors have emerged, which has put Europe in an interesting position where it could serve as a model for international cooperation in space and a model for engaging in space activities for the benefits of its citizens as opposed to viewing space as a sole means of power.

The complexity of Europe can be both its asset and its liability. The asset is clear. No other region in the world has such significant experience in international cooperation as Europe does. The countries within the region cooperate multilaterally through alliances they are part of – mainly the European Union (EU). The EU has a supranational power in many areas over its member states, which have mastered cooperation in order to achieve mutual goals and interests. In addition, the only existing international space agency in the world is in Europe – the European Space Agency (ESA), and it has proven that it is working for the benefits of all its members.

One could assume that due to many examples of successful international/ regional cooperation Europe could be a leader on the international scene precisely for that reason – international cooperation. However, what has proven to work within the framework of intra-European cooperation, it is proving far more difficult to achieve on an international level with non-European partners – particularly on space security issues. In this regard, Europe does not speak with one voice. The European Space Agency has a competence in space, individual members do as well, and many have their own space agencies/offices, plus since December 2009, according to the Article 189 of the Treaty of Lisbon, the EU also has a competence in space shared with its member states (Lisbon Treaty 2009). All of this creates a complicated environment for Europe to be considered as a space actor on the international scene. Who do we mean by Europe when we speak about space: ESA, the EU, perhaps individual European countries? It all depends and this is where things become complicated.

Due to a lack of coherent space governance in Europe, third countries often opt for bilateral cooperation with some individual European countries, ESA, or the EU. It is not unlikely that while partnership with one European entity might be challenging, it could be very successful with another. A good example is cooperation with China. For instance, almost 20 years ago ESA involved China in its European Remote Sensing (ERS) satellites program by setting up data reception opportunities for Chinese users, which has proven to be a fruitful partnership. On the other hand, there has been a glitch in the cooperation on the Galileo, the European GNSS project. Being a public-private consortium during its first stage, the project welcomed participation from foreign industries. In 2005, China agreed to invest in the project. Then in 2007, reshaping Galileo's budget and institutional functioning at the request of its member states, the European Commission took a more important role in the project implementation, making it a highly political issue and a strategic interest for the EU. Therefore, the participation of China was no longer suitable. Discussions are still ongoing about this setback and the Beidou (China's navigation satellite system) and the Galileo's security signals frequencies are now overlapping, which presents an issue (European Institute for Asian Studies and Secure World Foundation 2012).

To assess Europe's role in space security, one has to look at all its different players. As most other spacefaring actors, Europe also realizes the importance of space-based information systems in addressing various security challenges. One of the arguments behind developing Europe's own global navigation satellite system, Galileo, was that it no longer wanted to depend on systems controlled by foreign militaries. Galileo, although originally configured as a civilian system, will be able, when operational, to address security needs of the European militaries, which illustrates shift towards Europe's greater reliance on space. Of course, in comparison to the US investments in space assets, Europe's investments could still be considered as much more modest, most likely reflecting limited resources and other political priorities in the times of the economic crisis. Also the lack of clarity in goals, priorities, or vision when it comes to space security makes Europe a very difficult partner for cooperation.

That said, it does not mean that Europe has no experience with dual-use satellite technology. There are programs, initiatives, and research that have proven to be very useful or promising for the European space security purposes. Galileo program (not fully operational yet) has already been mentioned, but there is another space program of the EU (in cooperation with ESA) that also deals with space security. Global Monitoring for Environment and Security (GMES), now Copernicus, is a comprehensive Earth observation program, which, in addition to other things, is to provide Earth observation data for security purposes such as disaster and crisis management, maritime security, and monitoring of EU boarders. This program is not yet fully operational and its future budget is currently being reviewed. Once operational, however, Copernicus will truly be an asset for Europe and its partners. Certain European countries have developed competencies for radars (Germany and Italy) and optical satellites (France), which are also enhancing Earth observation initiatives in Europe.

In 2001, ESA launched the Envisat satellite, which was the world's largest Earth observation satellite (size of a school bus), and it has been considered one of the most significant European developments in space taking high-resolution pictures of Earth for nearly 10 years. However, in May 2012, ESA has announced the "death" of the satellite. Envisat is still orbiting the Earth making it, paradoxically, a major space debris risk, transforming itself from a security asset to a security risk.

## 22.3 Space Sustainability and the Role of Europe

As referenced in the article's introduction, space environment is very fragile, and since more actors are using space for variety of socioeconomic, security, and commercial benefits, space environment is becoming more crowded. Many of the activities utilize similar regions of Earth orbits, leading to potential problems such as signal interference or potential collisions. Unsafe or irresponsible actions by one actor can have long-term damaging consequences for all.

It is becoming more obvious that some sort of rules of the road need to be developed by the international community in order to keep the space environment safe and sustainable – not to prevent the beneficial use of space, but rather to ensure that it is done in a way that preserves the utility of Earth orbits for the long term. Fostering international cooperation, strengthening stability, and promoting responsible actions to help prevent mishaps, misperceptions, and mistrust are all key elements of space sustainability.

However, the growing importance of establishing some sort of best practices in space differs from the perception of the general public when it comes to the importance of space in today's society. After the launch of Sputnik, the ISS, Moon landings, and various human and robotic space missions, relatively few people are aware of the benefits of space technology today. During the Cold War, space was somewhat a "hot topic" with glamorous achievements of putting the first satellite and a first man in space, landing on the Moon, preventing Star Wars, etc. The space sector today has a different focus – more on science and technology – which has greatly enhanced human life but has not been a source of high-profile news. Although space benefits are very much integrated into our daily life, most people do not give it a second thought.

Also threats and accomplishments seem to be of different nature now than they were during the Cold War. Even though there is no record of weapons being deployed into the outer space to date, in February 2007 China successfully tested an antisatellite ballistic missile, which came as a shock to the international community. By shooting down one of its own satellites from the Low Earth orbit, China – a country, the majority population of which still lives under the poverty line – demonstrated that ground-based weapons can target objects in the Low Earth Orbit and that China is indeed a space power. In 2008, India successfully launched its own probe to the Moon. Moreover, around the globe, an increasing number of developing countries have begun to invest in space technologies, partner in various space projects, and build its own satellites.

In the recent years, the international community has begun to acknowledge the importance of establishing some sort of norms or rules of the road in order to protect the space environment so that it could be utilized for long time to benefit humanity. Europe has played a major role in many of these initiative demonstrating its commitment to, and understanding of, the issue. For instance in 2007, the Chair of the UNCOPUOS, Gérard Brachet, contributed a white paper on the topic of long-term sustainability of the outer space to the committee. The following year, the French delegation announced its plan to submit an official proposal to UNCOPUOS to add a sustainability item to the agenda. This led to an establishment of a Working Group on Long-Term Sustainability of Space Activities in 2010 (Chow 2012). Currently the WG has four Expert Groups and is actively working on putting forward recommendations, which will eventually be voted on by the General Assembly of the United Nations.

Another space sustainability initiative, in which Europe has played a leading role, is the Draft Code of Conduct for Outer Space Activities, for the first time introduced under the French Presidency of the EU and later revised in 2010 and 2012. The Code calls on states to "establish and implement policies and procedures to minimize the possibility of accidents in space, . . . or any form of harmful interference with another State's peaceful exploration, and use, of outer space." (European Union 2012). It is based on three principles:

- Freedom of access to space for peaceful purposes
- Preservation of the security and integrity of space objects in orbit
- Due consideration for the legitimate defense interests of states

The Code is not legally binding but rather a voluntary agreement among states with no formal enforcement mechanisms. The draft proposes measures on space operations, debris control and mitigation, cooperative mechanisms, and organizational aspects for all signatories. The aim is to minimizing accidents in space, refraining from deliberate destruction of spacecraft unless in self-defense or to mitigate debris, promoting space safety and sustainability, pursuing strategic stability, and implementing the UNCOPUOS Debris Mitigation Guidelines. In addition, the Code lays out mechanisms for cooperation including notification of launch and risky reentry, notification of maneuvers or collisions to those affected, sharing policies when appropriate, and avenues for consultation and investigation.

Finally, the Code proposes the establishment of biennial meetings, consensus decision-making, and a central point of contact and database for managing information (Chow 2012).

The draft Code of Conduct for Outer Space Activities has received mixed reactions from the international community. In February 2011, for example, thirty-seven US Republicans noted that they were “deeply concerned” about the Code because inadequate Obama administration briefings led to the mistaken belief that it could constrain missile defenses or antisatellite weapons. However, in the early 2012, US Secretary of State, Hillary Clinton, formally endorsed the idea of the Code on behalf of the United States. In addition Canada, Australia, Japan, and a few others have also endorsed the code.

Many countries, however, felt that they have not been consulted properly and that the EU has not taken their input seriously. The diplomatic process, rather than the Code itself, has been heavily criticized, as it has not been running very smoothly and there have been many mistakes made along the way, which has dissuaded some countries from supporting it. China, for instance, has not displayed big interest in the Code and is still pushing hard for their own proposal of the Treaty on the Prevention of Placing Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects (PPWT). Russia has been willing to work with the EU even though, like China, it has showed dissatisfaction with the discussions on the Code. If Russia’s feedback is incorporated, they might consider the Code, as they see it as a stepping-stone towards a possible treaty (PPWT) (Lukaszczyk 2012). All of the reactions imply that the EU needs to step up their diplomatic approach in order to make this initiative a successful one. This is an opportunity for Europe to appear as a leader of an international initiative on space sustainability/security, and it would be a shame if the initiative would fail due to an improperly managed process.

It is important to remember that space security issues can be politically very sensitive. Hence, spacefaring nations such as the United States, China, or Russia will often have a hard time to lead an international space security initiative regardless of how good it might be due to certain political implications that would go along with these countries leading it. Europe, on the other hand, is different and a unique as it can be a broker between the traditional Eastern and Western powers. It is situated right in the middle, and it alone is comprised of many countries, which would often mean that it already represents a sort of an international view, which can be a lot more neutral in comparison to the countries mentioned above. So far, when it comes to space, Europe hasn’t played that role too successfully but opportunity is still out there if carefully approached.

## 22.4 Europe’s Approach to Space Security

In order to understand Europe’s position, or perhaps what sometimes appears a lack thereof, on space security issues, one needs to understand that it has been fairly recent for Europe to even engage in such matters. European space program has been designed mainly for civilian and scientific purposes. ESA’s mandate has always been to focus on civilian and peaceful programs and only in the recent years Europe has begun to appreciate the benefits of space technologies for strategic military or crisis management purposes that could greatly benefit the security of Europe. Both Galileo and Copernicus (GMES) mentioned earlier in the chapter are dual-use programs. This implies that they will have both civilian and military applications even though the EU is trying very hard to “sell” them as purely civilian. Dual-use technologies remain highly politicized in Europe mainly due to the lack of agreement on the scope of the Common Foreign and Security Policy (CFSP) and the European Security and Defence Policy (ESDP) (Pasco 2010).

A Europe-wide Space Situational Awareness (SSA) system is another project that has been discussed on a European level, as it has been recognized that space debris possesses serious threat and it is in Europe’s interest to know what is happening in space. This project, unfortunately, has not, as yet, been able to gain the same momentum as the Galileo or Copernicus (GMES) programs due to the lack of funding and internal coordination within Europe. It is still not clear who should be in charge of the program. Both, the European Defence Agency (EDA) and ESA have been considered, but no decision has been made. Meanwhile, Germany and France have been closely cooperating on exchanging their space surveillance data while working on a better SSA system, which could in the future become a Europe-wide system, possibly with Germany and France in charge, rather than a European entity.

The 2008 Ministerial Council of ESA expressed support for a European SSA system and even allocated a substantive budget (50 Million Euros for 3 years). The program was to focus on surveillance, tracking, and imaging of objects, space weather, and near-Earth objects (NEOs). One year later the focus slightly changed to “one core element covering governance, data policy, data security, architecture and space surveillance, and three additional optional elements”: space weather studies, NEO surveillance, and pilot data centers (Ministers Meet to Define the Role of Space in Delivering Europe’s Global Objectives 2008). ESA continues to run the program. Accordingly, it appears that the main European actors, including the multinational entities, understand the importance, and even the urgency of, developing a proper SSA system. Coordination and cooperation to date, however, has been weak, which can be frustrating for other international partners who are eager to share data and work possibly towards an SSA international system.

## 22.5 Conclusion

As Europe is not a uniform actor, but rather a combination of actors seeking to reach a compromise and work together, it always faces challenges. Entities also often compete with each other because the governance of space-related matters in Europe has not been clarified, including the distribution of competencies and structuring of cooperation. The Lisbon Treaty calls on the EU to draft a European space policy, which should clarify the relationship with ESA and harmonize laws and legislations on space throughout Europe. That would be a first step towards proper European space governance. Responsibilities and competences among different actors would be defined enabling an efficient cooperation among the European entities so that they could speak with one voice when dealing with international partners. That would make international cooperation on space security much more efficient and straightforward. Currently the question constantly asked is “Whom do you call in Europe when you want to talk space?” There is no clear answer and it leads to a lot of duplication in work plus a lot of bilateral discussions with individual European entities that do not always represent Europe as a whole.

That being said, we have to remind ourselves that Europe is still trying to create an overarching structure for its space activities, and although there are a lot of areas for improvement, time and patience are needed for Europe to internally devise a proper space policy and governance scheme that will improve cooperation with Europe in space security and other space areas. It should not be expected from Europe to behave as a state because it is not a state; it is a region that represents views and interests of many states. As such, it needs more time to assume a particular position than individual state.

If Europe manages to organize itself internally, it has a potential to become a true international leader on space security issues. Its geographical and political position makes it an ideal broker for various space security initiatives. Europe can be a strong actor in space with existing international outlook and understanding of compromises that are necessary to achieve a particular goal. Due to the multinational and multi-organizational nature of Europe, once Europe achieves a compromise, it will most likely be a lot more balanced than that of individual states, particularly those with strong interests in space (the United States, China, Russia, etc.). The draft International Code of Conduct for Outer Space Activities represents a great point in case. Most countries around the world have no major problems with the EU’s proposal, but they are not satisfied with the diplomatic process connected with the Code. This only emphasizes further that Europe is capable of being a leader, content wise, on space security issues, but needs to organize itself in such a way that enables a smooth process.

Despite seemingly slow progress, it is important to note that there have been significant developments in the area of space security in Europe, and it has acknowledged the importance of space technology for military purposes as well as crisis and natural disasters management. There are currently several ongoing programs such as Galileo, Copernicus, and, to a smaller extent, an SSA system at European level which will enhance European security in many ways.

Unfortunately, Europe is now finding itself in a middle of a financial crisis, and space is not extremely high on the list of priorities for the decision-makers. Accordingly, funding for some space projects and programs may be reduced more than desired. Therefore, it is up to the space sector to increase awareness among the decision-makers about how space can enhance many other sectors and its crucial role for growth and security of Europe. The next few years will be decisive for space in Europe. Galileo and Copernicus programs should become fully operational. Europe-wide SSA system should finally take off. The draft International Code of Conduct for Outer Space Activities will either be adopted or will fail the international negotiations. Finally, the EU will draft the European space policy. These are all very exciting developments, which will strengthen Europe in space and beyond.

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# Space Security in Japan

# 23

Kazuto Suzuki

## Contents

**Abstract**

Japanese perspective on space security has begun with a very unique setting. The 1969 Diet resolution has put heavy constraints on its space activities, and interpretation of "nonmilitary" approach has refrained Japan from anything related to security. However, the 1998 Taepodong launch and subsequent reform of space policy eventually created the Basic Space Law in 2008. Although the organizational culture and history still influence on the decision-making process, the changing security environment and the role of Japan in the Asia-Pacific region made Japan to be more active and committed to security both by and of space.

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## 23.1 Introduction

The concept of space and security has never been close in the history of Japan. Any space activities should be considered as a peaceful one, which meant to be a place where military shall not play any part of it. This extreme interpretation of "exclusively peaceful purpose" has been challenged by many incidents concerning the security environment around Japan and eventually reinterpreted through the discussion on the Basic Space Law in 2008. However, the older interpretation of "non-military use of space" is still persistent in Japan (Aoki 2008).

This chapter discusses the reasons why space and security were not compatible in Japan and analyzes the recent developments on the issues of space security. This chapter defines that the concept of "space security" does not limit to the issue of "security of space environment" but also includes "security on the Earth by space systems."

## 23.2 The Diet's 1969 Resolution on "Exclusively Peaceful Purposes"

Japan has restricted itself from using space for its security needs. As one of the most advanced industrialized country, Japan possesses technological and industrial capability to use space for its national security. Thus, many non-Japanese space experts may wonder why it has not done so, if only for nonaggressive purposes.

The main reason for Japan's reticence is its pacifist constitution, which is interpreted to prohibit using space for security purposes. In 1969, the Japanese parliament, the Diet, passed a resolution "concerning the principle of the development and utilization of space," popularly known as "the exclusively peaceful purposes resolution." It stipulates that Japan's space programs may be conducted by the civilian sector, not the defense sector, and only for the research and development of new technology for exclusively peaceful purposes (Suzuki 2005).

The principle of "exclusively peaceful purposes" is not new, as it appears in the Outer Space Treaty and the ESA Convention. The Japanese application of this principle, however, was unique. While debating the resolution in the Diet in 1969, the Diet members argued that it should be applied to the development and use of space in the same way that nuclear technology had been. As a dual-use technology, they can be developed and used for both civilian and military purposes. In addition, because Japan's Science and Technology Agency (STA, currently MEXT) was in charge of both nuclear and space technology, the Diet felt that the development of space should be restricted as tightly as that of nuclear technology was. Ever since the horror of the nuclear holocausts in Hiroshima and Nagasaki, the Japanese people have been skeptical of using nuclear technology even for peaceful purposes, and therefore, the Diet stipulated that it be used only for civilian purposes and that the military not be involved administratively, financially, and politically in its development and operation.[1] Accordingly, this notion of “exclusively peaceful purposes” was applied to space as well.

Based on the interpretation of the Diet resolution, all of Japan’s operations in space have been conducted for scientific and technological purposes. The strategic goal of Japan’s space policy thus has been to “catch up” with the technology of other advanced countries such as the United States and European nations. Thus, the goal of most of Japan’s space programs, even that of those for communication, broadcasting, and meteorology, has been technological excellence. For many politicians, space was the “necktie of advanced countries” (Matsuura 2004), suggesting that Japanese space policy should aim at gaining national prestige.

The principle of “non-military” use of space is about to change, however, in accordance with the Basic Space Law which passed the Diet in June 2008. The aim of the law is to redefine the purpose and rationale for Japan to invest in space, and for the first time, the term *security* appears in an official document pertaining to space. Why has the notion of security suddenly appeared in the draft law, and how is it likely to change Japan’s space policy?

## 23.3 The End of the Cold War Paradigm

For many years, particularly during the cold war, Japan’s strictly “non-military” use of space was not challenged. The reason was that the alliance between Japan and the United States already provided the necessary infrastructure for telecommunication and intelligence gathering from space. In addition, Japan’s pacifist constitution was interpreted as prohibiting its Self-Defense Forces (SDF) from being deployed beyond its national border. When the cold war ended, however, Japan was forced to begin thinking about changing its space strategy (Suzuki 2007a).

With the end of the cold war, the threat of Communism had waned, and so the reason for stationing US troops in Japan also had become less compelling as well. Although the United States still maintains a need for forward deployment bases in Japan, it is no longer the only condition of the alliance. The unilateral collective defense – according to which the United States is obliged to defend Japanese territory and forces but Japanese forces are not obliged to protect American territory and forces – has now become too great a burden, so the US government wants the Japanese government to share more of responsibility for global security. Accordingly, Japan has enlarged its participation in the war on terror, particularly by deploying naval forces to support the multinational antiterrorist operations in Afghanistan and its own ground troops in Iraq.

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[1] Response by Masao Yamagata, member of the Space Activities Committee, in the Special Committee of the Promotion of Science and Technology, Lower House, minutes, 16 April 1969.

It is through these operations that the Self-Defense Forces have come to realize their technological shortcomings. Because the SDF are restricted from developing and operating their own space capabilities, they have had to rely on commercial satellite communication and commercial imagery services. But until now, because the SDF have limited opportunities to be deployed outside Japan's borders, they have not needed long-distance communication or imagery of foreign countries other than its neighbors. However, the SDF have recognized the gap in Japan's military technology, particularly in regard to the United States' military transformation and "Revolution in Military Affairs" (RMA) in recent years. Given the increasing possibility of Japan's sharing its security burden and joint operations with the US forces, the SDF and the Japan Defense Agency (JDA, now the Ministry of Defense) now acknowledge the importance of developing their own space capability.

In addition, the Japanese people's perception of their security has been dramatically changed by North Korea's launch of a Taepodong missile over Japanese territory in 1998. The alarmed Japanese public thereupon demanded that the government take measures to protect them, and the government immediately decided to launch what is known as the Information-Gathering Satellite (IGS) program.

## 23.4 The Information-Gathering Satellite Program: Treading a Narrow Path Through a Legal Jungle

At the start, the IGS program faced the serious legal constraints of Japan's space policy. Although it was clear that the purpose of the IGS program was to monitor the military activities of its neighbors, including North Korea, this was concealed under the guise of a "multipurpose" satellite program. This way the civilian nature of the program was implied in order to comply with the 1969 Diet resolution.

But this arrangement ran into problems. In the 1980s when Japan and the United States were sparring over trade, the US government pressured Japan to open its public procurement market in order to reduce the US trade deficit. The industry targeted was the satellite industry, in which Japanese companies enjoyed exclusive contracts with the National Space Development Agency (NASDA, now the Japan Aerospace Exploration Agency, or JAXA). The US government maintained that it was unfair to exclude its satellite industry from competitive bidding and therefore threatened to use its "Super 301" measure, according to which the US government could impose punitive tariffs on Japanese imports. In response, the Japanese government enacted the 1990 Accord on Non-R&D Satellite Procurement. The accord obliged the Japanese government to open the procurement market for civilian satellites to international competitive bidding, and as a result, large majority of civilian non-R&D satellites in orbit were contracted to American companies, and only few were contracted to a Japanese company (Sato et al. 1999).

As a result of the 1990 accord, the civilian multipurpose non-R&D satellites under the IGS program were part of the open procurement procedure as well, which put the Japanese government in a difficult position. If it wanted to avoid applying the 1990 accord, it would have to admit that the “multipurpose” satellites under the IGS program actually had a military mission, a position that would violate the 1969 Diet resolution.

This problem was resolved by careful legal interpretation. The government placed control of the satellites not under the Japan Defense Agency (JDA) but under the Cabinet Secretariat, a small office with a national intelligence-gathering mission and crisis management functions. The IGSs then were formally designated as “crisis management satellites” with both civilian and military purposes (Sunohara 2005).

This incident made politicians realize that the legal constraints of the “exclusively peaceful purposes” resolution allowed no room for maneuver and that in the changing security environment of the post-cold war period, it seemed counterproductive to maintain such a rigid pacifist position.

The Koizumi government’s decision in 2003 to participate in the missile defense program raised another problem for Japanese space and security community. If JDA depended completely on US intelligence for initiating the deployment of counterattack missiles, it might mistakenly shoot down hostile missiles flying toward US territory. And because shooting down hostile missiles aimed at US territory would be an exercise of the right of collective self-defense by Japan, which is considered unconstitutional, it needed to have its own early warning satellite to verify the US satellite intelligence. Thus, many people in the Liberal Democratic Party (LDP), particularly those interested in defense issues, demanded a reconsideration of the “exclusively peaceful purposes” clause of the 1969 Diet resolution.

## 23.5 Kawamura’s Initiative to Modify the 1969 Resolution

Despite the increasing demand to modify the resolution and the mounting pressure to reduce the space budget, neither the government nor the politicians took any action until the end of 2004. In early 2005, Takeo Kawamura, an LDP politician and a former minister of education, culture, sports, science, and technology (MEXT), took the initiative for change. While he was the minister, Kawamura witnessed the failure of the H-IIA no. 6 launch carrying two IGSs. Although he was responsible for the actual launch on the H-IIA and not the IGS program, both the public and the government accused him for not properly supervising a strategically important satellite project like the IGS. From Kawamura’s standpoint, those who accused him were confusing responsibility with competence. That is, even though JAXA was involved in developing failed launcher, Kawamura regarded it as still in a development phase, where a failure should be acceptable. The JDA, the main user of the IGSs, also was not permitted to take part in this program, in compliance with the Diet resolution. Furthermore, the Cabinet Secretariat, the nominal authority for the IGS, was unable to oversee the satellite’s development and launch because of a shortage of manpower. Thus, the JDA, the Cabinet Secretariat, and the MEXT (or JAXA) had no direct responsibility for this program. To Kawamura, this was a critical failure of Japan's national strategy, and he was convinced that something had to be done (Suzuki 2007b).

As soon as Kawamura left his post as minister of MEXT in September 2004, he convened an informal study group, the Consultation Group for National Strategy for Space, popularly known as the Kawamura Consultation Group. It was made up of members of LDP, including vice ministers in the MEXT, the Ministry of Economy, the Trade and Industry (METI), the JDA, and the Ministry of Foreign Affairs (MoFA). The Kawamura Consultation Group considered the problems of Japanese space policy, including the modification of the 1969 resolution and several public-private partnership programs such as the Quasi-Zenith Satellite System (QZSS), as well as the privatization of H-IIA (Suzuki 2006).

After ten meetings, the Kawamura Consultation Group issued an over 100-page report in October 2005, which argued that Japan's space policy lacked a coherent strategy and a clear institutional arrangement (Consultation Group for National Strategy for Space 2005). That is, because Japan's space policy was dominated by the Science and Technology Agency and MEXT, it did not have a plan for using space to pursue its national strategic objectives. The result was a lack of competitiveness in the Japanese space industry and the difficulty which Japan was facing in assuming a larger role on the international stage.

The report therefore suggested drafting a new space policy and an institutional framework within which a more coherent space policy could be formulated. First, it proposed that the government create a new minister for space in the office of the Cabinet, who would serve as the center for Japanese space strategy. Furthermore, the report pointed out that Japanese space policy had been to develop new technology but that along the way it had neglected the users' needs and demands. The report thus recommended that the new minister for space should bring relevant ministries into the policy-making process and refer their needs to the R&D program. The minister of space also should be authorized, the report continued, to use Japanese space assets to advance foreign and security policy purposes under the current constitutional framework.

The Kawamura Consultation Group's report also proposed the modification of the 1969 resolution. It suggested that any modification of the resolution would have to come from the Diet because the resolution was unanimously taken by the Diet, and the only way to legitimatize the modification should be done through new resolution or legislation. Consequently, members of the LDP and the government were pleased with the report, as it paved the way for Japan to change its space policy.

## 23.6 Legalizing the Strategic Objectives of Space Policy

Kawamura also submitted this report to the LDP's Policy Research Council. With support from Hidenao Nakagawa, then the chairman of the Policy Research Council and the third-ranking member of the LDP, Kawamura established the

Special Committee on Space Development (SCSD) with himself as its leader. In July 2006, when North Korea conducted a second missile test, the SCSD got another boost of support as public opinion quickly shifted from guarding its pacifist principles to demanding a more flexible interpretation of the 1969 resolution. In this atmosphere, the SCSD decided to submit to the Diet its draft Basic Space Law in June 2007. The bill was sponsored not only by the LDP but also by the New Komeito, its coalition partner, and Democratic Party of Japan (DPJ), the largest opposition. The reasons of DPJ sponsoring the bill was largely due to the belief of Kawamura that space is a national strategic issue and should not become a subject of partisan politics. He took initiative to invite Yoshihiko Noda, then the leader of Science and Technology policy group of DPJ and later became prime minister, to join the LDP sponsorship, and Noda agreed. The participation of DPJ, largely composed by liberal and pacifist politicians, was important because it would guarantee that this bill will remain the pacifist nature of the space policy. Also, bipartisanship gave stability and continuity of space policy after the change of government in 2009. The bill passed the Diet in June 2008.

The first and the most important feature of the Basic Space Law is its institutional renovation, in accordance with the Kawamura Consultation Group's report. It proposes establishing a new minister for space and a Strategic Headquarters of Space Policy (SHSP), which will serve as Cabinet-level interministerial coordination and decision-making body. The idea of establishing high-level political body is to make sure that the R&D activities and utilization of space systems will be seamlessly coordinated. For many years, Japanese space programs were decided based on the technological interests and "catch-up" to other spacefaring nations. However, under the heavy budgetary constraints, the government could not afford to spend large sum of money only for the sake of technological development. In order to secure and sustain space budget, the government has to prove that the investment in space is effectively contributing to the policies and services to the people. The minister for space will be coordinating space-related policies of various ministries. One such ministry is the Ministry of Foreign Affairs (MoFA), which is conducting a study of the utilization of Japan's space technology as part of its foreign policy.

The second feature of the law pertains to security. Article 2 of the law states that "Our space development shall observe the Outer Space Treaty and other international agreements and shall be conducted in accordance with the principle of pacifism upheld in the Constitution." In other words, the traditional interpretation of "exclusively peaceful purposes" as "non-military" should no longer apply. Instead, the policy should be in accordance with the Constitution and to adopt the international standard interpretation of the "peaceful use" of space as the "nonaggressive" or "nonoffensive" use of space. The new law would accordingly enable the Japanese defense authority to become involved in the development, procurement, and operation of space systems.

In addition, Article 3 states that "the government shall take necessary measures to promote space development that will contribute to international peace and security and also to our nation's security." Because this statement is so general, Article 3 could be interpreted as allowing the government to use space systems for aggressive purposes. But because Article 2 stipulates that the use of space systems for national and international security comply with both the framework of international agreements and the spirit of pacifism in Japan's constitution, it implies that Japan may use its space assets for crisis management and disaster monitoring in Asia and for peacekeeping missions outside its territory, but not for aggressive action towards outside. Article 2 also suggests that Japan can use early warning satellites for its missile defense, as this falls into the category of self-defense (Aoki 2009).

The law therefore is designed to strengthen Japan's capability in settling disputes and managing crises by peaceful means and is intended to change only the interpretation of the Diet resolution, preventing any use of space by Japan's military authority.

## 23.7 Regional and Global Security

With the Basic Space Law, the government will at last have a legal base for using space to strengthen its national security and expand diplomatic activities. This combination of security and diplomacy is important for two reasons. First, one of Japan's primary objectives of using space for security is to acquire the capability to defend its own country, particularly by means of a missile defense system. Given the small size of Japan's territory, space is not a very useful tool. It may not require a constant surveillance and communication capability. However, in the context of Japan's expanding role in international security and the Japan-US alliance, the SDF operations far from home would require long-distance telecommunications and satellite intelligence. Such needs were confirmed by the Maritime SDF ships sent to the Indian Ocean to support the United States or to protect commercial vessels from piracy in the Gulf of Aden and allied operations in Afghanistan as well as the ground and air SDF troops sent to Iraq.

The first SDF forces deployed outside Japan were sent to Cambodia in 1992 for UN peacekeeping missions. Since then, Japanese troops have been sent to places such as the Golan Heights, Mozambique, Zaire, East Timor, and South Sudan. Now the majority of Japanese no longer doubt their country's intention to contribute to international security and peace through UN operations, and consequently, the 1969 resolution has become both awkward and irrelevant. Although it states that space should be used for "exclusively peaceful purposes," during their UN operations, the SDF have not been allowed to use Japan's space assets to maintain "peace." The new law would not only enhance the scope of operation and capability of Japanese contribution to global security, but it would also increase the efficiency and effectiveness of its participation in multinational operations.

Second, the combination of security and diplomacy in the new law is important because Japan would be able to change Asia's security environment in Asia. A number of issues are causing instability and threatening the security of the region, particularly North Korea's nuclear and missile tests, tensions between Taiwan and China, China's opaque security strategy and defense budget, China's

ASAT test in January 2007 (Hagt 2007), and various territorial and resource disputes, including the one with Senkaku Islands of Japan. Although these conflicts have been contained by various international arrangements and the presence of the US forces, they still need to be closely monitored to develop confidence-building measures to ensure stability in the region and to seek peaceful solutions. Japan is, of course, the concerned party in some of these conflicts and needs to participate in such regional forums as ASEAN Regional Forum (ARF), the Asia-Pacific Economic Cooperation (APEC), and the East Asian Summit. Although it is committed to providing ideas and resources for their development, Japan needs first to prioritize the promotion of regional interests as well as its own domestic interests. Japan also uses its technological advantages to assume a leadership role in the region. To date, it has been providing its technological expertise through the Asia-Pacific Regional Space Agency Forum (APRSAF). Japan has been playing a central role in APRSAF, but this was mostly done by the MEXT and JAXA without coordinating with the Ministry of Foreign Affairs. Thus, Japanese initiative focused purely on technical cooperation and has not fully incorporated with Japanese diplomatic strategy (Suzuki 2012a). However, the establishment of the Basic Space Law changed this lack of coordination. The Ministry of Foreign Affairs has created the “Office of Space Affairs” under the Foreign Policy Bureau and assigned several diplomats to dedicate their efforts to utilize space systems and activities for the diplomatic affairs. In fact, MoFA supported the first ARF Space Security Workshop in Hoi An, Vietnam, and sponsored a session on space security at APRSAF-19 in Kuala Lumpur in 2012.

## 23.8 Changes of the Role of the Ministry of Defense

Due to the establishment of the Basic Space Law, the role of the Ministry of Defense (MoD) has changed dramatically. It has been excluded on any space activities until 2008, except the use of satellite communications, broadcasting, and weather imageries. Although the 1969 resolution has prohibited the JDA and later MoD to develop, own, operate, and use space systems, the government expressed its interpretation of the resolution in 1985 as follows:

The clause “exclusively peaceful purpose” in the Diet resolution means, of course, the SDF would not use satellites as lethal or distractive. In this context, the use of satellite, which is generally available and utilized, or possessing equivalent function to commercially available satellites, can be used by the Self-Defense Force (Kato 1985).

Under this interpretation, the SDF was able to “use” satellite systems, but still not allowed to “develop, own, and operate” them. However, the Basic Space Law urges that the government shall use space system “to ensure international peace and security and also to contribute to our nation’s security” (Article 3). This suggests that the MoD may develop, own, operate, and use space system for the purpose of international peace and security such as UN Peacekeeping Operations or national security. Nevertheless, the MoD was not given full-fledged space capability.

The Article 2 defines that "Our space development shall observe the Outer Space Treaty and other international agreements and shall be conducted in accordance with the principle of pacifism upheld in the Constitution." In other words, space activities of MoD shall remain within the framework of Japanese constitutional constraints, which limits its military capability solely for self-defense. It means that the new interpretation of the use of space system for security purpose remains for passive use of space such as telecommunications, surveillance, and navigation, and even in the case of surveillance and reconnaissance, it would not be acceptable to use satellite intelligence for aggressive purposes.

The MoD has created the "Office of Space and Maritime Policy" as an administrative body dedicated to space and maritime security in 2008. However, the office has very limited capability with small number of staff allocated to space. The executives of the MoD were not very enthusiastic to invest in space for several reasons. First, under heavy budgetary constraints, defense budget was targeted as the source of spending cuts. In order to protect existing programs, there was no luxury to increase spending for unfamiliar domain of space. In other words, space is not the high priority for MoD. Second, due to the long period of refraining from the investment in space, MoD has almost no staff or technical expertise in space technology that eventually makes MoD to depend on JAXA. Given the secretive nature of MoD, it would not be acceptable to depend on civilian agency to develop military-sensitive technology. So, instead of cooperating with JAXA, MoD chose not to invest much in space. Third, after the change of government in 2009, the relationship between the defense minister and the ministry was not good. With liberal pacifist politicians including former Socialist Party members, the DPJ government had very confusing defense and security policy. The defense ministers during the DPJ government were not experts of policy area or powerful enough to promote coherent defense and security policy. Even after the return of LDP to the power and strong preference of Abe Administration for investing in military, space has not been the priority. For these reasons, the role of MoD was limited even after the establishment of the Basic Space Law.

Nevertheless, there were some pressing needs for MoD to take action in space domain. The first priority was to develop telecommunication satellites. Since the 1985 government decision to allow SDF to use generally available satellite services, MoD has been using commercial satellite telecom services. The Sky Perfect JSAT, commercial operator, had satellite with X-band transponder dedicated to the use of SDF, but this satellite will reach the end of life by 2015. Thus, MoD needed to replace this satellite capacity with some other new services. Given the budgetary constraints and the lack of expertise, MoD decided to follow the British Skynet military communication satellite procurement model. The Skynet system was procured by the British MoD as Private Finance Initiative (PFI) that means the commercial operator develop, manufacture, launch, and operate the satellite system and the MoD spend money only on services (Suzuki 2006). In this way, the MoD does not have to invest in developing human resources and technical expertise for building and operating satellites. The contract was awarded to the consortium led by Sky Perfect JSAT in 2012.

The second priority is the Space Situational Awareness (SSA). It seems strange for MoD to pay attention of SSA because it does not own or operate space assets. Even for civilian programs, most of JAXA's assets are developed as engineering testing satellites, so that they are not operational satellites *per se*. There are commercial and operational satellites for telecommunications, broadcasting, and meteorology, but these are located at Geostationary Orbit, and the MoD does not take them as the assets to be protected. However, in the context of the US-Japan alliance, SSA became an important issue for MoD to deal with. Since the Basic Space Law passed the Diet in 2008 – 1 year after the Chinese ASAT test – the US government welcomed the new approach that Japan would invest in security-related programs in space and asked to participate in the construction of international network of SSA. Japan is strategically located to monitor airspace of West Pacific/East Asia, and the SSA data from Japan would complement the United States' own SSA stations (Suzuki 2012b).

In this circumstance, MoD approached the SSA issue reluctantly. On the one hand, it recognizes that the SSA capability is important for strengthening the US-Japan alliance, while on the other hand, it would spend certain portion of its budget for those not substantially important to protect Japanese assets. The MoD proposed to use FPS-5, X-band radar for missile defense system, for monitoring space objects, instead of building new radar or optical monitoring stations. It is not yet clear if FPS-5 would perform as space surveillance radar, but this is what MoD is trying to compromise its budgetary constraints and US request.

The third priority is the early warning satellite system. The Japanese government made a decision to construct missile defense system in cooperation with the United States when the Taepodong flew over Japanese territory in 1998. This incident made Japanese security policy community as well as the nation as a whole recognized that Japan is under serious threat and something has to be done within the limit of the constitution. Thus, together with the development of IGS, missile defense was introduced. Although the Japanese Theater Missile Defense System has constructed with four Aegis frigates and PAC-3 surface-to-air missiles, it lacked early warning satellite system to detect missile launch. Currently, the Japanese missile defense system depends on the United States for early warning signal intelligence, but it has some problems.

In 2009, North Korean regime prepared to test its launcher, and Japanese SDF has prepared to intercept if it falls on its territory. The launch itself was not successful and there was not harm in Japan, but the SDF ground-based radar has misinterpreted signals from Korean Peninsula and sent false alarm. Contrary in April 2012, when North Korea failed again to launch, Japanese government did not issue warning for the people living in the flight path because it wanted to double check if the early warning signal was not false alarm. The government was heavily criticized for both incidents. Thus, having early warning satellite of its own would improve the detection capability and verification of the US early warning signal. Although MoD understood the importance of having early warning satellites, it is reluctant to move forward because of the cost of developing these satellites. Thus, the policy priority is not as high as the other proposed programs, even though strategic importance is high. The fourth priority is the maritime surveillance system. For both Japan and the United States, the most concerning issue for the regional security is the emergence of China as a maritime power. Monitoring Chinese maritime activities, together with the activities of pirates in Strait of Malacca and Gulf of Aden, became the most important activities for Japan and the US to work together. Given the experience of Japan for developing remote sensing satellites, the development of maritime monitoring satellite constellations would be the most effective investment without investing much money in technology development.

## 23.9 JAXA's View on Space Security

For many years, JAXA (formerly NASDA and ISAS) was prohibited to develop satellite or launcher technology explicitly aiming to improve military capability. However, space technology in general is a dual-use technology, which does not discriminate military and civilian use. There has been always suspicion that JAXA would have a hidden agenda to develop space technology for military purpose, despite the 1969 Diet resolution. In order to eradicate the suspicion, JAXA had to emphasize that its programs were designed, developed, operated, and used for exclusively peaceful purpose. As a result, JAXA has averted anything that relates to security issues.

Thus, even after the Chinese ASAT test became public, JAXA was reluctant to call this issue as "space security" issue; but instead, it preferred to use the term "long-term sustainability of space environment." In other words, JAXA wanted to frame the issue of space security within the issue of space debris regardless of whether the debris was created intentionally or not.

However, given the rapid increase of debris population especially in Low Earth Orbit, JAXA became concerned about the risk of collision with debris. The JAXA's safety analysis procedure now contains the risk assessment of debris collision probability. Nevertheless, JAXA, as an R&D agency, demonstrated its interest not in the development of international regulation or rule of the road, but in the development of new technology for debris removal. JAXA is increasing its budget allocation for the study of debris removal technology.

The problem here is that any technology of debris removal has a possibility to be regarded as space weapon development, and also there are many political, economic, and legal problems to realize the debris removal technology even if JAXA would successfully develop one. JAXA's legal department has been working on the possible interpretation of Outer Space Treaty and other space-related international agreements, but has not taken any initiative to provide legal framework for debris removal activities.

## 23.10 Japanese Reaction to the Code of Conduct

After the ASAT test by China, the global space community has moved toward establishing a general rule to prevent similar action which created a large number of debris. In April 2007, the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) has adopted the Space Debris Mitigation Guidelines, based on the Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines, which was published in 2002. Although these guidelines are not legally binding documents, they set up an ethical and a social benchmark on what should be done to secure the safety of space environment. Furthermore, the delegates of European Union (EU) in the Conference on Disarmament (CD) in Geneva submitted Code of Conduct for Outer Space Activities (EU Code of Conduct). This document took a step further to set up norms of behavior of spacefaring states to protect space environment and prevent intentional as well as unintentional creation of space debris.

Since most of Japanese spacecrafts were R&D-oriented (not operational) ones, there was a little attention to the orbital environment. The risks of colliding with space debris or being targeted from hostile parties were considered minimum because Japanese spacecrafts were not in military, civil or commercial operations. In other words, the damages of losing these satellites were not important since the objectives of developing these spacecrafts were to test and demonstrate Japanese engineering capability.

Japan did not make an explicit action when the European Union proposed the Code of Conduct. Not only because Japan has not been ready yet to engage in the negotiation with the EU, but also because the United States, Japanese major ally, did not express its position concerning the Code. The Japanese government was well aware of the US national space policy which was published in 2006 during the Bush Jr. administration which explicitly rejected any international agreement that binds the freedom of American space activities. Although the Code assumed voluntary participation, the commitment to the Code would make the US space policy more constrained.

For Japan, the Code seems to be very suitable for the world after the 2007 ASAT test. Its voluntary nature would be essential for inviting as many nations as possible. Initially, the EU intended to make the Code a voluntary one in order to include spacefaring countries (the United States under Bush administration in particular). But since the United States under Obama administration preferred to establish international platform for negotiation based on the EU Code of Conduct, the dividing line emerged between Western countries (EU, US, Japan, and Australia) and China and Russia. By avoiding the division among spacefaring countries and making the Code as international norm, the voluntary nature of the Code is utterly important. Of course, it would be much effective if the Code is legally binding, but there is a trade-off. In order to include the countries such as China and Russia, it should be based on voluntary participation, at least in the beginning (Suzuki 2012c).

For a long time, Japan has developed technologies to use space environment responsibly, such as controlled reentry of upper stages and fairings of Japanese rockets. So, it welcomes the explicit statement that says “the responsibility of States . . . to take all appropriate measures to prevent outer space from becoming an area of conflict” and complies with the Space Debris Mitigation Guidelines.

The most important clause from Japanese point of view is the Clause 4.3, which states that "when executing maneuvers of space objects in outer space, for example to supply space stations, repair space objects, mitigate debris, or reposition space objects, the Subscribing States confirm their intention to take all reasonable measures to minimize the risks of collision." This allows Japan to invest in the development of the technologies to remove space debris. JAXA in particular is very interested in developing debris mitigation and removal technology, but it is well known that the removal technology can be used as space weapons. Thus, it is extremely important that the Code explicitly allows debris removal activities with good intention.

When Obama administration decided to launch a negotiation about the International Code of Conduct based on the EU's proposal, the Japanese government immediately responded to the call by the United States to join the international framework together with Australia. For Japan, the US initiative was welcoming because US objection was the only obstacle for Japan to participate in the Code.

These interpretation underlines that Japanese perspective on the Code is based on its diplomatic and technological concerns, not on its military and security needs. Since MoD is not engaged in the process of decision-making for the Code, it would be difficult to assume that Japan would commit to the Code for security purposes. Although Japan expressed its interest to participate in the process of negotiation for drafting the International Code of Conduct, its objective is not purely driven by the needs for securing healthy environment for space activities. Rather, its objective is driven by the interest of JAXA and MoFA.

## 23.11 Conclusions

Japanese perspective on space security has begun with a very unique setting. The 1969 Diet resolution has put heavy constraints on its space activities, and long and enduring interpretation of "non-military" approach has refrained Japan from anything related to security. However, the 1998 Taepodong launch and subsequent reform of space policy eventually created the Basic Space Law in 2008.

Although the new legal framework provides opportunity for Japan to play a much bigger role in the field of space security, it seems that Japan is still taking steps cautiously. It is largely because of the history and culture of Japanese space activities. The understanding of "exclusively peaceful purpose" as "nonmilitary" nature of space has been long and persistent not only among the people in space community but also the people working in the security field. The Ministry of Defense and Self-Defense Forces do not consider themselves as the actor in space policy making, and they refrained from investing in space because they have constructed Japanese defense system without relying on space assets. Similarly, JAXA is reluctant to take security programs as its central mission. Under severe budgetary constraints, JAXA had to give up some of its pet projects for the sake of security program. Thus, it has resisted changing its status as civilian R&D agency.

Nevertheless, the security environment as well as the role of Japan is changing. On the one hand, the emergence of China as military superpower and the territorial dispute over Senkaku/Diaoyu Islands urge Japan to improve its surveillance capability and space-based infrastructure for SDF operations in the West Pacific and East China Sea. Furthermore, the successful launch of the North Korean Taepodong launcher/missile in 2012 increased awareness for building robust missile defense system. Japan can no longer have a luxury to stay away from the discussion on the space for security purposes.

On the other hand, increasing number of countries in Asia-Pacific region began using space systems as their national infrastructure, which provides indispensable services to their socioeconomic activities. Japan as one of the leading spacefaring nations in this region is taking a leadership to formulate regional space cooperation framework which includes a forum to discuss space security. The Ministry of Foreign Affairs took initiatives with Australia to hold a workshop within the ASEAN Regional Forum and APRSAF. These initiatives cannot be capitalized if Japan would not play an active role for securing space environment.

Japanese space policy toward space security – both national and international security by space and security of space environment – is facing a long-term challenge with the changing international circumstances. It is up to the political leadership to change the history and culture of Japanese space-related agencies, particularly JAXA and MoD, to make sure that Japan will play an appropriate role in the new circumstances. The newly created Office of National Space Policy under the Cabinet Office which directly reports to the prime minister is expected to assist the political leadership and to play a role to coordinate Japanese space policy for improving security by and of space.

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# An Overview of Chinese Space Policy

# 24

Rongping Mu and Yonggang Fan

## Contents

**Abstract**

China has made remarkable progress in space development in recent years which has received widespread attention in the international community. Meanwhile,

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Chinese space policy is also drawing increasingly attention abroad. This chapter tries to give a holistic review and analysis of current Chinese space policy. Firstly, it reviews space policy research in China from three aspects such as national space policy, space S&T strategy, and commercial space policies. Secondly, it introduces the governance structure of space sector in China in general and four systems concerning policy making, academia, industry, and user in particular. Thirdly, it introduces and analyzes the current space policy system in China, focusing on Space White Papers, commercial space policies, space science and technology policies, and policies for space security and sustainability. Fourthly, it discusses five key issues in the future space policy agenda in China, namely, institutional environment, capacity building, human resource development, international cooperation, and industry development. Finally, it concludes with some recommendations for future space development.

## 24.1 Introduction

China has made a series of breakthroughs in space development since 1960s, including first space launch in 1964, first satellite into orbit in 1970, first Chinese astronaut with the Shenzhou V spacecraft into orbit in 2003, and the successful manned docking of the Shenzhou IX spacecraft and the Tiangong-I space lab module in 2012. With the successful implementation of manned space missions, lunar exploration programs, and the Tiangong space lab program, China has gradually joined the club of major spacefaring countries (Sun 2006).

In accordance with the significant achievements in space exploration practice, China has made remarkable progress in space S&T development. Publication statistics based on ISI Web of Knowledge database shows that China published 1,329 papers in top international space S&T journals in 2012, with an average annual growth rate of 45.3 % from 1993 to 2012 as shown in Fig. 24.1.

China ranks the fifth place in the world in terms of number of international space S&T publications in 2012, after the USA, Germany, the UK, and France. However, there is still a big gap between China and other major spacefaring countries in terms of total space S&T publications. For the last 20 years, around 9,000 publications on top space S&T journals are from China, in comparison with 135,000 from the USA and more than 20,000 from Germany, the UK, and France, respectively. The proportion of publications during 2003–2012 of China was significantly higher than other countries, which shows that China's space S&T development keeps remarkable growth in the past 10 years, as shown in Fig. 24.2.

China has gradually built a complete and effective space policy system although it is still to be further improved in some aspects. On the one hand, it is criticized that China is among the few major spacefaring nations without space legislation (Zhao 2007) and that the space policy system is unstable, inadequate, and not well targeted due to the absence of legislation foundation (Wen et al. 2009). On the other hand, there are also increasingly more demands for adjusting the space policy system so as to meet new challenges resulted from the rapid development of space S&T and

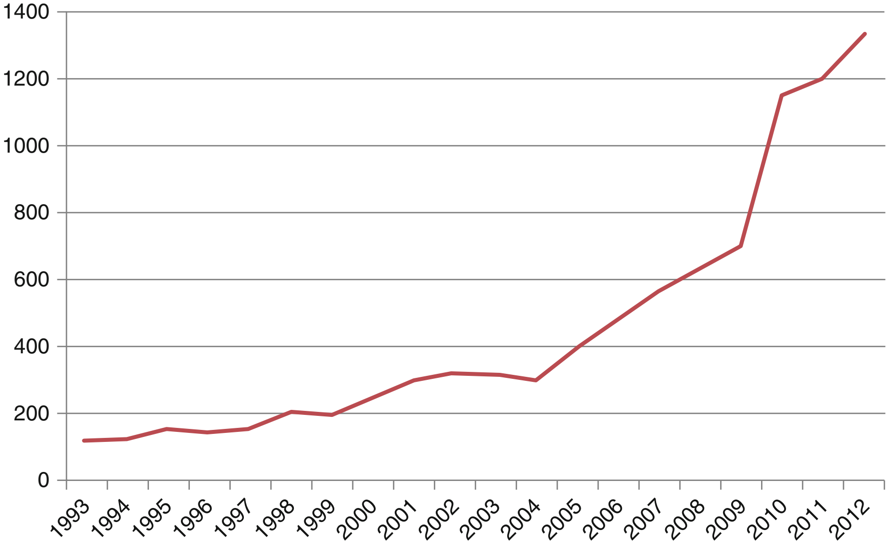

**Fig. 24.1** International space S&T publications from Chinese scholars (Source: Counted based on data of ISI Web of Knowledge)

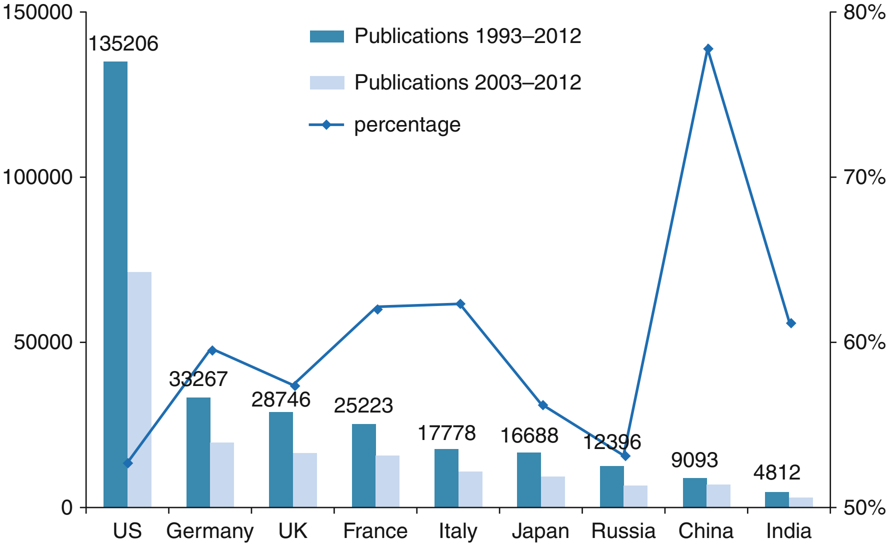

**Fig. 24.2** International space S&T publications. The percentages show the shares of publications from 2003 to 2013 out of all publications (1993–2012) for each country (Source: Counted based on data of ISI Web of Knowledge)

industries as well as the changing international relations. Therefore, it is necessary to introduce the governance of space sector in China, review the space policy system, and identify the key issues in the future space policy agenda so as to improve, China's space policy system and related understanding.

## 24.2 Space Policy Research in China

Space policy research in China began in 1980s. It was until late 1980s that there were a few open publications concerning space policy issues found in domestic journals and handful Chinese scholars publishing in top international journals. With the rapid development of space exploration, Chinese space policy issues draw increasingly extensive attention from both foreign and domestic scholars. Research topics on space policies in China range from national specific space programs such as the moon probe program and manned space program (He 2003; Dellios 2005; Zheng 2007) to the history of Chinese space activities (Harvey 2004; Handberg and Li 2007) and the examination of Chinese space activities from different perspectives such as cooperation and competition (Rathgeber et al. 2007).

Most active researchers in field of space policy are from the EU and the USA. Taking all 613 articles published in the journal of *space policy* from 1996 to 2009 (editorial review and book review are not included), for example, 303 are from EU member countries, 227 from the USA, and only 8 from China, accounting for 49.4 %, 36.9 %, and 1.3 % of the total, respectively, as shown in Fig. 24.3.

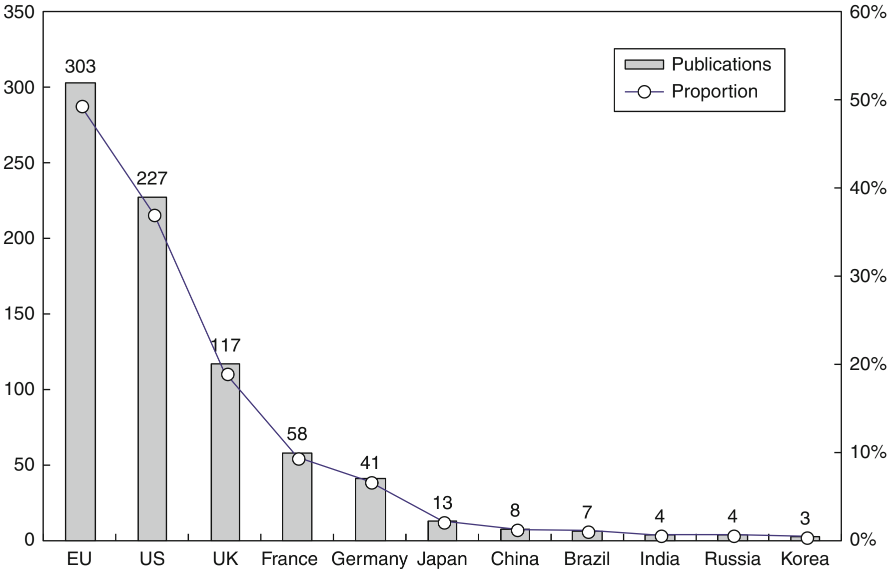

**Fig. 24.3** Publications in *Journal of Space Policy* by countries (1996–2009) (Source: Counted based on data of ISI Web of Knowledge)

According to literature review, the current research topics in the field of space policy research mainly focus on four aspects, including (1) the theoretical foundations such as the rationale of space exploration; (2) the global policy issues related to space security and sustainable development and the ethical problems resulted from space activities; (3) the transnational policy issues like geopolitics, international treaties, and international cooperation on space activities; and (4) the national space policy related to the commercial, civil, and security issues within a country. In contrast to the international research topics mentioned above, the space policy research in China mainly focuses on following three aspects, namely, (1) national space policy, (2) space S&T strategy, and (3) commercial space policy.

### 24.2.1 Studies on National Space Policy

Most of the space policy research focuses on the progress and trends of space policy issues of foreign countries in the early stage. For example, Wang (1989), Xie (1989), and Xie (1990a, b) introduced the progress of space policy in the USA, Japan, Australia, and India in the late 1980s. Articles about the policy development of other major spacefaring nations are predominating in related journals at that time. National space policy research has extended from introducing foreign space policies to providing policy recommendations by integrating foreign experiences of space activities since early 1990s. For example, Dong (1991) and Sun and Jiang (1991) discussed China's space technology policy, while Li (1995) studied the legislation issue of space industry.

Systematic research on space strategy and policy issues has been emerging in public literature since Chinese government issued the first Space White Papers in 2000. Luan (2000) reviewed the development of Chinese space activities, analyzed the main points of the White Papers, and identified the priorities in the twenty-first century. Sun (2006) analyzed the principles, targets, policy measures, and priority areas of Chinese space activities and pointed out that China should deploy its space missions systematically, strengthen overall plan, and promote the commercialization of space sector so as to fulfill these objects.

### 24.2.2 Studies on Space S&T Strategy

Chinese Academy of Sciences (CAS) has conducted a series of space S&T strategy research with a view to support decision and policy making. In 2009, CAS published the strategic general report ***The Science & Technology in China: A Roadmap to 2050*** and sixteen reports on development roadmaps towards 2050 in specific S&T fields. The report "Space S&T Development Roadmap towards 2050 of China" analyzes national strategic demands for space S&T and the development potential of space S&T by 2050 and points out the characteristics and objectives of the space science and exploration ability, the space technology ability, and the Earth observation and multi-spatial information application ability by 2020, 2030, and 2050. The report finally presents the China's space S&T development roadmap towards 2050, in which concrete steps by 2020 are introduced from three aspects, namely, the space science, the related space technology, and the space application.

In particular, the space science development consists of three steps, namely, (1) establishing an integrated space science research system and launching science satellites; (2) launching planetary scientific laboratory and Mars landing exploration; and (3) guarantee of permanent human residence in space. The related space technology development consists also of three steps, including (1) some optical and other payloads for space and Earth observation payloads reaching to world-leading level; (2) space communication data rate and key platform technologies at the world advanced level; and (3) achieving systematic breakthroughs in deep spaceflight, autonomous navigation, and positioning. The space application emphasizes two steps: (1) making use of domestic application satellite data and foreign satellite data and fast growth of Earth science satellite data and (2) establishing Earth system simulation network platform on the basis of the digital Earth scientific platform (CAS 2009).

Research Group of Technology Foresight towards 2020 in China has conducted the "Technology Foresight towards 2020 in China" with a series of Delphi surveys on technology foresight towards 2020 since 2003, including eight technology fields. As one of the eight fields, space S&T consists of eight subfields, namely, astronomical observation, exploration to the space of Earth and other planets in solar system, manned space and its application, space communication technology and its application, global navigation and positioning and application, space transportation, spacecraft platform, and remote sense and its application. The two rounds of Delphi surveys identified 78 key technological topics and top 10 technologies in terms of three criteria (significance to the economic development, the improvement of public life quality, and the national security). Besides, the surveys also estimated the possible schedule of realization of all technology topics, evaluated China's technological status in comparison with other major spacefaring nations, and analyzed the main obstacles to develop these technologies (CAS 2008).

### 24.2.3 Studies on Commercial Space Policy

Similar to the status of national space policy research, commercial space policy literature in the early stage focused on introducing foreign experiences and progress, including the analysis of market scale, main actors, competition strategies, and development trends. For example, Lin (2001) introduced the history and status of communication satellite enterprises in Europe and the USA and analyzed their competitive strategy and development trends. Lin and He (2002) gave a systematic introduction of the industrial structure and the surge of merger and acquisition in major spacefaring countries and pointed out that under the trends of economic globalization, cooperation has become a more common development pattern of space industry.

Recent works concerning space industry are extended to developmental strategy, industry competitiveness analysis, and industrial organization. Jin (2003) brought forward six key factors of space industry competitiveness following Porter's diamond model (namely, production factors, market demand, related industries, enterprise organization, management pattern, and competition status). It then discussed the advantages and disadvantages of Chinese space sector based on the six-factor framework and came up with policy recommendations at both company and national levels. Mu (2003) raised a set of indicators on the international competitiveness of Chinese aerospace and aviation industry and evaluated the competitiveness from three aspects including real competitiveness, potential competitiveness, and competitive environment. Zhang (2005) took the China Aerospace Science and Technology Corporation, one of the state-owned space enterprises, as an example; introduced its development strategy and management experiences; analyzed the history and status of Sino-EU space cooperation; and proposed some potential area for further cooperation, such as joint R&D and commercialization of satellites and their components and integrated application of space-related information.

## 24.3 Governance of Space Sector in China

Governance of space sector refers to the institutional structures and processes through which governments influence the operation and development of space sector. The governance structure of space sector in China is a complex system which can be roughly categorized as four systems, namely, policy making, academia, industry, and user, as shown in Fig. 24.4.

### 24.3.1 Space Policy-Making System

Policy-making system refers to the administrative agencies of space activities, which is in charge of space strategies and policies making, implementation and evaluation, priority setting, and regulation of related commercial activities. The State Council is the top policy-making body within the system, to which all the ministries and agencies are affiliated. Major ministries and agencies involving in space policy making include the State Administration of Science, Technology and Industry for National Defense (SASTIND, the former Commission for Science and Technology and Industry for National Defense, COSTIND), National Development and Reform Commission (NDRC), and Ministry of Science and Technology (MOST). In particular, SASTIND is responsible for making the space industry policy, development plan, regulations, and standards and for organization and coordination of major space programs. NDRC in charge of macroeconomy planning, operation, and adjusting also gets involved in policy making of space industry

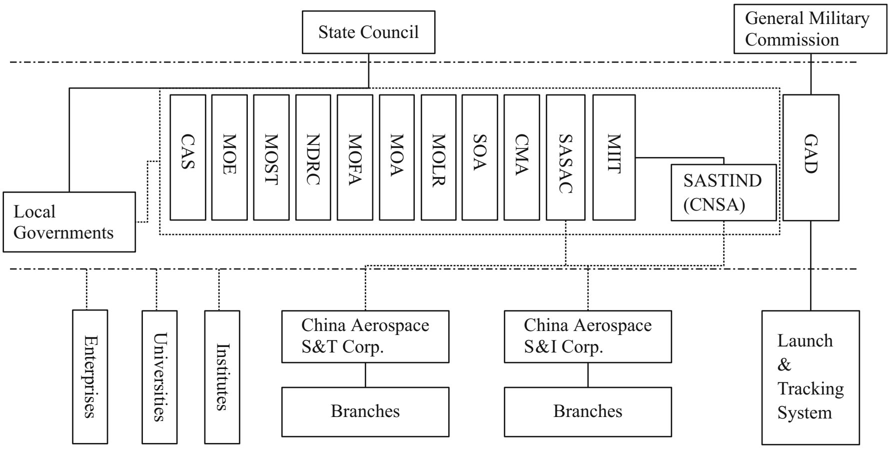

**Fig. 24.4** Governance structure of space sector in China. Abbreviations: *CAS* Chinese Academy of Sciences, *MOE* Ministry of Education, *MOST* Ministry of Science and Technology, *NDRC* National Development and Reform Commission, *MOFA* Ministry of Foreign Affairs, *MOA* Ministry of Agriculture, *MOLR* Ministry of Land and Resources, *SOA* State Oceanic Administration, *CMA* China Meteorological Administration, *SASAC* the State-owned Assets Supervision and Administration Commission of the State Council, *MIIT* Ministry of Industry and Information Technology, *SASTIND* State Administration of Science, Technology and Industry for National Defense

and commercialization of space technologies. MOST is in charge of S&T policy making and program management, including space science and technology development. Other governmental ministries and agencies, like Ministry of Education (MOE), Ministry of Foreign Affairs (MOFA), and the State-owned Assets Supervision and Administration Commission of the State Council (SASAC), are also getting involved in space policy making according to their functions and responsibilities.

## 24.3.2 Academia System

Academia system consists of universities and research institutions which conduct related science research, technological development, and talents training. For example, several institutes of the Chinese Academy of Sciences such as National Space Science Center and National Astronomical Observatories are all important players in space science research. Universities have also become important players in space S&T research and related human resource development. Most space-related universities and institutes are funded mainly by public finance. Besides, R&D outsourcing from commercial sectors is also an increasingly important source of funding with the rise of space industry.

### 24.3.3 Industrial System

Industrial system is the main body of Chinese space system. Two state-owned enterprises, China Aerospace Science and Technology Corporation (CASTC) and China Aerospace Science and Industry Corporation (CASIC), are the key conductors of space activities, whose business ranges from R&D and manufacturing to launching and operation of almost all satellites in China. Though these two corporations are wholly state owned, they are responsible for their own management decisions, profits, and losses. The SASAC is responsible to supervise and manage the state-owned assets, and SASTIND is in charge of overseeing the two corporations according to related laws and regulations. Both SASAC and SASTIND do not interfere in their business operations. Besides, a number of enterprises including private firms rise up in satellite application industry. For example, it is estimated that the market scale of navigation and positioning service in China will increase from around 100 billion yuan (around 16 billion USD) in 2012 to 250 billion yuan (around 40 billion USD) in 2015 (People's Daily 2013).

### 24.3.4 User System

User system consists of both public and private users. Ministry of Agriculture (MOA), Ministry of Land and Resources (MOLR), China Meteorological Administration (CMA), and State Oceanic Administration (SOA) are the main governmental customers of space infrastructure. For example, remote sensing satellite-based services are widely used in agricultural resource survey, crop outcome estimation, ecological environment monitoring, and natural disaster monitoring and evaluation, which serve as an important decision-making basis. Though government ministries and agencies are the main users of space infrastructure, the role of private actors has been on the rise for recent years. With the construction of regional BeiDou Navigation Satellite System, more than 50 enterprises got involved in the R&D and commercialization of BeiDou-based terminal equipment (People's Daily 2013).

## 24.4 Space Policy System in China

The space policy is the government agencies' conduct codes and action plans to achieve the development goals of the space activity in a certain period. Government agencies include all legislative, administrative, judicial, and bureaucratic authority, while the conduct codes and action plans consists of laws, regulations, and policy documents, such as plans, approaches, opinions, and decisions. The space policy can be classified in terms of the policy goals and the type of activities. The hierarchy of China's space policy is determined by the policy bodies. The policy issued by the State Council is much more important than that issued by ministries.

### 24.4.1 White Papers on China's Space Activities

Chinese government has issued the White Paper on China's space activities around every 5 years since 2000, which has become an important window for outside world to understand China's space policy and progress in space activities. The White Paper on China's Space Activities in 2000 is the first official document to introduce China's space achievements, strategy, and policies systematically, including aims and principles; present situation of space technology, space application, and space science; future development plans; and international cooperation issues concerning Chinese space activities. The aims of China's space activity are as follows: (1) to explore outer space so as to enhance understanding about the cosmos and the Earth; (2) to utilize outer space for peaceful purposes so as to promote human civilization and social development; and (3) to meet the growing demands of economic development, national security, S&T development, and social progress so as to protect national interests and build up national comprehensive strength. China carries out its space activities in accordance with the following five principles, namely, (1) to adhere the principle of long-term, stable, and sustainable development and making development of space activities serve national comprehensive development strategy; (2) to adhere the principle of independence, self-reliance, and indigenous innovation and promoting international cooperation; (3) to make breakthroughs in key areas by selecting limited targets according to national strength; (4) to enhance social and economic returns of space activities by means of technological progress; and (5) to adhere to integrated planning, combination of long-term and short-term development, combination of spacecraft and ground equipment, and coordinated development (The State Council 2000).

The White Papers issued in 2006 basically follow the structure of the first White Paper, including the aims, principles, progress, and major tasks of China's space activities, international cooperation, and policy measures (The State Council 2006a). The 2011 White Paper raised the major tasks from nine aspects, namely, (1) space transportation system; (2) man-made Earth satellites; (3) human spaceflight; (4) deep-space exploration; (5) space launch sites; (6) space telemetry, tracking, and command (TT&C); (7) space applications; (8) space science; and (9) space debris (The State Council 2011).

To ensure completion of the tasks, Chinese government has formulated policies and measures to promote the development of China's space activities, including (1) making comprehensive plan for and prudently arrangement space activities, giving priority to applied satellites and satellite applications, developing human spaceflight and deep-space exploration properly, and actively supporting scientific space exploration; (2) strengthening innovation capacity building in space science and technology by implementing key S&T space projects and building space innovation system; (3) promoting the development of satellite application industry by comprehensively planning and constructing space infrastructure and fostering the enterprise clusters, industrial chains, and market of satellite application; (4) strengthening basic capacity of space S&T and industry by constructing infrastructure for R&D and production and test of spacecraft and launch vehicles;

(5) strengthening space legislation and policy making; (6) guaranteeing the sustainable and steady financial investment for space activities by establishing a diversified, multichannel space funding system; (7) encouraging all kinds of organizations to participate in space activities; and (8) strengthening education and training of space professionals (The State Council 2011).

### 24.4.2 Commercial Space Policies

Commercial space policies refer to those laws, plans, rules, and regulations on space industry development. During the past 10 years, relevant ministries and agencies have issued several policies to promote the commercialization of space technologies and improve the competitiveness of space industry.

The former Commission of Science and Technology and Industry for National Defense (COSTIND) issued the Interim Measures on the Administration of Permits for Civil Space Launch Projects in 2002, with a view to regulating the administration of civil space launch projects, promoting the healthy development of civil space industry, maintaining the national security and the public benefits, and performing the obligations of China as a contracting state to the international outer space convention. It requests any natural person, legal person, or other organization undertaking civil space launch projects shall, in accordance with the present measures, apply for examination and approval. It also provides the procedures of permits application, examination and approval, and the supervision and administration of permits (COSTIND 2002).

The Eleventh Five-Year Plan of Space Development issued by COSTIND in 2007 puts forward the comprehensive strategy and policy measures for space industry development. It proposes six key measures to promote the development of space industry: (1) to complete the industrial chain which covers spacecraft manufacturing, launching service, ground equipment manufacturing, and satellite operation and application; (2) to promote the application of Earth remote sensing satellite in the field of agriculture, forestry, irrigation, homeland resources, land utilization planning, environmental protection, disaster mitigation, etc.; (3) to extend the application of communication satellite to remote education, remote medical care, etc.; (4) to implement the key projects for industrialization of BeiDou navigation system and cultivate the market for navigation service; (5) to promote the commercialization of space science and technology and foster several international brand; and (6) to promote international launching service and satellite export (COSTIND 2007).

The Several Opinions Relevant to Promoting the Development of the Satellite Application Industry issued by NDRC and COSTIND in 2007 further defines the policy measures of satellite application industry and puts forward to transform the applied satellite industry of China from “testing and application-based” to “business and service-based” by 2020. It also sets the target of building an applied satellite industry chain which covers satellite operation service, ground equipment and user terminals manufacturing, system integration, and comprehensive information service. It raised some policy measures, including strengthening the overall planning and macro supervision; promoting the intellectual property right protection of satellite products and services, the construction of satellite application standard system, and infrastructure building; and promoting international cooperation (NDRC and COSTIND 2007).

### 24.4.3 Space Science and Technology Policies

The 11th Five-Year Plan for Space Science Development issued by COSTIND in 2007 is the first specific national space science policy in China. The plan puts forward the objectives of Chinese space science in the following 15 years, including building a space science system with competitiveness, covering space astronomical observation, space environment, microgravity science, and space life science, etc. to reach world top level in major space science domains and meet national strategic demands. Besides, the space science and technology also draws great attention in many other comprehensive policy documents at national level in China.

The Outline of National Medium- and Long-Term Plan for Science and Technology Development (2006–2020) (the State Council 2006b) covers a full spectrum of science and technology development. The outline initiates 16 mega S&T projects with a view to strengthen national competitiveness by realizing critical breakthroughs in the limited fields that is significant to social and economic development. Three of the 16 projects are space-related projects, including high-resolution Earth observation systems, manned spaceflights, and the moon probe missions. Besides, the space technology is also listed in the eight frontier technology areas that aim to improve the capacity of hi-tech R&D and the international competitiveness of hi-tech industries.

The Twelfth Five-Year Plan for National Science and Technology Development (MOST 2011) takes the Earth observation and navigation technology as one of the priority areas of frontier technology and mainly supports researches on advanced remote sensing, geographical information system, navigation and positioning, deep-space exploration, etc. The National Medium- and Long-Term Program for Major Science and Technology Infrastructure (2012–2030) (the State Council 2013) sets space science and astronomy as one of seven major areas in the following 20 years and puts forward the construction plan of basic S&T infrastructures in three aspects: (1) in the field of cosmos and astrophysics, mainly focusing on large diameter radio telescope, the Antarctic Pole observatory, etc.; (2) in the field of solar and solar-terrestrial space observation, mainly focusing on ground-based observation network for space environment, large-scale solar observation infrastructure, etc.; and (3) in the field of space environment and materials, mainly focusing on the stimulation facility of space environment and materials, space microgravity experimental infrastructure, etc.

### 24.4.4 Policies for Space Security and Sustainability

Chinese government puts space security and sustainability in a prominent position in national space policy. The 2011 White Paper reiterates that China will work together with the international community to maintain a peaceful and clean outer space. In the international arena, China actively involved in the Inter-Agency Space Debris Coordinating Committee (IADC) and the UN Committee on the Peaceful Uses of Outer Space (COPUOS) for the security and sustainability of outer space and initiated a proposal, together with Russia, the Treaty on the Prevention of Placement of Weapons in Outer Space (known as PPWT) in 2007. A space data-sharing platform and an Earth-based optic space target observation network are developed under the Asia-Pacific Space Cooperation Organization (APSCO) frame.

To regulate domestic space activities, SASTIND issued the Interim Measures for the Space Debris Mitigation and Protection in 2010, which marked the legalized management of space debris issues in China (SASTIND 2010). In practice, China constructs three engineering systems to tackle space debris issues, namely, space debris monitoring and pre-warning, spacecraft protection, and space environment protection. Chinese government launched space debris action plan focusing on debris pre-warning, protection, and mitigation in 2000 and issued the Requirements for Space Debris Mitigation in 2005 in accordance with the IADC guidelines. China established space debris monitoring network and formed routine mechanism for space debris pre-warning. With regard to the spacecraft protection, China set hand to the passivation disposal of CZ-4 launch vehicles since 1990s. With a view to debris mitigation in the geostationary orbit (GEO), China executed deorbiting maneuvers to those satellites approaching the end of their lifespan.

## 24.5 Key Issues in the Future Space Policy Agenda

Chinese government raises a highly ambitious objective to become an innovation-driven country by 2020 (the State Council 2006b). Space S&T and industry development is expected to play an increasingly important role in meeting the newly emerging national demands. In the future space policy agenda, there are several issues that should be addressed so as to promote the space S&T and industry development.

### 24.5.1 Institutional Environment for Sustainable Space Development

Institutional environment for space development consists of laws and regulations and policies concerning space activities and is an effective guarantee of sustainable space exploration. China has made significant achievements in space development since 1970s. Meanwhile, Chinese space policy system has been formulated and improved gradually. However, it is still necessary to reform and improve current space institutional environment so as to promote the development and commercialization of space technology to meet the newly emerging demands with the change of both domestic and international environment. Therefore, the space legislation and the national space policy become two key issues for sustainable development of space sector. On the one hand, the issues related to space activities of diversified stakeholders should be given higher priority in legislation agenda of National People's Congress (NPC). On the other hand, it is necessary to set up more effective national space policy system in which the priorities of space technologies, space science, space applications, and related policy measures should be addressed and the responsibilities and obligations of related stakeholders should be further clarified.

### 24.5.2 Capacity Building for Space Development

Capacity building for space development to a large extent determines the efficiency, effectiveness, and efficacy of space S&T and industry development. Therefore, capacity building has become a key issue in space policy-making agenda. Space development capacity-building measures consist three aspects: (1) capacity building for managing space development, focusing on space legislation, space strategy and policy making, coordination among government ministries and agencies, multichannel space input system, and supervision of other sectors' space activities; (2) capacity building for space R&D, focusing on space research institutions and universities as well as related infrastructures in the fields of space S&T; and (3) capacity building for space industry, focusing on industrial innovation infrastructure, research-based space corporations with competitive production and service capacity, and space industrial clusters with a number of SMEs and space industrial chains.

### 24.5.3 Space Human Resource Development

Human resource is the key and foundation for sustainable development of space S&T and industry. With the rapid social and economic development, flow of talented personnel among sectors and countries is increasingly open and frequent. How to attract sufficient professionals working on space business is a big challenge for both governmental agencies and space enterprises. To maintain a large-scale and highly qualified space personnel, especially top scientists, technicians, and management experts who are dedicated to space business, is even harder. Three key issues should be paid special attention to attract and maintain space professionals: (1) the implementation of public space programs is well combined with training of space professionals, especially those leading talents; (2) effective selection, training, incentive, evaluation, and supervision rules and mechanisms are established; and (3) universities and research institutes set up courses on space science, technology, and policy issues and attract enough young talents committing themselves to space business.

### 24.5.4 International Cooperation for Space Development

China has actively participated in bilateral, regional, multilateral, and international space cooperation in diverse forms and at various levels on the basis of equality and mutual benefit, mutual complementarities, and common development for more than 40 years. With the dramatic shifting of international economic and political pattern, the rise of commercial space sector, and rapid technology upgrade, the situation of international space cooperation has changed fundamentally. Therefore, more active measures are needed to improve China's integration into the international space community: (1) to promote international space cooperation projects by various ways, such as diplomacy, economic cooperation, and confidence building measures; (2) to play a more active and constructive role in tackling global challenges such as space security and sustainability, debris elimination, and prevention of arms race in outer space; and (3) to encourage and supportinternational space exchanges and cooperation among space enterprises, universities, research institutes, as well as individuals.

### 24.5.5 Competitiveness of Space Industry

China has become one of major spacefaring countries. However, both the scale and competitiveness of Chinese space industry are still not comparable with other space powers. Therefore, the competitiveness is the key to the Chinese space industry development. As knowledge-intensive industry, Chinese space industry development has become a key issue in the national policy-making agenda. For example, satellite applications, including satellite communication, navigation and positioning, and remote sensing, are identified as priority areas in the 12th Five-Year Plan for National Strategic Emerging Industries (the State Council 2010). The space industry should integrate the advantage of the enormous domestic market with the advantage of policies for industrial restructuring and upgrading so as to promote the transformation of economic development pattern and the competitiveness of the space S&T and industry development.

## 24.6 Conclusions

China has made remarkable achievements in space science, technology, and industry in recent years. Along with its success in space exploration, China's space policy issues draw great attention from academia, industry, and governments. But there are still limited scholars involving in space policy research in China, mainly focusing on three aspects, namely, national space policy, space S&T strategy, and commercial space policy.

The governance structure of space sector in China is a complex system, consisting of four subsystems: policy-making system, academia system, industrial system, and user system. China has formed a unique and effective space policy system in accordance with the governance structure of space sector, which consists of laws and regulations and policy documents, such as plans, approaches, opinions, and decisions. These policies can be classified into four categories in terms of the policy goals and the type of activities: (1) White Papers on China's space activities issued by the State Council, (2) commercial space policies, (3) science and technologies, and (4) policies for space security and sustainability.

In order to promote the space S&T and industry development, there are lots of issues to be discussed in the future space policy agenda. This chapter identifies and discusses five issues concerning institutional environment, space capacity building, human resources, international cooperation, and industry development. Thereafter, six recommendations are presented as follows:

1. To build favorable institutional environment for space development, including accelerating the procedures of space legislation, improving the space policy system, and further clarifying the responsibilities and obligations of related stakeholders
2. To strengthen capacity building for space development, including capacity building for managing space development, capacity building for space R&D, and capacity building for space industry
3. To set up an effective mechanism for space human resource development, including training space professionals by integrating space programs and talents training programs; establishing effective mechanisms for talents selection, incentive, and evaluation; and setting up courses on space science, technology, and policy issues
4. To promote diversified and multilevel international space cooperation, including cooperation under the framework of COPUOS; bilateral/multilateral cooperation; and cooperation among space enterprises, universities, research institutes, and especially the private enterprises
5. To enhance the competitiveness of space industry, including increasing the investment in the industrial technology development, giving a higher priority to satellite application industry, and developing space industry clusters with deep involvement of private enterprises
6. To broaden and deepen space policy research, including space legislation, strategic and policy, special policies for space S&T commercialization and international cooperation, and global space legislation and policy framework

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# Chinese Concepts of Space Security

# 25

Dean Cheng

## Contents

**Abstract**

China views space as enhancing many aspects of comprehensive national power, including not only its military capabilities but its economic development and diplomatic outreach. In the military dimension, its space capabilities have strategic, operational, and tactical impact.

## 25.1 Introduction

With the 18th Party Congress in November 2012, China ushers in a new generation of leaders, led by Xi Jinping and Li Keqiang. While it is impossible to predict the precise policies that they will pursue for the coming decade, it is likely that they will

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sustain the long-standing interest in space capabilities that their predecessors have displayed.

That consistent support over the intervening six decades since the founding of its space program has allowed the People's Republic of China (PRC) to become a true space power. It fields an array of launch vehicles, controls multiple constellations of satellites, and is a member of the exclusive club of nations that can orbit their own astronauts. This is supported by a substantial space industrial complex, which remains part of China's state-owned enterprise system.

Not surprisingly, as China's space capabilities have grown, its encounters and interactions with other space powers have also expanded. Chinese space activities influence and affect other nations, not only in the physical sense of debris-generation and orbital deconfliction but in the policy realm as well. How China envisions the role of space for its own security will affect other nations' security efforts, both in space and terrestrially.

China's concept of space security is embedded within the larger context of Chinese conceptions of national security. Chinese discussions of national security, in turn, are usually undertaken within the construct of "comprehensive national power (*zonghe guojia liliang*; 综合国家力量)." Space capabilities affect many different aspects of comprehensive national power, so Chinese concerns about space and security include economic, and diplomatic considerations, as well as military ones.

## 25.2 Comprehensive National Power

The PRC defines its national interest not only in terms of military or economic factors but across a broad range of metrics. As the PLA textbook *Science of Military Strategy* notes, "In the period of our socialist modernization construction, national interest and the general line and principles of the Party focus on increasing social productive forces, revitalizing economy and strengthening comprehensive national power" (Peng and Yao 2005, p. 167) By "comprehensive national power," the Chinese are referring to all of the elements of national power that can affect national survival and standing, including military capabilities, economic development, popular support, diplomatic respect, and ideological motivation and coherence. According to the China Institutes of Contemporary International Relations (CICIR), a Chinese think tank associated with the Ministry of State Security, comprehensive national power is the "total of the powers or strengths of a country in economics, military affairs, science and technology, education, resources, and influence" (China Institute of Contemporary International Relations 2000). Space capabilities make a major contribution, because it touches on virtually every aspect of comprehensive national power.

### 25.2.1 Economic Development

Chinese leaders have long seen space as contributing to national economic development in both direct and indirect ways. When the Chinese first examined the idea of developing a space capability, Dr. Qian Xuesen wrote “A Proposal to Establish China’s Defense Aviation Industry” which recommended creating an aerospace industrial sector (which, for security reasons, was referred to as the “aviation industry [*hangkong gongye*; 航空工业]”) that could produce rockets and missiles indigenously (China National Space Administration 2011). He was supported by Mao Zedong, Zhou Enlai, and Marshal Nie Rongzhen. The Fifth Academy of the Ministry of Defense was established in 1956 – generally considered the birth of China’s space program – while the creation of a missile industrial base was incorporated into the “National Long-Term Plan for the Development of Science and Technology, 1956–1967” (Chen 1999; Deng 1993, p. 32).

Although China’s initial space development, especially under Mao, was not always linked to economic considerations, that changed after Deng Xiaoping succeeded “the Great Helmsman.” Under Mao, after China launched its first satellite in April 1970, it followed with only a handful of scientific satellites. After Mao’s death in 1976 and Deng Xiaoping’s rise to power in 1978, space development was further retarded, with Deng demanding that the Chinese space effort “concentrate on urgently needed and practical applied satellites” (Li 1999). This was consistent with his overall approach of “Reform and Opening,” where economic development had assumed highest priority.

This stance shifted in 1986, however, when four top Chinese scientists argued to Deng that China needed to foster science and technology, as the foundation for future economic and technological advances. The scientists were Wang Daheng, an optics specialist who had designed some of China’s first ground-imaging cameras; Wang Ganchang, one of the chief scientists on China’s atomic bomb effort; Chen Fangyun, an expert in radio electronics who designed satellite control systems; and Yang Jiachi, who had helped automate Chinese satellites (Deng 1993, p. 152; Feigenbaum 2003, p. 141). Deng was persuaded by this argument and authorized the creation of Plan 863, formally termed the National High-Technology Research and Development Plan (*guojia gao jishu yanjiu fazhan jihua*; 国家高技术研究发展计划).[1] The seven key areas under Plan 863 continue to benefit from additional financial and human resources – including aerospace.

China’s space program benefits the Chinese economy in several ways. In the first place, the manufacturing of space-related systems, including not only satellites and launchers but associated equipment and subsystems, represents a direct contribution to the growth of the Chinese economy. The two main Chinese space conglomerates, China Aerospace Science and Technology Corporation (CASC) and China Aerospace Science and Industry Corporation, are each believed to employ some 90–100 thousand workers.[2]

Additional commercial frontiers are constantly opening, to help maximize Chinese productivity. Precision agriculture, for example, uses satellite navigation

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[1] For further discussion of the creation of Plan 863, see Feigenbaum (2003), esp. pp. 141–143.

[2] Figures compiled from various articles drawn from *China Aerospace* and CASC and CASIC websites

information to tailor the application of pesticides and fertilizers to crops, as well as configuring crops to specific soil and topographical conditions. Distance learning and telemedicine facilitate the leveraging of scarce intellectual capital and can reach every corner of the PRC. Meanwhile, the introduction of the Beidou/Compass navigation system is helping to expand further China's satellite navigation market. Between 1998 and 2006, that market grew at the rate of 50 % per year (Lin and Shi 2006).

Space technology is also seen as providing the basis for many "spin-offs," technological advances that ultimately benefit the entire economy. The original impetus to develop better microchips, advanced materials, and new metals was based in part on the space program. Nor is it just physical products that may be spun off. Given the requirements for operating in the harsh environment of space, production of space systems requires a level of precision manufacturing, quality control, and advanced design. These qualities, in turn, may benefit non-space industries and products.

Similarly, by maintaining a high-profile interest in space, Chinese leaders hope to continue attracting talented students into aerospace-related fields. When the Chinese were debating whether to undertake a manned space program in 1992, for example, Yang Shangkun, then China's president and vice chairman of the powerful Central Military Commission, threw his support behind the program because it would help nurture a new generation of designers and engineers. Without a new mission, he observed, there could be a break from the older generation that had completed the "two bombs, one satellite" effort (referring to the indigenous development effort supporting China's atomic bomb, hydrogen bomb, and first satellite) (Zuo 2009).

Participation in the international space market also provides additional business opportunities. In the 1990s, China provided launch services for a variety of customers, competing successfully with the USA, European Space Agency, and Russia. It was only the Loral-Hughes incident, which led to American export controls on any satellite containing American parts that curtailed China's commercial space launch efforts. In recent years, however, China has gotten around this problem by offering a soup-to-nuts approach to satellite sales, designing and building the satellites for foreign customers, as well as launching the satellite and conducting in-orbit checks, before handing over the system to the customer. The first such sale, of a communications satellite to Nigeria, was valued at approximately $250 million, including satellite construction, launch, and insurance (deSelding 2005). A similar sale in 2010 to Bolivia, including training Bolivian scientists and operators, was valued at about $300 million, much of it financed by the China Development Bank (Garcia 2010).

### 25.2.2 Diplomacy

China's sales of satellites also serve diplomatic purposes. China's satellite customers have tended to be states that have strategic significance to the PRC. Some could serve as sources for key raw materials: oil from Nigeria and Venezuela and lithium from Bolivia (Piette 2009). Others are major strategic partners, such as Pakistan, or are in strategic locations, such as Sri Lanka (deSelding 2012). The reporting by *China Aerospace* (*Zhongguo Hangtian*) of the launch of the Pakistan communications satellite PAKSAT-1R, for example, notes that the launch involved two good friends, on the 60th anniversary of their establishing relations (Huang 2011)

Indeed, Chinese space development has long been motivated, in part, by concerns about international prestige and international standing. Mao committed the PRC to developing strategic capabilities (nuclear weapons and long-range rockets) on the grounds that "nuclear weapons are such a major item that without it, people will say that you don't count" (People's Daily 1999). Space developments were seen in the same light, as Mao declared, in May 1958, "we should also manufacture satellites" (Deng 1993, p. 356).

Prestige also influenced China's initial satellite designs. Mao demanded that the first Chinese satellite should be more capable than either the first American or Soviet ones. It should not be "like the chicken egg the Americans had launched [Explorer-1, the first US satellite, weighed 14 kg]. Rather, they should build a much larger one" (Chen 1999, p. 164). This besting of other nations' firsts appears to be at least a tacit goal even today, as most Chinese firsts have had longer endurance, more orbits, or more capability than other nations' firsts.

The recognition that China fields world-class space systems is a matter of pride to the Chinese. Chinese descriptions of the Fengyun series of satellites, for example, emphasize that China's Fengyun weather satellites are incorporated into the World Meteorological Organization's weather satellite network.[3]

But China has also used space as a means of expanding its influence. In 2003, China established the Fengyun Satellite Data Broadcasting System, or FENGYUNCast. The system, which is managed by the China Meteorological Administration (CMA), distributes data collected from China's Fengyun weather satellites to receiving stations. As one Chinese official noted, "the system has a daily satellite broadcasting bandwidth of 23 GB" and provides not only weather information but earth observation data suitable for environmental monitoring, natural disaster surveillance, and agricultural support (Zhang 2012). Moreover, the station can also download information from non-Chinese systems, allowing recipients to receive data from US and Japanese satellites as well (Lin 2007).

In 2006, and again in 2007, China donated receiving stations to a number of countries. The initial group of recipients included Bangladesh, Iran, Mongolia, Pakistan, Thailand, Peru, as well as Indonesia in 2006. China donated another 11 stations in 2007, including Malaysia, Nepal, Sri Lanka, Tajikistan, and Vietnam.

The initial groups of FENGYUNCast receiving stations, not coincidentally, were all donated to states that had expressed intent on joining the Asia-Pacific Space Cooperation Organization (APSCO). In 1992, Chinese, Pakistani, and Thai

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[3] See, for example, Fengyun Satellite Data Center (2012)

officials proposed the creation of an Asian grouping to discuss space matters. In November 2005, representatives from these three nations, as well as Bangladesh, Indonesia, Iran, Mongolia, and Peru, signed the APSCO Convention. In December 2008, the organization was formally launched, with the addition of Turkey (China National Space Administration 2005). China, which serves as host for the organization, clearly dominates this group. It is not only the largest state, economically, but it has the most advanced space capabilities of all the members. Moreover, it is notable that neither India nor Japan and the other major Asian aerospace powers are full members of this organization.

APSCO has proposed a number of joint projects, including a ground-based Asia-Pacific Optical Space Observation System (APOSOS), which would link member states' major optical telescopes into an integrated space observation network. The goal was to provide all the member states, at low cost and investment, a means of tracking objects in low Earth orbit (Guo 2011). It would also acclimatize the various participants to cooperating with each other and with the PRC.

China also established its first permanent overseas facilities as part of their space program. In support of the Shenzhou manned space program, Chinese tracking facilities were initially established in Namibia and Kiribati, although the latter facility was subsequently closed (Shie 2006). Additional ones were later established in Kenya and Pakistan.

## 25.3 Military Aspects of Chinese Security

While comprehensive national power includes a wide variety of factors in its calculus, an obvious one is the military component of national security. Chinese concepts of space security similarly exist within the broader context of Chinese concepts of military security. In particular, the role of space has risen, as the Chinese have observed changes in the shape of modern warfare, and in turn evolved their views on the form of future wars.

Under Mao Zedong, the keynote of the times was said to be “War and Revolution.” Mao emphasized the need to prepare for “early war, major war, nuclear war.” Future conflicts would be massive, global affairs, involving nuclear weapons. The Chinese would have to be prepared to conduct an extended guerrilla war in the wake of such a conflict, against either American or Soviet occupying forces.

When Deng Xiaoping succeeded Mao, the PRC altered its view of the global strategic situation. In 1978, the PRC formally altered its worldview, concluding that the prospects of world war were negligible and China no longer faced immediate, major military threats. Instead, the main concern was more limited conflicts, in terms of both scope and duration (Joffe 1987). At the same time, modern weapons were altering the shape of war. Weapons had greater reach and significantly improved lethality.

By the early 1990s, China's assessment of future wars was further refined. The continued information technology revolution now not only affected weapons but tactics and even strategic outcomes. Modern weapons, as seen in the first Gulf War, shifted the emphasis from the destruction of opponents to paralyzing them.

High-technology weapons mean that future conflicts will be all-encompassing, involving not only air, land, and sea areas but also outer space and cyberspace.

To fight such wars, the PLA, like the US, Soviet, and German militaries had in the past, increasingly focused on fighting campaigns and conducting the operational level of war. (Battles occur at the tactical level of war. Campaigns occur at the operational level of war. Wars occur at the strategic level of war.) In 1993, the PLA produced a new set of "Military Strategic Guidelines for the New Period," introducing the concept of "Local Wars Under Modern, High-tech Conditions." These guidelines constitute "the highest level of national guidance and direction" to the Chinese armed forces (Finkelstein 2007).

In a subsequent, December 1995 speech to the CMC, Party General Secretary Jiang Zemin, who had been designated to replace Deng Xiaoping, emphasized the importance of these new guidelines. He charged the PLA with undertaking the "Two Transformations (*liangge zhuanbian*; 两个转变)." These entailed a shift from a military focused on quantity to one focused on quality and from a military preparing for "local wars under modern conditions" to one that was preparing for "local wars under modern, high-tech conditions" (Zhang and Li 1997).

The core of this new type of war would be the conduct of joint campaigns, in recognition that future operations would not be conducted by single services in combined arms operations, but by multiple services operating together. Indeed, in June 1999, the PLA issued "New Generation Operations Regulations," which made joint operations the capstone (Finkelstein 2005). In essence, the PLA was stating that individual service campaigns are subordinate to joint campaigns and would train and equip itself to that effect (Gao 2001, pp. 12–25).

Integral to joint operations is the utilization of space. PLA assessments of the first Gulf War note that the USA deployed substantial space assets in support of coalition forces and that this was a major factor in the war's outcome (Chang 2005, p. 249). PLA writings conclude that some 70 satellites were employed, providing the USA with 70 % of its data transmission capacity and 90 % of its strategic intelligence (Gao 2001, p. 54).

Based on these observations, Chinese writings conclude that, in order to wage future "Local Wars Under Modern, High-Tech Conditions," PLA commanders would need:

A. Reconnaissance/surveillance capabilities. Commanders need to be able to better determine an enemy's situation, geography, and other related combat information.
B. Mobile firepower. The ability to undertake rapid yet ferocious attacks against an opponent, throughout the depth of the theater, based upon assets drawn from all available forces.
C. Electronic warfare. Necessary to both preserve one's own ability to utilize electronic systems and disrupt an opponent's ability.
D. Command and control capabilities, which can be sustained in combat. These command and control capabilities are essential for allowing commanders to coordinate the various forces, drawn from different services, in a mutually supporting fashion.

E. Deterrent capabilities. To limit the enemy's responses.
F. The ability to join disparate forces and elements together. Forces from different services and different locations must be able to interact promptly, in a coordinated, mutually supporting manner (Wang and Zhang 2000, pp. 44–48).

By 2004, there had been yet another evolution in the PLA's views of future wars. Having carefully observed US and allied operations in the Balkans, Afghanistan, and the march to Baghdad, Chinese military thinkers concluded that not all high technologies are created equal. Of particular importance are those related to information; indeed, according to the 2004 PLA defense white paper, future wars were now likely to be "Local Wars Under Informationized Conditions."

The "campaign guiding concept," the basis for planning operational level activities, is "integrated operations, precision strikes to control the enemy (*zhengti zuozhan, jingda zhidi*; 整体作战, 精打制敌)." "Integrated operations" refer to not only integrated forces, i.e., joint operations, but also combining offensive and defensive operations, hard-kill and soft-kill techniques, in the air, on land, at sea, in space, and in cyberspace. "Precision strikes" are described as those involving the use of precision munitions to attack vital targets. The goal is not only destroying key points but also precisely controlling the course and intensity of a conflict (Zhang 2006, p. 81). It also entails disrupting the enemy's system, and not just individual weapons or forces, so as to effect paralysis and not simply attrition (Wang and Zhang 2009, pp. 202–203).

Central to the conduct of such strikes is the ability to establish superiority, or dominance, over the information realm. Seizing information superiority or dominance (*zhi xinxi quan*; 制信息权) is seen as vital (Zhang 2006, p. 81). An essential means of attaining information dominance, in turn, would be through military space operations. "Establishing space dominance, establishing information dominance, and establishing air dominance in a conflict will have influential effects" (Zhang 2006, p. 83).

This growing emphasis on establishing space dominance is rooted, in part, on the conclusion that dominance of the information domain is predicated on the ability to control space. In the opinions of some PLA analysts, without control of space, any attempt at dominating the information domain, or exercising combat in the electromagnetic spectrum, is made much more difficult, if not outright impossible (Hong and Liang 2002).

The PLA's conclusion, based on both the Gulf War and Kosovo, was that space, therefore, represents the new strategic high ground (*xin de zhi gao dian*; 新的制高点). The combination of modern information technology and military space systems has created the means of coordinating land, sea, and air forces; control of space (and the information domain) is now crucial for coordinating joint operations (Gao 2001, p. 33). Whoever gains space dominance will be able to influence and control other battlefields and will be likely to retain the initiative. Thus, the US deployed extensive space forces early in the Gulf War, ensuring that the US retained "its initiative in the war. This played a key role in seizing victory" (Zhao 1998).

By contrast, loss of control of the space and information domains will likely lead to a reactive, passive stance. For both the Iraqis and Serbians, the result was combatants who were constantly subject to manipulation and utterly unable to respond effectively (Li 2002).

## 25.4 Space as a Strategic Factor

As noted earlier, conflict occurs at the strategic, operational, and tactical levels. Space capabilities contribute to all three.

At the strategic level, China's possession of space capabilities, in and of itself, constitutes a fundamental factor affecting its strategic situation. Unlike the vast majority of states that have confronted the USA or other western nations since the end of the Cold War (e.g., Iraq, Serbia, Libya), China possesses a complete array of space systems that are under its sovereign control. China does not depend upon external suppliers for technology, support, maintenance, or access to space. Consequently, Beijing can employ space systems to support its own ends, unlike most other countries.

Not only does this potentially alter the strategic calculus in any confrontation involving the PRC directly, but it also introduces a potential source of leverage, should Beijing choose to support other countries that are engaged in a confrontation. China, as noted previously, already provides weather and disaster information to various states through its FENGYUNCast network. It could choose to provide more refined information derived from its space systems as well (although not necessarily through FENGYUNCast).

Furthermore, strategic security is influenced by what Chinese analysts term "political warfare." This entails efforts to shape and influence both adversary popular perceptions and sentiment and those of the enemy leadership. Such efforts include "political combat styles under informationalized conditions (*xinxi tiaojian xia de zhengzhi xing zuozhan yangshi*; 信息条件下的政治性作战样式)," involving the use of various resources, not just military ones, to secure the political initiative and psychological advantage over an adversary (Academy of Military Sciences Operations Theory and Regulations Research Department and Informationalized Operations Theory Research Office 2005, p. 403). These "political combat styles," as specified in the "Political Work Regulations of the Chinese People's Liberation Army," include the "three warfares (*san zhan*; 三战)" of psychological warfare, public opinion warfare, and legal warfare.

- *Public opinion/media warfare* is the struggle to gain dominance over the venue for implementing psychological and legal warfare. While the news media plays a key role, public opinion/media warfare involves all the instruments that inform and influence public opinion (e.g., movies, television programs, books).
- *Psychological warfare* seeks to disrupt an opponent's decision-making capacity by creating doubts, fomenting anti-leadership sentiments, and generally sapping an opponent's will. It can include measures aimed at the political, military, economic authorities, or the general population.

- *Legal warfare* seeks to justify one's own actions in legal terms while portraying an opponent's activities as illegal, thereby creating doubts among adversary and neutral military and civilian authorities and in the broader population, about the wisdom and justification of an opponent's actions.

China's possession of a global communications capacity, including satellite systems, provides it with the ability to wage all forms of political warfare across the globe. Indeed, China's efforts to facilitate Xinhua's creation of a 24-h English language news service to counter CNN and Fox News and the expansion of state-owned China Central Television (CCTV) could not hope to gain a global audience without a robust satellite communications infrastructure to support it (Xinhua News Agency 2010; Branigan 2011).

### 25.4.1 Space Deterrence Operations

Another key strategic mission for space forces is to effect space deterrence. PLA thinking is that deterrence may be based upon nuclear, conventional, space, or information strength. It may also be based upon space-based strength. In each case, the intent is to "demand the opponent to submit to the deterrer's volition" (Peng and Yao 2005, p. 215). It is worth noting that the Chinese term for deterrence, *weishe*, and the underlying conception does not necessarily differentiate between dissuasion and coercion. Deterrence by whatever means, including space, is seen as providing the opportunity to achieve one's own strategic goals and to defeat an opponent without having to resort to the actual use of force.

Space capabilities can multiply the effects of other deterrent forces, by enhancing the effectiveness of nuclear and conventional forces. In conjunction with nuclear forces, for example, they can enhance one's own nuclear capabilities, while potentially neutralizing an opponent's (Hong and Liang 2002). Similarly, space systems can dramatically improve the lethality and range of conventional forces, enhancing its deterrent capabilities.

Space systems may also intimidate an opponent on their own. Given their expensive nature, threatening an opponent's space systems may suffice to dissuade an opponent, much as nuclear deterrence threatens to impose very heavy costs. Of course, threatening satellites is not the same as threatening nuclear destruction of cities; yet, the possibility that significant portions of a state's space infrastructure may be destroyed or damaged imposes a cost-benefit analysis that otherwise would not have to be made. The lack of human casualties also makes space deterrence more credible – there is less likelihood of strategic escalation if space systems, rather than cities, are attacked.

Moreover, given the expense, and the lack of spares, destroying or damaging an opponent's space systems will likely have effects that will be felt for many months, if not many years. This, in turn, can affect a state's long-term economic, political, and diplomatic well-being. Because space affects so many aspects of comprehensive national power, any damage inflicted upon space systems will, in turn, have repercussions across those same elements of comprehensive national power.

Chinese authors, in thinking about how to effect space deterrence, appear to have developed something akin to an “escalation ladder” of actions, each rung a more serious attempt to dissuade or coerce an opponent into altering their course of action. The more serious the measure, the more they are also intended to improve war-fighting capabilities, so that should deterrence fail, Chinese forces will be in a better position to conduct military operations. The rungs on this “escalation ladder” for space deterrence comprise testing space weapons, undertaking space exercises, shifting the deployment of space forces, and actually employing space weapons.

**Testing Space Weapons**. The first rung of the Chinese space deterrence ladder appears to be testing space weapons in peacetime. Successful testing demonstrates capability, so that potential opponents will have to incorporate that threat into their cost-benefit calculus in any future confrontation. Even a failed test, however, can nonetheless influence potential adversaries, since they cannot know if the causes of any failure have been resolved by the time of a new crisis. Moreover, by undertaking such tests, whatever the outcome, there is demonstrated a certain level of scientific and technical capability. This, in turn, not only can enhance political and diplomatic standing but will also show any potential adversary the rising level of comprehensive national power (Li and Dan 2002).

**Undertaking Space Exercises**. The next level of deterrence involves space force exercises. This can include not only offensive and defensive space operations but also antimissile exercises with an exo-atmospheric component. It also can involve the use of space forces to support conventional and/or nuclear forces, especially in joint operations-type environments. Not only do such exercises provide an object lesson in capability, but they also provide an opportunity for one’s own forces to engage in realistic training.

Such exercises are differentiated from testing space weapons by their timing. PLA writings suggest that the most effective time to conduct such exercises is in a crisis, to maximize deterrent effect and to demonstrate resolve and commitment. By contrast, tests of space weapons are best undertaken in peacetime, in order to maximize the opportunity to shape others’ perceptions. To further add to their effect, such exercises might be held in regions of space that are especially sensitive or strategic, such as in geosynchronous orbit. Doing so both further sensitizes any potential opponent and further demonstrates will (Chang 2005, p. 303).

**Shifting the Deployment of Space Forces**. Should further escalation be necessary in order to deter an opponent, the next rung would involve both reinforcing current space forces and shifting their location as necessary. Both moves would signal that the situation is becoming ever more dangerous, thereby demonstrating resolve.

Moreover, by deploying additional satellites, one’s own capabilities are improved, which may not only provide additional deterrence but also complicate an opponent’s targeting. Furthermore, if additional reconnaissance systems are deployed or shifted, this will also probably increase the chances that opponent force deployments and activities will be detected, also contributing to deterrence by denying the chance for surprise. Should an opponent nonetheless remain committed to their course, increased deployments can provide the additional capabilities necessary to help secure space and information dominance (Chang 2005, pp. 303–304). This last aspect will not necessarily generate a deterrent effect, but is expected to help war-fighting capacity.

**Actual Use of Space Forces.** There are two ways in which space forces might be actually used; each has a different effect on deterrence. One is to have employed space capabilities in other conflicts. In this view, previous displays of actual capabilities can serve to deter future conflicts.

Other analyses, however, suggest that the deterrence involved in actual attacks is not based on prior experience, but on the effective implementation of actual attacks in an ***ongoing*** crisis. One author describes such operations as reprimand or punishment strikes (*chengjie daji*; 惩戒打击). The actual employment of space forces, in this view, constitutes the strongest kind of deterrent (*zuigao qiangdu de weishe*; 最高强度的威慑). The aim is to "cow the enemy with small battles (*yixiaozhan er quren zhibing*; 以小战而屈人之兵)" (Chang 2005, pp. 302–304).

The use of space weapons does not have to be destructive. For example, one could interfere, suppress, or otherwise disrupt enemy space systems, such as by jamming communications and data links or damaging their command system through computer network attacks (Chang 2005, p. 304). By inflicting confusion and disruption on their space systems, an opponent may yet decide to cease hostilities. At the same time, such moves would not necessarily generate debris (and, indeed, may even be publicly deniable), thereby limiting the diplomatic impact on third parties.

But the PLA is not committed to purely soft-kill forms of weapons employment in support of deterrence. PLA authors also suggest that this rung might involve implementing sudden, short-duration strikes against enemy space systems, such as space information systems, command and control centers, communications nodes, and other key facilities.

Such attacks would inflict a greater psychological blow than the option of jamming and interfering with an opponent's systems, since there could be actual physical destruction of hard-to-replace facilities and equipment. Moreover, by destroying such targets, other elements of the opponent's space infrastructure will likely be affected, whether they are themselves targeted or not. It would likely require extensive efforts and delays, for example, before orbiting satellites could be shifted, or new systems launched, in the wake of attacks on mission control facilities. The logic seems to be that the ability to inflict punishment is the greatest deterrent; "the foundation of space deterrence must be preparation for real war (*bixu yi shizhan zhunbei zuowei kongjian weishe de jichu*; 必须以实战准备作为空间威慑的基础)" (Chang 2005, p. 302).

The divergence of views on how to execute a policy of space deterrence, however, raises questions about the extent to which the PLA necessarily governs larger Chinese space policy. This is underscored by the discrepancy between how PLA authors describe the utility of testing space weapons and how the PRC actually behaved at the time of the January 2007 ASAT test. Not only was there no prior publicity, but the PRC Foreign Ministry seemed to handle the aftermath in a singularly hesitant fashion. Consequently, one must wonder whether the Chinese political leadership (which is composed of civilians) necessarily subscribes to the same view of deterrence as that laid out by Chinese military space analysts.

## 25.5 Space as an Operational Factor

While space forces can have a strategic impact, their greatest contribution to Chinese military operations may be at the operational level of conflict. China's growing inventory of space assets provides the PLA with an expanding set of capabilities, facilitating the conduct of joint campaigns. China's space systems are likely to provide substantial support for the planning, conduct, and sustainment of joint campaigns.

As noted earlier, for the PLA, joint operations are seen as a hallmark of future Local Wars Under Informationized Conditions. A core element of joint operations is "integrated operations (*zhengti zuozhan*; 整体作战)," which entails integrating forces, domains, and activities.

- *Integrating forces* involves coordinating the activities of all the participating services, as well as mobilizing relevant civilian resources.
- *Integrating domains* involves linking activities within all the relevant battlespaces, including not only land, sea, and air but also outer space and cyberspace.
- *Integrating activities* means linking offensive and defensive operations by all forces, as well as coordinating positional warfare, mobile warfare, air and naval operations, and combat operations with combat support and combat service support functions.

In order to integrate the various forces, domains, and activities, it is essential that the PLA's commanders operate within a unified command system, capable of creating a common situational awareness among all the participating forces. This, in turn, requires a unified command, control, communications, computers, and intelligence (C4I) structure, linking together all the various forces. This command system will have several main tasks, each of which is likely to rely upon space systems.

### 25.5.1 Grasp the Situation

The first and most basic task is understanding the situation (*zhangwo qingkuang*; 掌握情况). All subsequent efforts and activities are built upon this foundation. Grasping the situation, in turn, entails collecting, processing, and distributing information about both adversary and friendly forces. It also includes collecting background material and providing longer-term assessments, so as to understand not just the immediate situation but the strategic context as well. Reconnaissance and surveillance capabilities, employing a variety of systems, are therefore essential, as well as the ability to collate the collected information, analyze it, and then exploit it.

The PRC currently fields a variety of space systems to provide information support to their commanders. These include:

*Meteorological satellites*. The conduct of military operations is often affected by weather. The success of D-Day, for example, rested in part upon superior allied ability to predict the weather in the English Channel. China fields the Fengyun (Wind and Cloud) constellation, which includes both sun-synchronous (FY-1, FY-3 series) and geosynchronous (FY-2 series) satellites. The 2007 ASAT test targeted FY-1C, the third of the FY-1 series of satellites.

*Earth observation satellites*. The Ziyuan (Resource) and Tianhui (Satellite Mapping) series of Earth observation satellites can transmit their data to Earth, providing much more responsive coverage. The first Ziyuan satellites, also known as the China-Brazil Earth Resource Satellite (CBERS) had a charge-coupled device camera (CCD camera) with a 20 m resolution, among other sensors. The Ziyuan-II and Ziyuan-III series are believed to be military reconnaissance satellites, also referred to as the Jianbing series, with higher-resolution sensors (Cliff et al. 2011, pp. 98, 100–101). The Tianhui Earth observation satellites are also believed to be military satellites, with a five-meter resolution CCD camera, and may be related to the Ziyuan-III satellites (Chinese Academy of Surveying and Mapping 2011).

*Other intelligence-gathering satellites*. China also fields a number of other satellite systems that provide commanders with a range of information. The Haiyang (Ocean) series of small satellites currently provide oceanographic data, including wave heights and water temperature (Clark 2011a). These will be supplemented by at least two maritime radar surveillance satellites by 2020 (China Daily 2012).

There have been 17 Yaogan (Remote Sensing) satellites placed into orbit, some with optical sensors and others equipped with synthetic aperture radars (SAR), which allow imaging through clouds and at night. These have often been orbited in pairs, allowing for comprehensive coverage of any given target, under all weather conditions (Clark 2012; Cliff et al. 2011, p. 101). China has also deployed a number of Shijian (Practice) satellites, which may have a reconnaissance role. In addition, China has orbited the Huanjing (Environment) series of disaster-monitoring satellites. These mount visible light and multispectral cameras or synthetic aperture radars. While all of these are believed to have low resolution, they can provide additional information.

### 25.5.2 Planning and Organization and Control and Coordination

The commander, once acquainted with the situation, must undertake planning and organization (*jihua zuzhi*; 计划组织). This involves making assessments and issuing broad directives, which will be supplemented by guidelines formulated by his staff. These will inform the subordinate command staffs in their formulation of more specific plans, including those governing operational activities (*zuozhan xingdong*;

作战行动), various safeguarding activities (*baozhang xingdong*; 保障行动), and command activities (*zhihui xingdong*; 指挥行动) (Yuan 2008, p. 14). As multiple services will be participating in any joint operations, one key task for the joint campaign command headquarters is to reconcile the various services' plans, integrating them into a coherent whole.

Once the campaign has begun, the commander and his staff must engage in control and coordination (*kongzhi xietiao*; 控制协调), so that the engaged forces can respond to battlefield situations as they arise. Given that conflicts under informationized conditions are much more complex, involving more participating services, larger physical scale, and more varied operational styles (*zuozhan yangshi*; 作战协同), the tasks of coordination and control of participating forces will be much more difficult. Campaign commanders and staffs will require ready access to both information about friendly and enemy forces and reliable communications to adjust force dispositions and activities.

To support these tasks, China fields communications and data relay satellites, to allow commanders to receive updates and issue new orders.

*Communications Satellites*. China has access to a range of commercial communications satellites, including those owned by AsiaSat, a Hong Kong-based company. China itself has only a limited number of commercial satellites in orbit. In addition, it fields two military communications satellite systems. The Fenghuo (Signal Fire) system provides C-band and UHF communications, while the Shentong (Wide Ranging) satellites are reportedly China's first military Ku-band communications satellites (Cliff et al. 2011, p. 94). It is possible that the two satellites serve different communities; the Fenghuo may be intended for tactical communications, while the Shentong may support higher echelons.

In the wake of the 2008 Sichuan earthquake, Chinese officials relied upon their communications satellites to coordinate disaster relief efforts. In subsequent reviews, Chinese officials noted the role of the Beidou (Northern Dipper) navigation satellite system as a supplement to the Fenghuo and Shentong satellites (Lu 2008). While the geosynchronous Beidou satellites are intended primarily as a positioning, navigation, and timing (PNT) system, it also can transmit text messages of approximately 120 characters (China Satellite Navigation Office 2011). This capability was apparently heavily exploited in the aftermath of the earthquake.

*Data Relay Satellites*. Most of China's tracking, telemetry, and control (TT&C) network is located in the PRC itself. As a result, Chinese ground-based stations can only maintain communications with any given mission for approximately 12 % of an orbit. Beginning in 2008, the PRC began to deploy additional Tianlian (Sky Link) data relay satellites, to bolster this coverage. The three Tianlian satellites placed in orbit by 2012 had increased Chinese coverage to over half of each orbit (Clark 2011b). While these satellites were ostensibly placed in orbit to support China's Shenzhou and Tiangong manned space missions, they can obviously provide support for other space systems and tasks as well.

## 25.6 Space as a Tactical Factor

In the course of waging "Local Wars Under Informationized Conditions," PLA forces will seek to overcome the enemy through precision operations. Such missions, in turn, involve precision in several specific areas, including the selection of targets, the application of force, and the choice of tactics (Zhang 2006, pp. 89–92).

The *precise selection of targets* (*jingque xuanze daji mubiao*; 精确选择打击目标) involves determining the most vital enemy targets, so as to maximize the effect of attacks. Destruction of enemy military forces may not be as essential as key military, political, or economic targets. Timing and sequencing is also important.

Similarly, the campaign commander and his staff are expected to *precisely apply forces against key points* (*jingque zhongdian yongbing*; 精确重点用兵). Weapons must be carefully allocated against targets, to assure that the right weapons are matched against each target. It may be better to apply "soft-kill" capabilities, e.g., against orbiting satellites, so as to minimize collateral damage, especially to third parties. In other cases, such as launch and mission control facilities, the goal may be to maximize permanent destruction, with an emphasis on "hard-kill" capabilities.

Precision also applies to the choice of tactics and techniques (*jingque yunyong gezhong zuozhan fangfa he shouduan*; 精确运用各种作战方法和手段). This requires the campaign command to be familiar with one's own forces and enemy forces, with the ability to fight the close-in as well as distant battles. The campaign command must be able to flexibly and innovatively adjust one's actions, engaging in both simultaneous and sequential operations while responding to contingencies as they arise.

In undertaking precision operations, key targets would include:

- Command and control facilities and associated elements, in order to paralyze an opponent
- Logistics and reinforcement centers, as well as power infrastructure and other targets that help sustain the enemy's forces
- Key missile, air, and naval bases and combat information facilities, in order to blunt an opponent's ability to conduct offensive campaigns or seek to establish information, air, or naval dominance
- Transportation choke points, including railways, highways, vital bridges, and harbors, so as to disrupt an opponent's mobility and isolate their forces (Chang 2005, p. 314; Dong et al. 2003)

Space capabilities play an essential role in supporting such precision operations. The various reconnaissance and surveillance systems allow commanders to develop detailed understanding of the nature of fixed targets and also are central to locating enemy and friendly forces. The communications satellite network allows the coordination of participating forces drawn from all the services.

In addition, the PRC fields its own *PNT satellite network*. The original Beidou constellation first took shape in 2000 and is comprised of satellites in geosynchronous orbit, which provided regional geo-location with an active portable set and a fixed site in the PRC. The Compass portion of this PNT network adds a group of mid-Earth orbit (MEO) satellites that operates along the same lines as the American

GPS, Russian GLONASS, or European Galileo system, with the satellites providing regular signals to passive receivers. By operating its own satellite navigation system, the PLA is assured access to PNT data in event of conflict.

Beyond information support from space, Chinese forces are likely to engage in offensive and defensive operations specifically against an opponent's space forces. It is important to note that, in this context, the PLA would target not only an adversary's systems in orbit but also terrestrial installations such as launch sites, mission control centers, and TT&C facilities and the data links that combine them into a systemic whole. The objective would be to cause the enemy's overall *space system* (*kongjian tixi*; 空间体系) to fail, not simply individual satellites or even mission aspects. Attacking an opponent's mission control facilities would have powerful effects that would ripple through the system, much as attacking an opponent's command and control systems would cause widespread disruptions (Hong and Liang 2002). Attacks against launch sites, meanwhile, would affect an opponent's ability to reinforce or replace damaged or destroyed orbiting systems. As one analysis notes, striking at both space and terrestrial targets is necessary to establish local space superiority (Dong et al. 2003).

Attacks against terrestrial targets could be undertaken with a panoply of systems, ranging from special operations forces to guided missile attacks or long-range bombers, depending on the location of the target. Such attacks would need to be coordinated with other operations, however, and are recognized to have a high potential for strategic escalation (Chang 2005, p. 294).

In addition, the PLA is likely to mount attacks against assets in space. This might involve the physical interception of enemy satellites. In January 2007, China tested a kinetic kill vehicle (KKV), when it destroyed a defunct FY-1 weather satellite. Available information indicates that the test was conducted with a solid-rocket booster launched from Xichang Satellite Launch Center (Kan 2007). Chinese military writings, however, acknowledge that such attacks would likely generate debris (the 2007 test was one of the first debris-generating incidents in history), which would, in turn, pose a threat to friendly and neutral satellites (Chang 2005, pp. 290–291).

Consequently, in addition to physical attacks against terrestrial facilities and orbiting systems, the PLA is likely to conduct "soft-kill" attacks against an opponent. One essential element would be to attack the data links that tie the various elements of a space system together. For example, it is noted that attacks against satellite uplinks can affect a satellite's orbital orientation or turn on (or off) its sensors. Thus, electronic interference can cause a satellite to become operationally ineffective (Chang 2005, pp. 292, 296). Another possibility would be the use of lasers, microwaves, or particle beams against a satellite's instruments and sensors. Such an attack would not necessarily cause the satellite to disintegrate, but even a low-powered attack would likely disrupt instruments (Chang 2005, pp. 292–293).

At the same time, commanders should expect an opponent to undertake similar attacks against key space assets, both terrestrial and orbital, and therefore must prepare defenses. In particular, an opponent, upon discovering one's own side has organized and prepared space strike operations, may well seek to preempt.

Consequently, an essential part of any successful space defense effort is attacking the enemy's space system. As one PLA analysis observes

> Only by using space attack strength and long-range strike weapons (such as long-range bombers) of other [military] services and branches, at the appropriate time, and using actively offensive activities for concentrated attacks against enemy space launch bases, ballistic missile launch bases, space command and control centers, and aerospace production bases, destroying or reducing the enemy's offensive capacity, can one effectively block and disrupt the enemy's undertaking of space attacks against us (Chang 2005, p. 321).

Meanwhile, in addition to augmenting active defenses by deploying air and ground defenses around key space facilities and systems, it is essential to engage in passive defense as well. Chinese writings suggest that the provision of camouflage and other stealthing measures can help satellites survive, by concealing the nature of a satellite's functions and nature (Chang 2005, p. 316). In addition, they should be hardened or otherwise shielded from enemy efforts at dazzling and electronic interference.

Another option is dispersing satellite functions, by fielding groups of small satellites and microsatellites, rather than relying on individual platforms. This would increase resiliency, allowing a mission to continue despite the destruction or disruption of any individual satellite. Where one must rely on a single satellite, it should be capable of altering its orbit, so as to evade enemy attacks, and of functioning autonomously so that even if their ground links are severed, they would nonetheless be able to continue operations (Chang 2005, p. 320).

## 25.7 Conclusions

The Chinese see space as contributing to many different aspects of their national security, including not only the military but economic and diplomatic components. This is in part because they see space itself as a holistic entity, including not only the systems in orbit but also terrestrial facilities and the data links that bind the system together.

Within the military realm, space contributes to all the levels of conflict: strategic, operational, and tactical. The various systems within China's space program provide support for its military at each of these levels; as they acquire additional capabilities, the space program's contributions will only grow. Its importance, too, will also expand, since space is a key avenue for the acquisition, transmission, and exploitation of information, the cornerstone for successfully fighting future wars.

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# Space Security in India

# 26

Rajaram Nagappa

## Contents

## Abstract

In November 2013 India will be celebrating the Diamond Jubilee of its space program. Starting from the launch of a Nike-Apache sounding rocket on 21 November 1963, the space program has progressed at a steady pace and today has evolved into a self-reliant system of application satellites and launch vehicles to place them in the required orbit. Limited commercial exploitation of space products and services is taking place. Diversification from purely application satellites to scientific missions and deep space missions are being pursued and more are on the anvil. In the long run manned missions and development of reusable launch vehicles are planned. Being dual use technology, these applications are of use to the defense and security forces also. India does not contemplate weaponization of space. To support the space missions, the ground infrastructure in terms of manufacturing and process facilities, launch center, tracking, telemetry and command network, ground stations and industrial

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support have been established. The investment in space has been substantial and together with the operational space services and commercial output are worth a few tens of billions of dollars. Security of these space assets and space services is very important to India. India would like space essentially to be an enduring and sustaining system to be used for the socioeconomic well-being and security of its citizens.

## 26.1 Introduction

The beginning of the Indian space program can be traced to 1962 when the Indian National Committee on Space Research (INCOSPAR) was constituted in the Department of Atomic Energy. The Committee was headed by Vikram Sarabhai and tasked with developing activities and supporting facilities to aid space research. Initial program concentrated on study of space sciences in the equatorial region. Sarabhai recognized the power of space for reaching out to large sections of rural India for imparting informal adult education in topics relating to agriculture practices, health, hygiene, nutrition, and family planning. The other issue needing attention was to get a measure of the country's resources for optimum utilization and management. Towards this Sarabhai and his successors laid stress on the development of application satellites for communication and remote sensing, development of launch vehicles to place the satellites in orbit, and the necessary supporting infrastructure. Having fulfilled to a great extent the application satellite requirements, the space program has taken up a modest initiative involving deep space missions and scientific missions. There is obviously a market for the space application products and services and this aspect is handled by ANTRIX, the commercial arm of the space program.

## 26.2 Development Status

Indian space program started with development of sounding rockets and payloads for studying atmospheric sciences in the 1960s. India started on the development of satellite launch vehicles and satellites in the 1970s. The first indigenously built satellite was the Aryabhata, a scientific satellite weighing 360 kg and launched on 19 April 1975 from Kapustin Yar aboard a Russian launch vehicle. Bhaskara 1 lofted into orbit in June 1979 and APPLE in June 1981 were the first experimental remote sensing and communication satellites. These provided the development experience and the learning for the later series of application satellites. Similar learning for launch vehicle design and development came through Satellite Launch Vehicle 3 (SLV-3) which was successfully flight tested on 18 July 1980. Further launch vehicle technology consolidation took place with the development and flight tests of the Augmented Satellite Launch Vehicle (ASLV) during the years 1987–1994. The Polar Satellite Launch Vehicle (PSLV) has turned out to be a very successful and reliable launch vehicle. It is mainly used for placing the

**Table 26.1** Planned satellite application missions

| Satellite | Mission |
|---|---|
| SARAL | *S*atellite for *Ar*gos and *Al*tika (SARAL) is a joint ISRO-CNES mission. The Ka band radar altimeter (Altika) is provided by CNES. The mission provides for precise orbit determination system |
| INSAT-3D | Meteorological satellite; met payloads include a 6-channel imager, 19-channel sounder along with data relay transponder; additionally includes search and rescue payload |
| GSAT-10 | Communication satellite with 12 Ku band, 12 C band, and 12 extended C band transponders; also carries GPS and geo augmented navigation (GAGAN) payload |
| GSAT-14 | Satellite is configured with six Ku and six extended C band transponders. The satellite is a replacement for Edusat which was launched in September 2004 and is near the end of its useful life |
| IRNSS-1 | The satellite is the first in the constellation of seven satellites for the Indian Regional Navigational Satellite System and carries navigation payloads and C band ranging transponder |

IRS series of Indian Remote Sensing satellites of 1,600 kg class in sun-synchronous polar orbit of 620 km. The PSLV is capable of placing 1,000 kg class of satellite in GTO and is also used for commercial launch services. The Geosynchronous Satellite Launch Vehicle (GSLV) is designed for placing communication satellites in the 2–2.5 t class in Geosynchronous transfer orbit. The vehicle is yet to become operational. India is also developing a new vehicle called GSLV Mk III for placing heavy satellites in the mass range 4.5–5.0 t in GTO. In the long run India has plans to develop reusable launch vehicles.

As of April 2012, India had 11 operational remote sensing satellites constituting the largest constellation of such satellites in the civilian domain (Annual Report 2012). The radar imaging satellite, RISAT-1, is the latest in the series and was launched on 26 April 2012. The satellite carries a synthetic aperture radar payload operating in C Band. Microwave remote sensing allows for imaging on a 24×7 basis and under all weather conditions. Megha-Tropiques satellite launched on 12 October 2011 is a joint Indo-French mission for studying the water cycle and energy exchange in the tropics. For orbiting communication satellites, India has used both procured and indigenous launches. A total of 20 communication satellites have been successfully orbited of which 8 are currently operational. Nearly 200 transponders, mainly operating in the C band, extended C Band, and Ku band, are used for the communication services. While the first four satellites of the Indian National Satellite (INSAT) System – the INSAT-1 series – were custom built by a US company to Indian specifications, the remaining satellites in the INSAT 2, 3, and 4 series as well as the GSAT series have all been designed and developed in India. Meteorological payload is included in a few of the communication satellites, and one dedicated meteorological satellite – Kalpana 1 – is operational in the geostationary orbit. In addition a few scientific satellites have been launched as also micro/nano satellites built by ISRO and Indian/foreign universities. Satellite application missions currently on the anvil are shown in Table 26.1.

For providing continuity and improvements in earth observation for resource management applications new technology development initiatives are planned. These include (a) TES hyper-spectral, which as the name suggests involves the development of a Technology Experiment Satellite in hyper-spectral imaging, (b) DMSAR-1, which is a radar imaging satellite for disaster management, (c) Cartosat-3 for advanced cartography application, and (d) GISAT, which is planned to be a multispectral, multi-resolution satellite for imaging from geostationary orbit.

Besides application satellites, India has promoted science missions, some of which are with international participation. Microgravity experiments were carried out on Spacecraft Recovery Experiment, SRE-1 in January 2007. Further microgravity experiments are planned in SRE-2. India undertook a successful lunar mission in October 2008. The spacecraft Chandrayaan-1, placed in lunar polar orbit at a height of 100 km from the lunar surface, carried out remote sensing to obtain information relating to chemical, minerals, and geology. The spacecraft carried 11 experimental payloads from India, the United States, the United Kingdom, Germany, Sweden, and Bulgaria. The major outcome of the mission was the discovery of water molecules on the surface extending from the lunar poles to 60° latitude. A second lunar mission – Chandrayaan-2 – is planned involving the landing of a rover vehicle on the lunar soil. Experiments towards getting a better understanding of the origin and evolution of the moon are planned.

The other scientific missions planned are Astrosat, an astronomical observatory, and Aditya 1, solar coronagraph study mission. India has also plans for a navigation satellite constellation and in the long run plans human spaceflight activities.

Societal applications form an important component of the space missions. Some percentage of application satellite capacity is used for domestic commercial use; but a large percentage of the capacity is used by the Government Departments; and some capacity is marketed.

## 26.3 Management of Space Activities

Space activities in India are managed by the Department of Space (DOS), which is an independent department of the Union Government functioning under the Prime Minister's Office. The space program in India is civilian in nature and its policy formulation is done by the Space Commission. The Chairman of the Space Commission also functions as the Secretary to the Government of India. The Department of Space carries out its mandate through a number of subordinate entities of which the Indian Space Research Organization (ISRO) is tasked with the development of launch vehicles, satellites, associated subsystems, and services. The Chairman of the Space Commission also functions as the Chairman of the Indian Space Research Organization. ISRO has a number of technology-specific field centers and units for carrying out technology development related to launch vehicles, satellites, satellite products, and services for designing, planning, and realization of complete end-to-end missions. The main ISRO field centers and units distributed in different locations in India are listed below:

- Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram, is the lead center for the development and realization of launch vehicles.
- Liquid Propulsion System Centre (LPSC), Thiruvananthapuram, specializes in the development of liquid propellant rocket stages for the launch vehicles as well as spacecraft propulsion systems. The LPSC integration and test facilities are located in Mahendragiri and the spacecraft propulsion requirements are carried out from Bengaluru.
- ISRO Satellite Centre (ISAC), Bengaluru, is the lead center for the development and realization of satellites and satellite systems.
- Space Applications Centre (SAC), Ahmadabad, develops the payloads for the ISRO satellites.
- Satish Dhawan Space Centre (SDSC), Sriharikota, provides launch services. Solid propellant production and Solid Propellant Motor test and qualification facilities are also located here.
- ISRO Telemetry, Tracking, and Command Network (ISTRAC), Bengaluru, provides space operation services like telemetry and tracking, spacecraft control for LEO satellites and deep space missions.
- Master Control Facility (MCF), Hassan and Bhopal, addresses the telemetry, tracking, command, and control functions for geostationary satellites.
- National Remote Sensing Centre (NRSC), Hyderabad, is responsible for remote sensing data acquisition and dissemination. NRSC provides the decision support for disaster management.
- Units like the ISRO Inertial Systems Unit (IISU) and the Laboratory of Electro-Optical Systems (LEOS) carry out specialized component and subsystem development required for the launch vehicles and satellites.

Antrix Corporation incorporated as private limited company of the Government of India in September 1992 functions as the commercial arm for promoting and exploiting the business opportunities arising out of the space program. It offers launch services, space products, technical consultancy services, and transfer of ISRO developed technologies to domestic and international customers.

Allotment of funds to cover establishment charges, laboratory infrastructure maintenance and creation of additional infrastructure, launch vehicle and satellite development, and launch and operational services is done by the Government of India based on the recommendations of the Space Commission and the Planning Commission. The development activity planning is done on a 5 yearly basis to match with the country's 5-year plan projections. The year 2012–2013 (the accounting year in India is reckoned from 01 April to 31 March of the subsequent year) is the last year of the 11th 5-year plan. The space activity started in India in 1963, but the creation of DOS happened only in 1972. Formal funding as part of the plan process started from the fifth 5-year plan which was operational from 1974 to 1979. The 5-year plan funding profile for DOS is shown in Fig. 26.1 (Plan Document 2008).

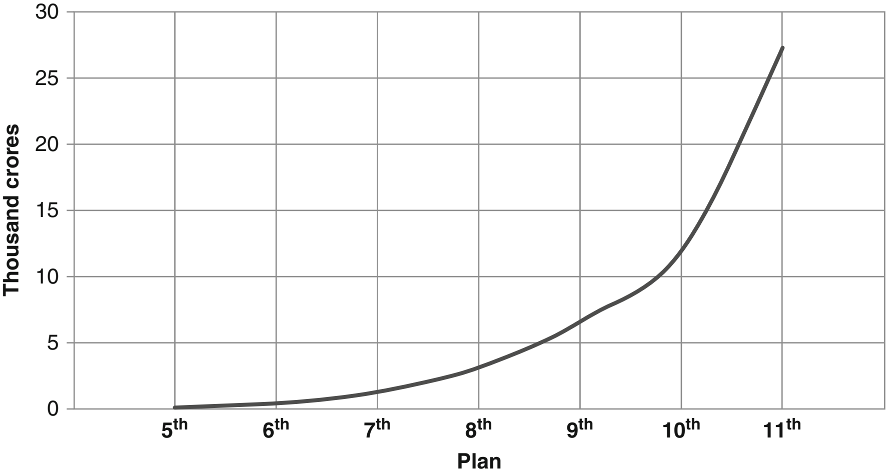

**Fig. 26.1** Planwise funding profile for DOS

The funding for the space activity has grown significantly during the tenth and eleventh plan periods, with the 11th 5-year plan outlay being Rs. 27,305 crores (about $ 5.46 billion). Extrapolation of the trend shows that the 12th plan outlay can be expected to be in the region of $ 7 billion. The cumulative expenditure from the first to the eleventh plan amounts to Rs. 73,506 crores which approximates $ 14.7 billion assuming 50 rupees to the dollar as the exchange rate. U. Shankar has analyzed the annual space expenditure and has found that it was less than 0.5 % of the Central Government expenditure till the year 2000 and averaged 0.54 % during the years 2000–2005. The corresponding number for the percentage in GDP was 0.092 (Sankar 2007). It is difficult to get a measure of the returns on this investment as bulk of the services provided by DOS is used by the government. The usage by the government falls in the category of public goods, private goods, and social goods. The DOS policy of industry outreach has enhanced self-reliance, improved quality consciousness, and generated capability, capacity, and employment creation opportunities (India S&T 2008). A number of spin-offs have also accrued. The value of the Indian space assets was estimated to be around $ 25 billion in 2009. With the planned additional launches and services, the value is expected to increase in the coming years.

## 26.4 Space Security Issues

India is a state party to the United Nations Outer Space Treaty and conducts its space affairs as a responsible member of the spacefaring community. India's position in relation to the United Nations treaties/conventions on peaceful uses of outer space is summarized in Table 26.2.

**Table 26.2** India's position relating to UN Treaties

| | Treaty/convention | Status |
|---|---|---|
| 1 | Treaty on principles governing the activities of states in the exploration and use of outer space, including the moon and other celestial bodies | Ratified |
| 2 | Agreement on the rescue of astronauts, the return of astronauts, and the return of objects launched into outer space | Acceded |
| 3 | Convention on international liability for damage caused by space objects | Acceded |
| 4 | Convention on registration of objects launched into outer space | Acceded |
| 5 | Agreement governing the activities of states on the moon and other celestial bodies | Signed |

India has also ratified related treaty banning nuclear weapons tests in the atmosphere, in outer space, and under water and the convention on the prohibition of military or any other hostile use of environmental modification techniques. India is an active member of the Inter-Agency Debris Coordination Committee and practices the United Nations Debris Mitigation Guidelines. Notwithstanding these positive aspects, India has space security concerns common to other space faring countries. Some of the concerns are listed below:

- **Space Debris**: The quantum of orbiting space debris of various dimensions has been adequately commented upon by several experts. The tracked space objects number is 16457 and 78 % of these relate to debris and only 6.7 % to active satellites. Retired satellites and spent orbital stages account for the remaining (Kelso 2012). The damage potential of the debris has also been adequately documented. These issues concern Indian spacecraft as well and the IRS remote sensing satellites in LEO are the most vulnerable. Routine assessment of collision probability for Indian satellites with objects in space and collision avoidance measures when required are carried out.

**India has taken proactive steps in debris mitigation** (Hegde 2010). **They are as follows**:

- India has developed software for estimating the proximity of space objects to its satellites. Analysis based on the Space Object Proximity Awareness (SOPA) program is carried out on a daily basis using the spacecraft data and the resident space object data obtained from the US Space Surveillance Network (SSN). Collision avoidance maneuver is performed if the collision probability exceeds 1 in 1,000 or the minimum conjunction distance is found to be below 100 m. In 2009, a collision threat required the maneuvering of an Indian spacecraft in LEO for avoidance and later orbital relocation.
- The PSLV top stage is powered by pressure-fed earth storable hypergolic propellants, and the stage is passivated after the satellite is separated from the stage. Passivation is achieved by venting out the pressurant gas and the residual propellant vapors. India currently does not use solid propellant motors for orbit injection purposes and does not contribute to debris resulting from aluminum particle condensates in solid propellants.
- After completion of their mission life, Indian satellites in geostationary orbit (GSO) are boosted to a graveyard orbit to minimize the threat of accidental

**Table 26.3** Colocated satellites

| Longitude | Colocated satellites |
|---|---|
| 55°E | INSAT 3E, GSAT 8 |
| 74°E | INSAT 3C, Kalpana, INSAT 4CR |
| 85°E | INSAT 2E[a], INSAT 4A, GSAT 12 |
| 93.5°E | INSAT 3A, INSAT 4B |

[a] INSAT 2E completed its mission on 13 April 2012 and is not operational

collision and debris creation. Transfer to graveyard orbit is in tune with the International Telecommunication Union (ITU) recommendation and is performed before the exhaustion of the onboard propellant. The perigee of the graveyard orbit is maintained at least 200 km above the geostationary altitude. Such an operation has been performed with INSAT 2E whose mission ended in April 2012.

- Space debris could also affect vehicle launch event. To mitigate this risk, another in-house developed software, the Collision Avoidance Analysis (COLA), is used. The potential collision probability is estimated and the launch time is reset if the worst case collision probability estimate is more than one in $10^6$ in the ascent phase and 1 in $10^5$ till the first apogee after injection. The launch of PSLV C11 was delayed by 1 minute to avoid such a possibility.
- Space object reentry is also a critical event as the reentering body poses a collision threat to other orbiting satellites in its path. Spent vehicle top stages, debris, and satellites in low orbit at the end of their life constitute the reentry bodies. ISRO's Space Object Reentry Analysis program is used to assess such situations. India currently depends largely upon the US SSN for information on space debris and other space objects.

**Limited Orbital Slots**: The orbital slots used by India are 48°E, 55°E, 74°E, 83°E, and 93.5°E. India has, since June 1981, placed 23 satellites in GSO and has had to make do with these limited orbital slots. India has overcome the limitation of available orbital slots by colocating more than one satellite in the same longitude. The colocated satellites are shown in Table 26.3.

At the ground station, the colocated satellites present themselves as a single large satellite with double capacity of each individual satellite. Colocation also eases the workload on the ground station. Colocation of satellites allows for optimum use of available orbital slots and the limited frequency spectrum. However, the necessity of maintaining the colocation within a longitudinal separation band of 0.1° (10 km) entails operational overheads. These overheads are the need for knowing the precise positions of the satellites; the increased frequency of tracking for this purpose; and the necessity of performing control maneuvers for maintaining the separation distance.

- **Frequency-Related Issues**: India follows the prescribed routine for filing frequency requests with the International Telecommunication Union for all its satellites. Indian requests for the frequency bands have been largely accommodated by the ITU.

However, India is concerned by the congestion in the radio spectrum, especially in the GSO orbit where the demands for spectrum resources is significant. Among its own colocated satellites, India has avoided the interference problem by transmitting signals which are polarized and orthogonal to each other. For its IRNSS constellation, India has to make do with one L band allocation and manage with S band allotment for its spectrum needs. India would have preferred more spectrum allocation in L band.

Instances of radio frequency interference experienced by Indian satellites have been rare and have been resolved. The rare instances experienced appear to be accidental rather than deliberate. Conflicts in radio frequency allotments and interference can be expected to increase as these resources are limited and demands are increasing. The problem is aggravated as under article 48 of the ITU constitution, installations for national defense services are exempt from the application of ITU rules and regulations.

India's space plans call for the launch of communication, remote sensing, navigation, and scientific satellites in the coming years. Demands for military-specific missions will also need to be carried out. India will be competing with more than 900 satellites expected to be launched in this decade for orbital slots and frequency requirements.

- **Jamming**, **Spoofing and Eavesdropping**: Instances of jamming of GPS signals have been reported by some satellite operators. Indian spacecraft have not experienced such issues, but the possibility cannot be ruled out. Building in appropriate shielding against such measures in a general sense is not practical and adds to the cost. Such practices can at best be adopted where specific needs are there. For critical applications, India uses encrypted signals. For example, image digital data of specific satellites is encrypted; and the IRNSS signals for special users will obviously be encrypted.
- **Weaponization of Space**: India would like to keep space free of weapons and as a responsible nation utilize space/space applications in a long-term sustainable fashion. This said India cannot remain passive if there are attempts by other countries to weaponize space and needs to plan appropriate safeguards, verification, and deterrent measures. Non-state actor groups active in the region also pose security threats especially to the ground segment assets.

Selective hardening against nondestructive type of attacks and providing redundancy in select segments in both space and ground are partial solutions to hostile actions. Another possibility is to have satellites with distributed functions and have launch-on-demand capability. This is difficult to achieve from resource and cost considerations.

## 26.5 Militarization of Space

Space applications are inherently dual use in nature and consequently, there is significant overlap in the utilization of space output for civilian and military needs. India is no exception to this dual nature aspect, and the output of the civilian communication, remote sensing, and weather satellites of ISRO is used by the defense and security agencies in the country. It must be remembered that the primary function of ISRO satellites is tuned for social and development tasks and not for surveillance and intelligence gathering. Consequently, the output of the ISRO satellites fall short of the defense needs. Dedicated satellites with additional features may be needed to meet the requirements of the defense services. Some of these features are easily adaptable or modifiable from the technologies required for the civilian program, while other features may be specific for military requirements.

A listing of the satellite applications – both civilian and military – and comments indicating the special features required for military purposes are listed in Table 26.4.

It is essential to note that the listing in the table is indicative and may not be complete; more importantly, it is not meant to communicate that India is working on all the technologies or has drawn plans towards them. It must be noted that there will be increasing demands by the defense and security forces for space services for military applications and for military use. There is a growing realization that the military requirements of space utilization for security purposes cannot be kept isolated from the civilian needs. Noting the importance of these requirements, the question arises of how to address them within the framework of the civilian nature of India's space program. Recognizing this need and the threats to Indian space assets, the Indian Defense Minister, A.K. Anthony, while inaugurating the Unified Commanders' Conference on 10 June 2008, announced the formation of an Integrated Space Cell under the aegis of the Integrated Defense Services Head Quarters to counter "the growing threat to our space assets." He added, "although we want to utilize space for peaceful purposes and remain committed to our policy of non-weaponization of space, 'offensive counter space systems like anti-satellite weaponry, new classes of heavy-lift and small boosters and an improved array of Military Space Systems have emerged in our neighborhood." Shri Antony said "the new Cell will act as a single window for integration among the Armed Forces, the Department of Space and the Indian Space Research Organization (ISRO)" (MoD 2008).

The Indian navy will be the first among the three services to have a dedicated communication satellite to network its off-shore and on-shore assets. The requirements of the Air Force and the Army also will be addressed by the Integrated Space Cell. In time to come, the use of space assets for reconnaissance, communication, navigation, weather monitoring, and intelligence gathering is bound to increase. The defense services will be keen on building space-based C4ISR capabilities.

## 26.6 Ensuring India's Space Security

The Indian assets in space – the current and the forthcoming for civilian and military needs – are substantial and will continue to grow. The safety and

**Table 26.4** Dual use applications

| Satellite application | Civilian | Military | Specific feature for military use |
|---|---|---|---|
| Communication | Dual use | | Anti-jamming, encryption, and frequency hopping |
| Remote sensing/ reconnaissance | Dual use | | Infrared thermal imaging, hyper-spectral imaging, radar imaging, cartography, encryption of select downlinks |
| Navigation | Dual use | | Separate band will be required for military purposes and the signals have to be encrypted. The navigation system has applications for precise position fixing, rescue, and precision targeting |
| Weather | Dual use | | Operational and mission planning needs of the armed forces |
| Monitoring missile launch | Not applicable | Early warning | INSAT/GSAT capability enhancement required with mosaic sensor, IR sensing |
| Electronic intelligence (ELINT) | Not applicable | Required | Satellite and payload to be designed. Broad band reception capability is a requirement. A set of colocated three satellites may be required along with a complement of optical and radar imaging satellites will be needed |
| Microsatellites | Dual use | | Formation flight, distributed tasks, miniaturization, launch on demand |
| Rockets | Satellite launch vehicles | Missile interceptors, satellite launch | Launch from different platforms; diverse storage and service environment; altitude and homing requirement; ECM; reentry thermal management; low CEP, MIRV, and MaRV adaptations; road/rail mobility |
| Reusable launch vehicles | Dual use | | Hypersonic cruise missiles. Number of technologies to be developed. This is a long-term perspective |
| Space platforms | Dual use | | Rendezvous, docking, robotic flights, and human habitation |

vulnerability of the Indian space assets is a matter of serious debate in the country spurred to quite some extent by the Chinese and American anti-satellite kinetic kill tests of January 2007 and February 2008, respectively. India is opposed to weaponization of space. This is the official policy reiterated by Minister of State for Parliamentary Affairs, Personnel, Public Grievances, and Pensions in Prime Minister's Office in the Lok Sabha. Responding to a query of 23 February 2011, the Minister replied: "India strongly opposes any attempt to place weapons in space or conducting any unconventional weapons tests in space as it would pose a perennial threat to all space systems regardless of their use for civilian or military purposes." While adhering to the principle of non-weaponization of space, India still needs to address the safety of current and future space assets from any potential hostile action, address any space access denial attempts, and address its commitment to using space for its legitimate development and security requirements (Kasturirangan 2008).

The means of safeguarding one's space assets therefore demands on the one hand the capability to track and monitor threatening situations and on the other hand have the means to deter and prevent any hostile action. In the extreme, if deterrence and prevention do not work, then one should have the means also to retaliate. Even if all countries follow internationally accepted norms and guidelines, one must have the capability to verify the capability to deter.

The collision with debris risk for Indian satellites has already been highlighted. India depends upon the US SSN which is providing yeoman service in tracking space objects and providing their orbital track two-line element data. Even for limited SSA capability, India will have to make heavy investment in ground-based optical and radar sensors complemented by a few space-based sensors. To keep expenses at manageable levels and as this is a problem affecting other spacefaring nations, international cooperation is also most desirable. India has a long record of international cooperation and collaboration and it sees a win-win situation in this regard.

India is extremely conscious of the space debris issue and, as a responsible spacefaring country, its response to threatening situations in space will be calibrated. India has adopted, for deterrence purposes, the next best thing to an actual ASAT test. Alternate to an ASAT test, India has adopted a strategy for developing the building blocks required to ensure space security. This means necessary technologies will be developed, but they will be used only if Indian assets are attacked or disabled. India has already carried out ballistic missile interception tests and today has the capacity to intercept satellites. This was stated by the Scientific Adviser to the Defense Minister after the successful launch to the Agni 5 ballistic missile. It was claimed that a full-fledged ASAT system based on Agni 5 could be ready by 2014, but will not be actually tested for such application (Unnithan 2012).

## 26.7 India's Space Policy

India's space policy is still evolving. Policy-related legislation and rules governing space functions and services are in place (Nagappa 2011). The Indian space program is guided by the government-formulated allocation of business rules for Department of Space along with the following policy guidelines:

- Policy framework for satellite communication in India approved by the government in 1997
- Norms, guidelines, and procedures for implementation of the policy framework for satellite communications in India approved by the government in 2000 (The INSAT Coordination Committee with membership drawn from the user departments coordinates the need, distribution, leasing, and utilization of communication satellite capacity).

- Remote sensing data policy approved by the government in 2011. The data policy prescribes distribution of all data up to 1 m resolution on a nondiscriminatory basis. However, data with resolution better than 1 m requires, from national security considerations, screening and clearing by an appropriate agency.

As can be seen the rules and guidelines are user driven, and there is control only regarding the distribution of imagery of better than 1 m resolution. Changes in the space policy framework will be necessary to address the security needs in a setup which hitherto has been essentially looking at civilian developmental applications. A study on Space Security carried out by a working group of the New Delhi-based Institute for Defense Studies and Analyses (IDSA) recognized that besides ISRO and the defense services, other bodies like the Defense Research and Development Organization, the Ministries of External Affairs and Home, and the Indian industry are stakeholders and their roles and requirements need to be integrated in the policy framework (Gupta et al. 2012).

It also needs to be emphasized that the Indian industry – both the public sector and the private sector – is an active participant in space matters. Industry role has played a prominent role in manufacturing of specialty components and subsystems, testing, and services. Industry has also played an active role in the downstream application services such as TV broadcast, DTH services, and the like. The industry has the potential to contribute more and take up system integration activity. The Department of Space foresees much larger industry participation in the 12th plan period (i.e., 2012–2017).

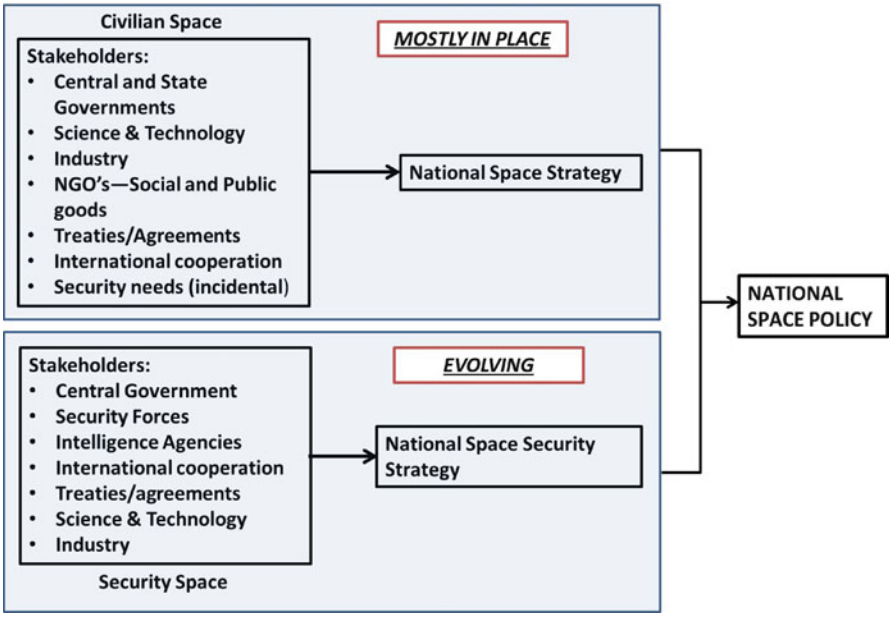

**Fig. 26.2** National strategic plan

Consequently, the National Strategic Plan, building up on the strong foundation of civilian space to address the security needs, is needed. The civilian components for drawing up a space policy are mostly in place. The security component is evolving and appropriate interplay between the two has to be defined. An outline for an integrated approach requirement is suggested in Fig. 26.2.

To advance the evolution of such an approach, the Government of India has constituted in 2010 the Space Security Coordination Group (SSCG). The SSCG, according to a news report appearing in India Today of 28 April 2012, is chaired by the National Security Adviser and has members drawn from the Air Force, Defense R&D Organization, and National Technical Research Organization.

The European Union brought out its revised voluntary code of conduct for outer space activities in June 2012 and is discussing the draft code with other spacefaring countries. The United States has indicated that it will work with other nations to develop an international code of conduct for outer space. While India, as a responsible spacefaring nation, has been practicing the guidelines presented in the "Rules of the Road," appropriate government bodies will coordinate India's formal response and approach to the international code of conduct for space.

## 26.8 Conclusions

India is one of the few countries with a civilian space program which is not an offshoot of the missile program. The space program is therefore developed with application satellites targeting societal and developmental missions. The development has progressed to larger systems in satellites and launch vehicles with India offering commercial launches and also marketing its remote sensing imageries worldwide. The missile program started separately a few years later, but has achieved significant milestones. The geopolitical happenings have spurred the thinking towards space security and related issues. While adhering to the principles of responsible space behavior, the country has started addressing the security issues.

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# Brazilian Perspective on Space Security

# 27

Jose Monserrat Filho

## Contents

**Abstract**

This chapter aims at highlighting and commenting on the views and positions assumed, directly or indirectly, by the Brazilian government authorities and representatives, as well as by Brazilian and foreign researchers, concerning the most relevant contemporary questions related to outer space security, the sustainability and stability of space activities, and the peaceful use of outer space. The following crucial issues are discussed: the definition of outer space security, the outer space weaponization, the Code of Conduct for space activities proposed by the European Union, the right of self-defense in outer space, and transparency and confidence-building measures (TCBMs) in space activities.

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DOI 10.1007/978-1-4614-2029-3_20,

> *Peace and development will have to be increasingly global – or simply will not happen.*
>
> Celso Amorim (2011)
> former Brazilian Minister of External
> Relations and today
> Minister of Defense

> *A paz e o desenvolvimento cada vez mais terão de ser globais – ou simplesmente não serão.*
>
> Amorim C (2011)
> Conversas com jovens diplomatas (Conversations
> with young diplomats). Benvirá, São Paulo, p 275
> (in Portuguese)

## 27.1 Introduction

Brazil is a deeply peaceful country. Suffice to say that it has lived in peace with its neighbors for nearly a century and a half. These healthy historical roots have created a solid foundation. It is not a coincidence that today Brazil is part of all global disarmament treaties, such as the Treaty on the Non-Proliferation of Nuclear Weapons (NPT 1968) (www.un.org/en/conf/npt/2005/npttreaty.html). It also plays a role of regional stabilizer of peace and pacification, either as part of regional treaties such as the Treaty of Tlatelolco (1967) (www.opanal.org/opanal/tlatelolco/tlatelolco-i.htm), which banned the nuclear weapons in Latin America and the Caribbean, or as part of informal groups, such as London Group of nuclear suppliers (More 2006, p. 21).

The Brazilian Constitution (www.v-brazil.com/government/laws/constitution.html), promulgated on October 5, 1988, states that Brazil will be governed in its international relations, inter alia, by the defense of peace, peaceful settlement of conflicts, and cooperation among peoples for the progress of humanity. In this context, it is completely natural that the Brazilian Space Program has always been peaceful (National Paper of Brazil 1999). It is not surprising that the country's space activities always have been, and are, seen, in fundamental aspects, as similar to the nuclear activities. In accordance with the Article 21, § XXIII, a) of the Constitution, "all nuclear activities within the national territory shall only be admitted for peaceful purposes and subject to approval by the National Congress." In other words, through a constitutional provision, Brazil renounced the use of nuclear energy for non-peaceful purposes. The same spirit conducts the space activities in the country.

Established on February 10, 1994, as a civilian entity, the Brazilian Space Agency (Law No. 8,854 of 10 Feb 1994, Brazilian Federal Register) (AEB, in its Portuguese acronym) replaced and assumed the functions of the Brazilian Commission for Space Activities (COBAE, in its Portuguese acronym) founded in 1971 and chaired by the armed forces chief of staff. In August 1995, the then-President Fernando Henrique Cardoso announced: "Brazil no longer possesses, nor does it produce or intend to produce, to import or to export long-range military missiles capable of carrying weapons of mass destruction (Cardoso 1995)". On October 5, 1995, the Brazilian Senate enacted President Fernando Henrique Cardoso's Export Control Law, No. 9112, which penalizes Brazilian entities that breach export controls on the transfer of dual-use materials, including missile-related goods and services, as well as sophisticated weapons and items intended purely for military use (Jornal do Brasil). Six days later, on October 11, Brazil's membership in the Missile Technology Control Regime (MTCR) was approved unanimously at the regime's 10th plenary meeting in Bonn, Germany (Brazil Relishes Freedom as MCTR Member).

It is worth noting that as a consequence of the approval of the Export Control Law, many thought that it would enable Brazil to acquire sensitive space technology from abroad. That did not prove to be so. The space powers did not open their markets with parts, components, and equipment to Brazil as expected. Moreover, in 1998, the Italian government was diplomatically pressed by the US government not to permit the participation of the company FiatAvia in the Brazilian-Ukrainian joint venture to promote the commercial flights of the Ukrainian rocket Cyclone-4 from the Brazilian Alcantara Launching Center. Brazil and Ukraine were forced to take on the business alone without a strong investor partner. Oddly, Brazil seemed to be marked as a country not reliable to deal with rockets. It is amazing that this distorted view still persists in some countries.

The reality, however, is quite different, as it is clearly demonstrated by the Brazilian National Program of Space Activities (Programa Nacional de Atividades Espaciais 2005) (PNAE, in its acronym in Portuguese) in its third revised version dedicated to the period of 2005–2014. The PNAE program resulted from a wide open debate, which culminated in the Review Seminar of the Brazilian Space Program, held in December 2004 at the National Congress. The seminar saw participation of representatives from the governmental, scientific, and academic communities, as well as various businesses. As strategic rationale, "the PNAE aims to enable the country to develop and use space technology in solving national problems and for the benefit of the Brazilian society, contributing to improve the quality of life, through the generation of wealth and job opportunities, improvement of scientific activities, expanding awareness of the national territory and better perception of environmental conditions." The purposes are purely peaceful and constructive.

In his foreword to this historic document, the then-Minister of Science and Technology, Eduardo Campos, stresses: "The PNAE is strategic for the sovereign development of Brazil. The importance of capacity building in the domain of space technology, which, in a broader sense, includes launch centers, launch vehicles, satellites and payloads, arises from its relevance for the nation's future. No strategic technologies will be made available by third parties. These must be developed with domestic resources, in a widespread and integrated manner, in order to address the challenges posed by the era of satellite telecommunications and imaging. Only those countries that master space technology will have the autonomy to develop global evolution scenarios, which consider both the impact of human action, as well as of natural phenomena. These countries will be able to state their positions and hold their ground at diplomatic negotiating tables."

Seeking to achieve technical advantages of real benefit to the country and, in parallel, responding effectively to the needs of society, four areas of space applications were selected: Earth observation, science and technology missions, telecommunications, and meteorology.

This decision was confirmed by the fourth version of PNAE[1], launched in 2012. This version refers to the period of 2012–2021. The review of the PNAE, expected to take place only in 2014, has been anticipated in view of the new opportunities created by the federal government, as the program for the development of critical technologies, the initiatives of technology's absorption, as well as of transfer of technologies in the context of development of the Geostationary Defense and Strategic Communications Satellite (SGDC), new allocations of the Sectorial Funds, the National Strategy of Defense (END), the initiatives of the Sectorial Technological Agenda (ATS) in connection with the Greater Brazil Plan, and the special support of the "Science Without Frontiers" Program to the Brazilian Space Capacity Building Initiative of the Brazilian Space Agency, among other governmental actions.

The new PNAE seeks the path of concrete and productive achievements, based on the strength and creativity of industrial companies, mobilized by public policies, and supported by expertise in universities and research centers.

"Right now, in this new phase for the space area, the sector's national industry is called upon to play a key role, and the structuring and mobilizing projects defined by the Program will be the technology and research drives capable of organizing a national supply chain and expanding the market for space goods and services," as stresses the current Minister of Science, Technology, and Innovation, Marco Antonio Raupp, in the presentation of the new PNAE.

In turn, the President of the Brazilian Space Agency, Jose Raimundo Braga Coelho, in his introduction, points out: "The truth is that, in terms of space, we need to take leap. A qualitative leap. A transforming leap. And with all possible haste." And adds: "We are engaged in the battle of innovation, seeking to create and consolidate a culture that was generally absent throughout our history and our economy. What we still lack is a thriving, proactive, bold, groundbreaking space industry. (. . .) We also need, in particular, big companies capable of leading large-scale projects and designing huge achievements – that is, global-scale business, for the benefit of the country, the population, the national economy and our partners."

"Why master critical technologies?," the new PNAE formulates this question and gives a clear answer: "Because we need to overcome the barriers put up by certain countries to prevent us from having access to knowledge and commercialization of important space technologies. Such restrictions paralyze the development of our launch vehicles and satellites – projects always developed for peaceful purposes."

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[1] See the integral text in English of the new Brazilian National Program of Space Activities (PNAE 2012–2021) in the site www.abe.gov.br, with the presentation of the Minister of Science, Technology and Innovation, Marco Antonio Raupp, and the introduction of the President of the Brazilian Space Agency, José Raimundo Braga Coelho.

## 27.2 Defense and Peaceful Space

It should be emphasized that, according to the dominant view in Brazil, the program "National Strategy of Defense – Peace and Security for Brazil (www.defesa.gov.br)", approved in by the Decree no. 6703, of December 18, 2008, is consistent with a peaceful international conduct in general and with the principle of the use of space for peaceful purposes, in particular.

This document starts affirming that "Brazil is a peaceful country, by tradition and conviction. It lives in peace with its neighbors. It runs its international affairs, among other things, adopting the constitutional principles of non-intervention, defense of peace and peaceful resolution of conflicts. This pacifist trait is part of the national identity, and a value that should be preserved by the Brazilian people. Brazil – a developing country – shall rise to the first stage in the world neither promoting hegemony nor domination. The Brazilian people are not willing to exert their power on other nations. They want Brazil to grow without reigning upon others."

The document, at the same sense, presents a significant relationship between the National Strategy of Defense and National Strategy of Development, considering that the development is the driving force of the defense and not the contrary. It is worth to know the arguments used in clarifying and supporting such position:

1. The national strategy of defense is inseparable from the national strategy of development. The latter drives the former. The former provides shielding to the latter. Each one reinforces the other's reasons. In both cases, "nationality" emerges and the nation is built. Capable of defending itself, Brazil will be in a position to say no when it has to say no. It will be able to build its own development model.
2. It is difficult – and necessary – for a country that has dealt very little with war to convince itself about the need to defend in order to build itself. Although they are fruitful and even indispensable, the arguments invoking the usefulness of both technology and defense knowledge for the development of a country are not enough.

   The resources demanded by defense require the transformation of consciences so that it becomes a defense strategy for Brazil.
3. It is difficult – and necessary – for the Armed Forces of such a peaceful country like Brazil to keep, amidst peace, the encouragement to be ready for combat and to develop the habit of transformation in favor of this state of readiness. Will to change; this is what the nation currently requires from its sailors, soldiers and pilots. It is not only a matter of funding and equipping the Armed Forces. It has to do with having the Armed Forces transformed to better defend Brazil.
4. A strong defense project favors a strong development project. A strong development project is guided by the following principles, whatever its remaining guidelines are:
   (a) National independence achieved by the mobilization of physical, economic and human resources to invest in the country's production potential. Taking advantage of foreign savings without depending on them;

(b) National independence achieved by an autonomous technological capacity building, including the spatial, cybernetic and nuclear strategic sectors. Whoever does not master critical technologies is neither independent for defense nor for development; and
(c) National independence ensured by the democratization of educational and economic opportunities, and by the opportunities to extend public participation in the decision-making processes of the political and economic life of a country. Brazil will not be independent until part of the population lacks the appropriate conditions to learn, work and produce.

Therefore, as it can be deduced, Brazil believes that dominating military space technology is no longer a necessary condition for a nation to reach reasonable weight in the global scenario where political discussions on space issues take place. This view seems to be in line with the more general observed trend of resorting to peaceful approaches to solve problems in the area, even major challenges such as ensuring the outer space security for all countries and the long-term sustainability of space activities. There are, inter alia, good economic reasons for that.

The fact is that space activities expand and intensify increasingly through international cooperation, both to facilitate projects and missions of high costs and to join efforts on the need to tackle global problems that threaten all nations. In this context, solutions to issues arising from the use of space also tend increasingly to be addressed more comprehensively by agreements and commitments naturally peaceful among nations. This extremely sound and timely trend surely deserves more effective support than it has, until now, received from some great powers.

## 27.3 Brazil's First International Dialogue on Space Security

Over the last decades, Brazil has seen a great increase in the number of research centers on international issues, graduate and undergraduate courses on international relations, as well as scientific publications and books on different global topics in politics, economics, law, society, and culture (More 2006, p. 21). However, there is a notorious lack of studies on space strategic questions, such as military uses of outer space, the placement of weapons in Earth orbits, the increasing quantity of space debris, outer space security, and sustainability of space activities. Even at official levels the existence of documents prepared entirely on such matters is unknown. Many Brazilian diplomats and specialists, however, agree that this situation needs to, and should, be changed without delay.

An important impulse in this direction was given by the first dialogue between Brazil and the United States on the issue of outer space security, held on April 5, 2012, in Brasilia. It was the first meeting in which Brazil officially interchanged information and views on this issue with another country. The Brazilian-American dialogue was decided on March 19, 2011, during the historic meeting in Brazil between the presidents of both countries, Dilma Rousseff and Barack Obama (www.itamaraty.gov.br/sala-de-imprensa/notas-a-imprensa/comunicado-conjunto-da-presidenta-dilma-rousseff-e-do-presidente-barack-obama-brasilia-19-de-marco-de-2011) During this occasion, the two countries agreed that the dialogue was very frank and positive, as both sides had an opportunity to interchange views, as well as to understand each other's positions, despite the difference of opinions. At that time, it was decided that the dialogue would continue in future meetings. Of course, Brazil has reaffirmed its commitment to the peaceful use of outer space and its willingness to maintain dialogue on how to effectively increase the security and the sustainability of space activities of all countries.

In this regard, it is pertinent to recall the speech by the Brazilian President, Dilma Rousseff, at the opening of the 66th session of the UN General Assembly, on September 21, 2011 (http://gadebate.un.org/sites/default/files/gastatements/66/BR_en_0.pdf). As the first woman in the world chairing an UNGA session, she affirmed: "We have insisted that development, peace, and security are interrelated and that the Security Council's strategies for achieving sustainable peace must be partnered with development policies." She also pointed out that "we have lived in peace with our neighbors for over 140 years" and that "Brazil is a force for peace, stability and prosperity in its own region and even beyond it." She further stated that "the quest for peace and security in the world cannot be limited to interventions in extreme situations. We support the Secretary-General in his efforts to engage the United Nations in conflict prevention through the tireless practice of diplomacy and the promotion of development." Moreover, "much is said about the responsibility *to* protect; yet we hear little about responsibility *in* protecting. These are concepts that we must develop together. For that, the role of the Security Council is vital – and the more legitimate its decisions are, the better it will be able to play its role."

These presidential ideas provide a consistent general view about the Brazilian approach to major questions of global security, including outer space security. In this strategic context, Brazil assumes a strong autonomous position. The former Brazilian Minister of Foreign Affairs, Celso Amorim, pointed out in clear and well-chosen words: "What we cannot do is to abdicate our capacity to judge for ourselves, nor delegate our decisions to the more powerful States, for fear of a supposed isolation (Amorim 2011, p. 275)."

## 27.4 Brazil and the United Nations

Brazil has been supporting the United Nations since its creation, mainly because it was founded upon the concepts of multilateralism, sovereign equality of all its member states, collective security, settlement of international disputes exclusively by peaceful means, refraining from the threat or use of force against the territorial integrity or political independence of any state, and international cooperation to solve international problems of economic, social, cultural, or humanitarian character. Brazilian authorities are aware that, although the threats to peace and security are different today, the United Nations continues to be central to handle this task. As Thomas J. Schoenbaum underlined, "only the

United Nations has the universal membership, the agreed system of rules, the collective security institutions, and the wide ranging mandate – including both traditional threats to peace and humanitarian concerns of social, economic, and environmental problems – that are an integral part of peace and security in the twenty-first century (Schoenbaum 2006, p. 104)."

Brazil also firmly supports the concept of the "rule of law" and sees it as "the very heart of the mission of the United Nations." It requires "measures to ensure adherence to the principles of supremacy of law, equality before the law, accountability to the law, fairness in the application of the law, separation of powers, participation in decision-making, legal certainty, avoidance of arbitrariness and procedural and legal transparency (United Nations, Security Council, S/2004/616)." International law plays today an amplified role "in structuring relations among participants in international life, thereby diminishing the influence of unequal power, wealth and capabilities." It also tends to provide for "far greater reliance on third-party procedures for dispute settlement and conflict resolution. The spread of international tribunals in such specialized areas as trade, oceans, and human rights is already suggestive as a trend in this direction that partly reflects growing normativity (Falk 2004, pp. 33–34)."

In this sense, it is worth noting that on December 6, 2011, the Administrative Council of the Permanent Court of Arbitration (PCA) adopted the "PCA Optional Rules for the Arbitration of Disputes Relating to Outer Space Activities (www.pca-cpa.org/showpage.asp?pag_id=1188)." Brazil actively participated in this opportune initiative. The author of this article had the privilege and the honor to be member of the special commission that elaborated these new rules, which was approved unanimously by the member states of the International Court of Arbitration, including Brazil. This court was established by the Convention for the Pacific Settlement of International Disputes, concluded during the first Hague Peace Conference in 1899. It is worth to note that this conference was convened "with the purpose of seeking the most objective means of ensuring to all peoples the benefits of a real and lasting peace, and above all, of limiting the progressive development of existing armaments." Today, as an intergovernmental organization with over 100 member states, it is a modern and multifaceted institution that works at the interface of public and private international law to provide services for the resolution of disputes involving various combinations of states, state entities, intergovernmental organizations, and private parties.

In the view of Brazil, the rule of law is absolutely imperative in all areas of life, including in space activities, as a matter of security for all countries. Space security and the long-term sustainability of space activities, and the ways and means to keep outer space activities exclusively peaceful, as well as mitigation of space debris are among the most important legal issues to be discussed by Space Law, affirmed the Brazilian Ambassador in Austria, Julio Cezar Zelner Gonçalves, when speaking at the 51st session of the Legal Subcommittee of the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS), on March 20, 2012. He also stressed: "Brazil is extremely concerned with the possibility of an arms race in outer space. My delegation welcomes all measures of transparency and confidence-building as important first steps to avoid future hostilities in outer space. Compliance with, and improvement of, the existing Space Law are the only means to ensure peace, transparency and predictability in outer space activities. Brazil considers it of the utmost importance that the outer space be maintained exclusively for peaceful activities."

Brazil has traditionally supported the main multilateral institutions which deal with global outer space issues, the UNCOPUOS and the Conference on Disarmament, considering both as the most legitimate and representative entities to examine the space needs and demands of the international community.

Brazil is among those countries advocating the need for negotiation of a binding instrument to ensure that outer space remains free of any kind of weapons and from the threat of the use of force, without prejudice to the right of countries to develop legitimate, peaceful space programs. It is, therefore, without reason that, in 2008, Brazil supported the Russian-Chinese proposal of the Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects (so-called PPWT), officially presented to the Conference on Disarmament (CD), on February 12, 2008. The project aligns with the aspiration and the practical efforts of most countries of the United Nations to prevent an arms race in outer space (PAROS)[2]. In Brazilian view, the negotiations concerning this agreement could send an important political signal in support of the multilateral systems related to outer space. Even though they do not exist yet as strong and effective mechanisms, such systems become increasingly necessary as the world witnesses the emergence of new types of high-tech destabilizing weapons and new areas of confrontation, mainly in outer space.

## 27.5 The Importance of Defining Space Security

The phrase "tell me how you define the space security and I will tell what is your approach to this crucial issue" expresses that it is very important to analyze and evaluate the existing settings on space security. Having this in mind, some of such definitions that are already publicly known are discussed below.

James Clay Moltz remarks that "in general, we can define "space security" as the ability to place and operate assets outside the Earth's atmosphere without external interference, damage, or destruction." He also underlines: "Unfortunately, challenges to space security are increasing today, particularly as space becomes more crowded. Arguably, at least three policy alternatives exist: (1) space actors can assume the worst and prepare for eventual warfare; (2) they can hedge their bets with weapons research and begin efforts at better coordination and conflict avoidance; or (3) they can reject military options altogether and heighten their

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[2] Letter dated 12 Feb 2008 from the Permanent Representative of the Russian Federation and the Permanent Representative of China to the Conference on Disarmament addressed to the Secretary-General of the Conference transmitting the Russian and Chinese texts of the draft "Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Force Against Outer Space Objects (PPWT)" introduced by the Russian Federation and China (CD/1839, 29 Feb 2008).

efforts to build new cooperative mechanisms for developing space jointly (Moltz 2011, p. 11).”

The panel on “Defining Space Security for the 21st Century” was one of the most important events of the conference on “Space Security through the Transatlantic Partnership,” promoted by European Space Policy Institute (ESPI) and the Prague Security Studies Institute (PSSI) in Prague, Czech Republic, on June 13, 2011 (www.state.gov/t/avc/rls/165995.htm). Speaking at the panel, Frank A. Rose, the US Deputy Assistant Secretary of State, from the Bureau of Arms Control, Verification and Compliance, stressed: “. . .space is becoming increasingly contested – meaning, space systems and their supporting infrastructure confront a range of natural and man-made threats that could potentially deny, degrade, deceive, disrupt, or destroy them. As more nations and non-state actors develop counter-space capabilities over the next decade, threats to the U.S. and other nations’ space systems will increase. The interconnected nature of space capabilities and the world’s growing dependence on them mean that irresponsible acts in space have damaging consequences not only for the United States but also for all nations.”

Mr. Rose also affirmed that “based on the U.S. National Space Policy (National Space Policy of the United States of America) and other Presidential guidance, as well as our obligations under the 1967 Outer Space Treaty and other international law, we associate ‘security’ as it relates to space with the pursuit of those activities that ensure the sustainability, stability, and free access to, and use of, outer space in support of a nation’s vital interests.” According to him, “this is reinforced by several other related principles in the new U.S. National Space policy: (1) It is in the shared interest of all nations to help prevent mishaps, misperceptions, and mistrust; (2) All nations have the right to explore and use space for peaceful purposes, and for the benefit of all humanity, in accordance with international law. Consistent with this principle, “peaceful purposes” allows for space to be used for national and homeland security activities; and (3) The United States considers the space systems of all nations to have the rights of passage through, and conduct of operations in space without interference. Purposeful interference with space systems, including supporting infrastructure, will be considered, in the U.S. view, an infringement of a nation’s rights.”

The above referenced definition of space security, suggested by Moltz, as “the ability to place and operate assets outside the Earth’s atmosphere without external interference, damage, or destruction” emphasizes the capacity of each State in particular to create the necessary conditions for space security. In that case, space security would not be a commitment and a collective work of the community of States, even though outer space is considered as the “province of all mankind,” according to Article I of the Outer Space Treaty (OST) (www.unoosa.org/oosa/SpaceLaw/outerspt.html). This kind of definition underestimates the necessity of a strong alliance among all interested states to ensure security in outer space. Besides, it does not provide adequate and effective answers to the global demands of our globalized age. Moltz admits as policy alternatives that space actors “can assume the worst and prepare for eventual warfare” and “can hedge their bets with weapons research,” when the best alternative for all countries obviously is his third alternative – the space actors “can reject military options altogether and heighten their efforts to build new cooperative mechanisms for developing space jointly.” This certainly would be the Brazilian choice.

As to the Frank Rose’s observation that “irresponsible acts in outer space have damaging consequences not only for the United States but also for all nations,” hardly any country would disagree with that. As a matter of fact, it could be more appropriate to say that “irresponsible acts in outer space have damaging consequences for all nations, including the Unites States,” since according to the letter and the spirit of UN Charter, it is absolutely reasonable to consider that no State may take precedence over all others, especially on security issues. The right to national security is legally equal for all states.[3] Another relevant requirement is to define the term “irresponsible act in outer space,” aiming at preventing unilateral and arbitrary actions carried out on the basis of a subjective definition not recognized by the international community.

Frank Rose, however, also associates space security with “the pursuit of those activities that ensure the sustainability, stability, and free access to, and use of, outer space in support of a nation’s vital interests.” Here again we have a definition of space security as a set of actions carried out by one nation in support of its own interests. This means a definition that takes an individual nation’s perspective seemingly neglecting the fact that outer space is a commonplace for all nations, which have equally legitimate vital interests in having free access to outer space and in benefiting from its use, as well as in carrying out sustainable and stable space activities.

In another part of his speech, Frank Rose rightly points out that “it is in the shared interest of all nations to help prevent mishaps, misperceptions, and mistrust” in space activities. However, he adds that “purposeful interference with space systems, including supporting infrastructure, will be considered, in the U.S. view, an infringement of a nation’s rights.” Of course, any country has the right to denounce and condemn all purposeful interference with space systems of any other countries. However, it seems quite clear that no State has the right to unilaterally judge and punish the accused country.

It should be noted that this purposeful interference in this case may be a very serious crime not only against the space systems of one country but also and more importantly against the normal space activities of all countries. It may as well be against the legitimate interests of the entire international community in ensuring the sustainable and stable development of space activities, which became essential to

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[3] Charter of United Nations, Article 2: “The Organization and its Members, in pursuit of the Purposes stated in Article 1, shall act in accordance with the following Principles. 1. The Organization is based on the principle of the sovereign equality of all its Members....” Harold Brown, former US Secretary of Defense (1977–1981), defines national security for all States as “the ability to preserve the nation’s physical integrity and territory; to maintain its economic relations with the rest of the world on reasonable terms; to preserve its nature, institution, and governance from disruption from outside; and to control its borders.” See his 1983 work “Thinking about national security: defense and foreign policy in a dangerous world,” as quoted in Watson, Cynthia Ann (2008), *U.S. national security*: *a reference handbook*; Contemporary world issues; ABC-CLIO, p. 281. ISBN 978-1-59884-041-4.

support all forms of life on our planet. It is a true case of collective security. The experience shows that the safest remedy here is the mechanism of collective security established in the UN Charter. As Lynn H. Miller argues, “the first normative generalization relevant to strengthening global security in our time is that only community authorization should justify the threat or use of force, which means that force ideally should be wielded in the interest of the whole community (Miller 1994, p. 232).”

In Ben Baseley-Walker’s view, “it is imperative that all space actors are engaged and invested in space security initiatives. This is a fundamental requirement necessary in the building of fair, responsible and sustainable methodology to continue to allow humanity to maximize their long-term use of the tremendous benefits that space has to offer (Baseley-Walker 2010).” In sum, it is rather more advisable, useful, and forward-looking to define space security not according to the interest of only one or some individual countries but according to the interests of all countries, of all the international community, and of all humankind. In the century of the greatest challenges to the survival of human species and our common planet, this seems to be the most effective, fair, and responsible approach to space security. This surely is the dominant thinking on this subject in Brazil.

## 27.6 Outer Space Weaponization

It cannot be repeated enough times that the outer space weaponization and the outer space battles can trigger unpredictable consequences for the entire international community, not less serious than a nuclear conflict. This is known since the 1950s. Since the beginning of the Space Age, the international community has defended within the framework of the United Nations that the exploration and use of outer space be oriented exclusively towards peaceful purposes in the interest and for the benefits of all mankind. The Soviet Union and the United States, which spearheaded the space activities, supported this view in the period between 1957 and 1965 (Wolter 2005, p. 9). In those years, the heavy weight of world opinion – terrified by the danger of a third world war even more destructive than the previous ones – led the major powers to introduce the principle of peaceful use as essential part of the proposals destined to develop a space legal order in accordance with the UN Charter and capable to limit the military use of outer space (Monserrat Filho 2007, p. 23).

It is timely to note that the first space activities were carried out during the International Geophysical Year of 1957–1958, organized by the International Council of Scientific Unions and dedicated to the peaceful international exploration and use of outer space (Annals of the International Geophysical Year, 1957–1958). This brings us to Eilene Galloway (1906–2009) (www.nasa.gov/topics/history/features/galloway_obit.html), a great American expert on Space Law, a founder of the International Institute of Space Law. Galloway helped write the National

Aeronautics and Space Act, which created the National Aeronautics and Space Administration (NASA), signed by President Dwight D. Eisenhower on July 29, 1958. She was also famous for her work in favor of international cooperation and the exploration and use of outer space for peaceful purposes only. As Detlev Wolter stated, "as long as an arms race in outer space has not yet begun, the positive assessment of the Outer Space Treaty by Eilene Galloway will hold true. She used to link U.S. space policy with regard to the peaceful use of outer space in the interest of mankind with the result: '... that we have been successful in achieving the main goal: preserving outer space for peaceful space exploration and uses and preventing the new environment from becoming the arena for orbiting weapons and international conflicts (Wolter 1998, p. 9; Galloway 1998)."

Frank Rosa, as was described above, includes in the concept of "peaceful purposes of space activities the use of outer space for national and homeland security activities." In reality, today there is a general recognition of the use of outer space in military activities for monitoring and data collection, reconnaissance, surveillance, navigation, communications, and precision targeting, among others (Doyle 1993, p. 4). At the same time, some great powers have already built special weapons to place in orbits of the Earth and are engaged in developing new ones. Not coincidentally, the discussion about the advantages and disadvantages of outer space weaponization is increasingly urgent today.

Outer space weaponization signifies the deployment of antisatellite weapons, as well as space-based weapons to hit targets on Earth. No matter if they are labeled as offensive or defensive. In outer space this division hardly exists anymore. If the weaponization is really implemented, it will most likely transform outer space into a new battlefield, a new theater of war. That never happened all along the Space Age until now. It is extremely worrying to imagine that once a conflict in outer space is triggered, it is going to be difficult, almost impossible, to predict how it will evolve and what its outcome may look like. Corroborating this view is a warning made by Norberto Bobbio in the 1990s: "When the war breaks out, everything becomes uncertain. It is even uncertain whether there will be a winner and a loser (Bobbio 2003, p. 23)." Scientists and other international security experts warn that such a course would be ruinously expensive and entirely counterproductive, rendering all space assets – including commercial communications and broadcast satellites – more, not less, vulnerable, as noted the former Canadian Ambassador to the United Nations for Disarmament Affairs (1989–1994), Peggy Mason (Mason 2006).

At the beginning of the nuclear arms race, characterized by the increasing number of tests of nuclear weapons, some of them were carried out high in the atmosphere. Later on, the great powers, for health reasons, decided to limit these tests. On August 5, 1963, they signed the Partial Test Band Treaty (Treaty Banning Nuclear Weapon Tests in the Atmosphere), which prohibited the tests in outer space. Brazil signed the treaty 3 days later, August 8. Health implications could be invoked now too, as resulting from the destruction of the ionization belt caused by the explosions (Hinde and Rotblat 2003, pp. 154–155). This is another reason for the international community to take all measures necessary to prevent any kind of weaponization of outer space. Such course of action is considered by the Brazilian government an urgent imperative of our time.

The report of the informal meeting on the agenda item 3 – prevention of an arms race in outer space (PAROS) – held in March 31, during the 2011 Conference on Disarmament session[4], coordinated by the Brazilian Permanent Representative to the Conference, Ambassador Luiz Filipe de Macedo Soares, offers an indicative overview of the main ideas discussed at the meeting, with the interventions of the delegations of Russia, China, Brazil, Belarus, India, Algeria, the United States, Iran, Australia, Syria, Chile, Ireland, Egypt, Republic of Korea, Germany, France, and Pakistan:

- "Many delegations highlighted the growing global dependence on space technologies and the importance of keeping outer space safe for peaceful activities. They referred to the increase of space debris, to the growing possibility of satellite collisions, as well as to the development of space-related weapon technology that threatens outer space security. Delegations expressed that outer space should be used solely for peaceful purposes and for the benefit of all countries and should not become an arena for competitive strategic policies. Some referred to outer space as a common heritage of humankind. Most member States believe that the placement of weapons in outer space could deepen global insecurity, affecting all countries."
- "There was a general recognition that current international instruments are not sufficient to prevent an arms race in outer space. Many delegations believe that a specific international legal instrument is needed to strengthen or complement existing regimes. Some interventions commented on the need to adopt a preventive approach for avoiding an arms race in outer space."
- "The great majority of member States supported the establishment of a Working Group on PAROS within the CD. There was no consensus, however, on the nature or the mandate of the Working Group. Some member States defended that it should carry out substantive discussions on the issue, others supported that it starts negotiations of a legally-binding instrument on PAROS."
- "Many delegations expressed that the proposal of a draft treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects (PPWT, based on document CD/1839) constitutes a good basis for negotiation, and should be further analyzed by the Working Group. It was mentioned that the PPWT offers an initial framework to develop definition, scope and verification for a legally-binding text. However, the means to verify the compliance with such a treaty were questioned by

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[4] Letter dated 1 Sept 2011, from the president of the Conference on Disarmament addressed to the Secretary-General of the conference transmitting the reports of the five coordinators submitted to the president of the conference on the work done during the 2011 session on agenda items 1 to 7. According to CD/WP.565/Rev.1 (CD/1907), the informal meeting on agenda item 3 was chaired and coordinated by a Brazilian representative (Document CD/1918).

some member States, which do not consider the draft a good basis for negotiation."

- "The debate was a reflection of the wealth of ideas on the issue and that PAROS is a concern for all delegations. There were varying views on the measures to be taken to address the matter. Many expressed hope that informal debates may contribute to the formulation of a Program of Work that includes a discussion on PAROS, preferably with the establishment of a subsidiary body…"

In the light of the above, there are considerable signs that the major trend in today's world is against the weaponization of outer space. In Brazil, of course, we see this trend as a valuable manifestation of common sense.

## 27.7 The Draft Code of Conduct for Outer Space Activities Proposed by the EU

Brazilian government is concerned with possible attempts to undermine international law and the multilateral systems in force, through the adoption of informal mechanisms, instruments, and regimes, outside the UN framework. Since the 1960s, Brazil is committed to strengthening the role and the performance of the UNCOPUOS and its two subcommittees, Legal and Scientific and Technical. UNCOPUOS is the legitimate body for conducting the International Space Law-making process.

The Legal Subcommittee of the UNCOPUOS discusses and drafts treaties, agreements, and resolutions on outer space issues, which are subsequently submitted to the UN General Assembly (UNGA). New and more effective documents to ensure the peaceful exploration and use of outer space must be developed multilaterally. This is fundamental to ensure transparency, safety, security, and predictability to all space activities. For these reasons, Brazil has serious doubts concerning the draft Code of Conduct for Outer Space Activities (www.cfr.org/eu/eu-code-conduct-outer-space-activities/p26677), proposed by the European Union (EU) in 2008 and revised in 2010 and 2012. Brazil's major reservations regarding the draft Code of Conduct are as follows:

- The Code is not designed to be a document of the United Nations, although, as mentioned before, this is the main intergovernmental organization comprised of almost all existing States, whose first purpose is "to maintain international peace and security, and to that end: to take effective collective measures for the prevention and removal of threats to the peace, and for the suppression of acts of aggression or other breaches of peace, and to bring about by peaceful means, as well as in conformity with the principles of justice and international law, adjustment or settlement of international disputes or situations which might lead to the breach of peace."
- The Code was not thought to be widely and openly discussed at the Conference on Disarmament or at COPUOS, the central organ of the United Nations to examine and debate the outer space issues, especially via its Legal

Subcommittee and subsequently presented to the UNGA, as it has traditionally happened along all the decades of Space Age.

- The Code was originally a pragmatic "top-down" European proposal to the international community under the logic of "take it or leave it," without offering to countries from other continents the opportunity to discuss it or to propose changes and amendments to it.
- According to Article 4 of the latest version of the Code, the subscribing States commit to adopt and implement, in accordance with their own internal processes, appropriate policies and procedures or other effective measures in order to implement the Space Debris Mitigation Guidelines of COPUOS as endorsed by UNGA Resolution 62/217 (2007). Brazil has insistently supported the discussion on this issue at the COPUOS Legal Subcommittee. Some countries block a juridical debate on the question, although from rational point of view one can hardly deny its urgent necessity.

Brazil, for example, strongly supported the working paper submitted by the Czech Republic to the Legal Subcommittee of COPUOS, in its 2011 and 2012 sessions, proposing the review of the legal aspects of the Space Debris Mitigation Guidelines with a view to transforming the guidelines into a set of principles to be adopted by the UN General Assembly. Unfortunately, in two sessions, the Czech proposal did not reach the necessary consensus. Brazil is also concerned with the Code's provision on space debris, as it can impose additional costs to space programs of developing countries. For Brazil, space debris mitigation is a global challenge that must be addressed by all countries, taking into due account the responsibilities for the creation of the current amount of debris in the more used Earth orbits. The Code does not mention this historic reality.

- The Code is considered by Scott Pace, Director of the Space Policy Institute at the George Washington University, as "a collection of non-legally binding transparency and confidence building measures (TCBMs) for space (Pace 2012)." But if it is not a mandatory document, the question is why it should require to be opened for signature by nations interested in supporting it. It is questionable whether it is a democratic and fair solution in case it seeks, in this manner, to create a customary norm among certain number of spacefaring nations.
- Scott Pace also stated, "TCBMs and Codes of Conduct can be helpful in reducing the chances of accidental conflict and in providing cues to unusual activities." Yet, as the same author recognizes, "they cannot be seen as a substitute for the military capabilities necessary to deter potential adversaries (Lyall and Larsen 2009, p. 504)." It means that, although TCBMs and Codes of Conduct are capable to perform a peaceful role, this peaceful role, depending on the context, can simply be neutralized by the arbitrary and unilateral use of military capabilities, as it has been happening too often. It should be noted that there is not yet any international legal definition for the concept of "potential adversary," and no State has the right to act against a country under the allegation that it is a "potential adversary." "To deter potential adversaries" may be interpreted as a preventive use of the right of self-defense.

On that topic, the Brazilian professor Guido Fernando Silva Soares stressed: "From the exam of the rules of international law currently in force, there is no possibility of a legitimate preventive war, understanding "war", in its most current conception, as an effective use or threat of Armed Forces by a State or group of States in international relations today. If the conditions required by international law are not fulfilled – as stipulated by the Article 51 of the UN Charter (use of force in individual or collective self-defense), or the Articles 39 and 42 (use of the military service of the United Nations, in cases of threats to international peace and security, as formally considered by the Security Council), there will be an act of aggression, as defines and typifies the Resolution 3314 (XXIX) of 1974 of the UN General Assembly (Soares 2003)."

- The purpose of the Code is "to enhance the security, safety and sustainability of all outer space activities" and "to prevent outer space from becoming an area of conflict." Yet, at the same time, the Code, in its Article 2, adopts the principle of "the inherent right of individual or collective self-defense as recognized in the United Nations Charter" which remains the major justification, not only "for the maintenance of armed forces by states throughout the world (Pace 2012, p. 59)" and for the growth of the "industrial-military complex"[5] but also for the numerous cases of the use of force and the unleashing of terrible wars along the last six decades. In Brazilian view, the right of self-defense might legitimize the use of force in outer space. Moreover, it can legitimize and even promote an arms race in the new environment, instead of preventing this dispute.

In outer space, defense and attack can be equally disastrous. They can produce the same deleterious results, affecting quite probably not only the belligerent sides but also many other countries, if not all. For these reasons, among others, an ideal Code of Conduct or any other instrument dedicated to the prevention of outer space from becoming the scene of war, conflicts, and destruction cannot – in any way – serve as legal basis for initiating hostilities or even for preparing the indispensable means to carry out such acts of warfare.

The most comprehensive, wise, and consequent solution for this challenge seems to be the negotiation and signature of a multilateral Treaty on Common Security in Outer Space. As Detlev Wolter suggests, "the concept of common security in outer space could include, beyond the prohibition of active military uses of a destructive nature in outer space, a comprehensive package of confidence-building measures with multilateral satellite monitoring and verification system as well as a protective regime for peaceful space objects based on immunity rules for satellites..." For Wolter, an appropriately negotiated multilateral Treaty on Common Security in Outer Space would be "the adequate mechanism for implementing the Outer Space Treaty (Wolter 2005)."

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[5] The phrase "Military-Industrial Complex" was immortalized by outgoing United States President Dwight D. Eisenhower in his 17 Jan 1961 farewell address to the nation. In his speech, he considers the military-industrial complex as a warning to the American people – to not let this establishment begin to dictate America's actions at home or abroad.

## 27.8 Transparency and Confidence-Building Measures (TCBMs)

Brazil is determined to participate actively in the UN Group of Governmental Experts (GGE) on Outer Space TCBMs, established by Resolutions 65/68 during the 65th session of the UN General Assembly, held in 2010. The group held its first session in July 2012. Brazil is persuaded that TCBMs can play a highly relevant role towards making important progress at multilateral level in addressing the threats to space security, such as the competition over access to orbital slots, the proliferation of space debris, and the specter of space warfare. Such progress, as we know, has been "glacially slow (Hitchens 2011)."

Working together to propose recommendations on TCBMs could bring all countries closer together as never before, promoting deeper understanding about their national positions, trimming differences, settling doubts, and clarifying the current and prospective state of their programs, projects, and affairs in outer space. The overall result of this joint effort would hopefully lead to the establishment, deepening, and strengthening of a strong trust between all participating countries.

As to space military activities, the TCBMs can, inter alia:

- Bring about a high level of predictability and reliability, avoiding ambiguities and suspicious attitudes, as well as situations that could lead to international tensions and unexpected threats.
- Create a favorable political atmosphere to facilitate the solution of the quite complex question of how to elaborate the indispensable system of verification for new agreements on banning the placement of any weapons and the use of force in outer space.
- Contribute to delineating the differences between military uses that are genuinely peaceful (and thus protective) and those that are effectively threatening.
- Establish balance among the interests of military, commercial, and civilian users around the world.
- Reduce the need for early military preparation to face situations presumably dangerous to national security.

Due to dual-use nature of space capabilities, "sustainable space security will require more refined rules for military uses of space that reinforce, rather than undermine, an approach to terrestrial security based on reassurance and restraint," as recommends Gallagher (Gallagher 2005). Fortunately, as Theresa Hitchens noted, "2010–2011 saw the emergence of a consensus around the notion that multilateral cooperation/action is now required to avoid harmful competition, accidents, and the increased potential for conflict in the global commons of outer space." According to Hitchens, "this now unquestioned assessment has led to movement, on several fronts, towards establishing the underpinnings of a more defined international governance structure for space activities. At the foundation of all these efforts is the widespread recognition that before new governance practices and/or structures can be developed, transparency and confidence in state-to-state relationships in space must be increased (Hitchens 2011)."

Brazil supported the recent advances in TCBMs during the meeting on prevention of an arms race in outer space (agenda item 3 of the 2011 Conference on Disarmament), held on March 31, 2011. At that time, the Brazilian representative expressed the view that the European draft Code of Conduct for outer space activities – as a set of transparency and confidence-building measures – cannot substitute a legally binding instrument. This view was supported by most of the other delegations. It is worth emphasizing an important remark made in the report on this meeting: "The majority acknowledged that confidence building measures and a legally-binding instrument are not mutually exclusive. Others pointed out that TCBMs do not replace verification but may function as a start towards a step-by-step approach on preventing the weaponization of outer space (Vasiliev 2010)."

## 27.9 Conclusions

It is time to bring Manfred Lachs (1914–1993) to the present era. Lachs was a famous Polish educator, jurist and diplomat, former judge and president of the International Court of Justice, as well as former chair of the International Institute of Space Law (IISL), honored by the institute. A prestigious and unique international juridical event of our time in the fields of education and culture was named after him, the Manfred Lachs Space Law Moot Court Competition. After elected in 1957 to the UN International Law Commission, Lachs became the first chair of the Legal Subcommittee of the UNCOPUOS, where he acted from 1962 to 1966, conducting the historical process of discussion, preparation, and approval of the basic existing documents of International Space Law, including the 1967 Outer Space Treaty.

Lachs left us many lessons which remain valid today and for a long time to come. In 1972, he wrote in his book: "If all the activities connected with outer space are to be conducted for the benefit of all and to the detriment of none, international cooperation is essential, and if all the possibilities opened up are to be used in a responsible manner, the conduct of States in regard to outer space must be submitted to the rule of law (Lachs 2010, p. 5)."

If we consider these ideas in the light of today's reality, we can say without hesitation that international cooperation that can benefit everyone and not hurt anyone in the area of security in general and, particularly, in outer space security is the adoption of deep and solid measures of transparency and confidence building in all aspects of international relations. When a genuine trust among all nations is nonexistent, there cannot be true global collaboration and, consequently, solid and durable peace. Only if genuine trust can be achieved, there will be better future for our civilization, including in outer space. Without it, the humankind can hardly live well and move forward. Moreover, it is only through the rule of law (i.e., a high level of certainty, reliability, stability and predictability assured by legal norms adopted by all interested nations) that genuine trust can be built in a responsible way. This is especially true when regarding essential issues of global, and consequently national, security. Naturally, resolutions and declarations adopted by the great majority of the UN General Assembly are also of high value, as they represent an unquestionable expression of the will of the majority of countries. This enables them to become a customary norm or a foundation for future binding agreements.

Highlighting the advantages of international cooperation as a strong model of transparency and confidence building, Moltz underlined that “moving forward with a weapons-based approach toward security is more difficult to reverse than an approach based on international cooperation.” He also noted: “The main lesson we can draw from the past is that space will continue to be a highly interactive environment. A high level of effort will be required to manage this important experiment in environmental security, technological development, and human conflict prevention (Moltz 2011, pp. 351–353).”

In summary, a number of key issues by the international community need to be addressed. They include the following:

- To decide with determination and good faith how to implement the application, development, and strengthening of existing international law, based on the UN Charter
- To create a climate of unprecedented level of understanding, trust, and cooperation
- To prevent the placement of any kind of weapons in Earth orbits
- To avoid the use of the right of self-defense in space as it can be disastrous for many countries and fateful for the very existence of space activities
- To neutralize any possibility and hypothesis of using military force and of warfare in outer space
- To establish a just, equitable, and efficient system to clear outer space from of space debris
- Fully ensure space security and long-term sustainability of space activities
- To accomplish all of the above by respecting, honoring, and strengthening the United Nations, the best multilateral system in human history

Although these pressing issues are still unanswered, they seem to indicate the right way to proceed in achieving the realization of exclusively peaceful use of outer space. This quest is perhaps one of the most decisive political and juridical debate of the twenty-first century. The outcome should be the triumph of all parties, nations, and the mankind. In short, it will have to be a victory for all; otherwise there will be no winners.

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# Israeli Perspective on Space Security

# 28

Deganit Paikowsky, Isaac Ben-Israel, and Tal Azoulay

## Contents

## Abstract

Israel has a 30-year tradition of space activity developing, operating, and launching satellites into space. As a small country, Israel enhances its power through space in ways otherwise not possible. This opportunity is accompanied by significant challenges, especially in maintaining the qualitative gap and preserving Israel's position at the forefront of technology, as well as securing the space environment. The significance of space in Israel's strategic

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conception shapes Israel's perspective on space security. This chapter provides a short overview of the Israeli space program, outlines Israel's strategic conception focusing on the role of its space program, analyzes Israel's approach to space security, and outlines current challenges and opportunities space presents for Israel.

> *Presence in space essential to us. . .and I am convinced that we must establish this as an objective to which we must aspire. (Mofaz S (2003) Lecture at the conference, A new security paradigm. Yuval Neeman Workshop for Science, Technology and Security, Tel Aviv University)*
> *Defense Minister, Major General (Res.) Shaul Mofaz 2003.*

## 28.1 Introduction

In the early 1980s in order to fulfill acute security needs, Israel embarked on an ambitious space program, which placed it among the group of states which are capable of self production, maintenance, and control of satellites and launchers. Having an indigenous national space, capability is part of Israel's national security strategy. As a traditional spacefaring nation and a sophisticated producer and user of space technologies and applications, Israel attributes great importance to securing the space environment for peaceful uses for all nations.

Looking back 30 years, the overall space activity of Israel is much broader than national security activity. In the 1990s Israel commercialized its space activity. It has a robust commercial space industry, alongside a strong scientific sector. Nevertheless, this chapter analyzes Israel's security needs and overall approach to space security. Israel's approach to space security may be described as threefold: (1) developing and maintaining self-sufficiency in niche technologies and applications important to Israel's strategic needs, (2) protecting its systems and capabilities, and (3) securing the space environment for all users.

The main body of the chapter is composed of five sections. The first section depicts the overall Israeli approach to space. The second section provides a short overview of the Israeli space program. The third section outlines Israel's strategic conception focusing on the role of its space program. In the fourth section the authors analyze Israel's approach to space security. The fifth section outlines challenges and opportunities space presents for Israel.

## 28.2 Israel's Pragmatic Approach to Space

Israel's approach towards space and space security emerges primarily from its position in the regional and global systems. As a small and threatened country, Israel strives to secure and assure its national security, as well as achieve a lofty position (especially in its region).

Israel's need to relate to a broad circle of states which surround it, beyond its immediate neighbors, and its national and security interests demand an orientation towards space. As a small country, Israel suffers from an acute lack of resources. For these reasons, the country manifests a pragmatic approach to space power, aimed to satisfy national security needs. Generally, these consist of the capability to reach distant threats from an intelligence and operational point of view. This mainly involves early warning, intelligence, deterrence, and self-reliance in advanced technologies.

Israel seeks a presence in space and regional dominance in space in niche areas: Earth observation (i.e., lightweight satellites, high resolution electro-optic, and SAR), low-Earth orbit (LEO) launch capability, and communications. Israel does not undertake to build all systems entirely on its own. It has, for example, no navigation or weather systems and has no manned mission. However, Israel seeks to cooperate with international partners on projects of this nature, as well as scientific projects.

## 28.3 Israel's Space Program: Evolution and Overview

In the last 30 years, Israel developed a highly advanced space industry and indigenous infrastructure of space technology in two main niche areas: Earth observation and communications, including the ground segment of communications satellites.

The major impetus leading to the decision to embark on an independent Israeli space program was the 1979 Egypt-Israel Peace Treaty, and the perceived need to protect Israel, including through the need to verify Egypt's compliance with the treaty. The agreement, signed in 1979, did not neutralize Israel's concerns of hostile Egyptian aspirations. There was a clear need for intelligence on what was happening in Egypt without violating its sovereignty. It was determined that independent operation of a reconnaissance satellite would provide the optimal solution to this operational problem. In 1981, the Israeli space program was established out of a pragmatic approach aimed to satisfy national security needs of early warning, deterrence, and self-reliance in advanced technologies.

In 1988, the first satellite – Ofeq-1 – was successfully launched. Two years later, Israel launched Ofeq-2. In 1995, Ofeq-3, the first operational electro-optic reconnaissance satellite, was put in orbit. In the years that had come, Israel successfully put in orbit several more Ofeq series satellite (5, 7, and 9). In 2008, Israel launched TECSAR, a sophisticated lightweight synthetic-aperture radar [SAR] satellite.

In the 1990s, besides its national space expertise, Israel developed commercial satellites (Amos communication satellite series, EROS remote sensing electro-optical series), subsystems, and other equipment. In the next few years, Israel is expected to launch several more satellites of different payloads including hyperspectral and a nanosatellite, which will be used to demonstrate new technology capabilities.

## 28.4 Israel's National Security Strategy and the Role of Its Space Program

Israel has built its strength in space in accordance with priorities that correspond to its national and security needs. Understanding Israel's perception of space and of space security demands an analysis of Israel's strategic conception, especially in relation to space.

### 28.4.1 Israel's Strategic Conception

Israel has no official publication that presents its security doctrine and grand strategy. The only officially adopted document is an "Overview" written in 1953 by David Ben-Gurion, Israel's first Prime Minister (Ben-Gurion 1981; Ben Israel 2001). Ben-Gurion's report (originally 46 pages long) was submitted to the government on October 18, 1953. In this overview, Ben-Gurion evaluates and analyzes the geostrategic facts, challenges, and threats faced by the young State of Israel, which was established 5 years earlier in 1948. Ben-Gurion also provides principles of addressing these threats and challenges.

A fundamental part of Israel's security doctrine is the concept that because Israel's independence was not recognized by its neighbors, the country might go through many "rounds" of warfare, and cannot afford to lose even one. The doctrine has always been based on three principles: deterrence, early warning, and decisive victory.

The first and foremost principle of Israel's doctrine is to deter war, and if deterrence fails, to bring the battle to a rapid and clear conclusion, by destroying the attacking forces on the adversary's territory. For this reason and due to the overwhelming numerical and geographical inferiority of Israel, assuring early warning intelligence is vital for Israel's national security. Decisive victory is necessary to keep wars brief and to develop aggregate deterrence over the course of many "rounds" of conflict. In order to deter war or low-intensity conflicts, Israel projects an image of a capable force that will retaliate disproportionately. This strategic posture is often misunderstood, and Israeli military reaction is often accused of applying "excess" force.

Although 60 years have passed, many of the threats and challenges described and analyzed by Ben-Gurion, including some of the methods of mitigation, remain relevant today. Nevertheless, over the years there were several attempts to update the national security policy and formalize it. The most recent one took place in 2004–2006 by a committee headed by Dan Meridor, appointed by then PM Ariel Sharon and Defense Minister Shaul Mofaz. Given the rise of rocket and terrorism threats in the last two decades, the Meridor committee suggested an additional fourth dimension – "civilian defense."

Under these conditions and principles, national space capabilities and infrastructure for military and civilian applications are perceived as force multipliers boosting Israel's technological advantage, which allows it to enhance military capabilities. These capabilities also contribute to a number of nonmilitary fields. This, in turn, enables the country to increase its level of national security and strengthen its status in the region. Hence, a strong state-of-the-art space program is highly important to Israel's national security. Nonetheless, as explained above, Israel's limited resources dictate that it must concentrate on those fields that are critical.

The following statement by Major General (Ret.) David Ivry, former Air Force Commander (1977–1982), provides valuable insight into the role of the Israeli space program in Israel's deterrence strategy:

> The perception of one's capabilities and one's willingness to use those capabilities are important components of deterrence. The perception of space capabilities is one of the primary components in Israel's future deterrence. Therefore, Ofeq 1, 2, and 3 contributed far more than anyone estimated. Imaging resolution is not the strategic measurement. Rather, the strategic measurement is the perception of capabilities that the State of Israel displays. Not what we possess, but rather what the enemy estimates that we possess. The gaps in capabilities and information, in the tactical field, miniaturization field, and others are an immeasurably important component in the dimension of our strategic deterrence.

The next section delves into the principles of Israel's national security conception and analyzes the role of space.

### 28.4.2 Quality Over Quantity

The basic principle of Israel's national security concept is that Israel must balance its numerical inferiority by creating and maintaining a qualitative edge in all civilian and military realms: education provided to citizens, expertise of scientists, the level of research and development, the quality of weapons systems, and strong motivation among the military cadres. In particular, investments in science and technology are central factors in the power equation between Israel and its neighbors.

The "Quality over Quantity" concept has remained valid throughout the years and is applied to all aspects of Israel's security doctrine. So far, it has been proven successful in countering conventional wars, terrorism, and low-intensity conflicts. This concept also plays a role in the development of Israel's space capabilities.

### 28.4.3 The Need for Self-Reliance in Space

Israel is an isolated country which suffers severe security problems that are intensified by a long history of wars, acts of terror, and atrocities that date long before the state was established in 1948. Analyzing its problems, interests, and objectives, Israeli decision-makers reached the conclusion that self-reliance, especially in science and technology, is needed in order to achieve qualitative superiority over its adversaries.[1] The same rationale was applied in embarking on a space program. Israeli decision-makers aspired to have the capability without having to rely on other nations or consider potential pressure. Furthermore, the internationally acknowledged norm in which having a national space capability is a means, and a symbol of, power, had also played a role (at least partially), in Israel's decision to access and utilize space using its own launchers and satellites (Paikowsky 2009b).

The following statement by IDF Colonel Eli Polak testifies to the importance of indigenous Israeli satellites: "Satellites" products enable a better understanding of the intelligence picture, provide combat support, and aid decision-making at high political level. It is not possible to describe a conflict scenario today without Blue-and-White (i.e., 100 % Israeli) satellite intelligence (Blizovsky 2009).

### 28.4.4 Strategic Depth

Israel's narrow borders constitute a lack of strategic depth and have posed existential threats which necessitated a search for solutions to avoid the elements of strategic surprise and sudden attack. For these reasons, Israel's security doctrine demands advanced intelligence capabilities for early warning; as well as combat capabilities for a rapid transfer of battle away from Israel's population centers to enemy territory. The orientation towards space assists Israel in coping with the challenges presented by the lack of *strategic depth*.

The opportunity to observe enemy territory from space is a scientific and technological solution to the military problem which Israel faces. Observation from space enables Israel to cope with threats from Arab countries directly bordering the country, as well as those that threaten Israel but are located farther away geographically. At the 2010 Ilan Ramon Space Conference, the then IDF Air Force Commander Major General Ido Nechushtan pointed out the advantage provided by Israel's space program regarding the lack of strategic depth, and said space is a force multiplier that provides Israel with a strategic depth crucial to its national security (Nechushtan 2010).

### 28.4.5 Improving Intelligence Capabilities for Near and Distant Arenas

Satellite-derived intelligence information is considered to be a great equalizer in strategic terms because it increases transparency among states and diminishes the sense of uncertainty, thus reducing the risk of surprise. Use of satellites, therefore,

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[1] For more information on the history of the Israeli space program and the motivation of Israel to embark on an indigenous capability, see Paikowsky (2009)

reduces the fear of surprise, increases the level of security, and permits the building and preservation of relations based on trust (Shafir 2004).

In this context, in recent years Israel has been witnessing a worrying expansion of Iranian military activity. Iran has pushed forward with ballistic missile development, space capabilities, and most notably a nuclear weapons program. Additionally, Iran actively engages in ground-based satellite disruptions. Satellite imagery and analysis have played an essential role in the international community's awareness and response regarding the above referenced Iranian programs. Despite increasing international condemnation, these activities have continued and serve to emphasize the importance of protecting space assets from attacks, as well as making use of space assets to detect and deter attacks.

In Israel's strategic thinking, the Israeli space program is recognized as a critical component of its independent intelligence capability. The issue of Israel's self-sufficiency is a complex one. Israel is far from being totally self-reliant; it depends on American political support in international forum and economic aid. Nevertheless, in the field of intelligence, Israel has a great deal of autonomy and does not rely on foreign sources for supplying it with intelligence technology.

Possession of independent intelligence capabilities has many implications for Israel beyond the field of intelligence. It enhances the power of the state and the image of Israel in the eyes of its opponents as well as its allies, and increases its flexibility, both from the perspective of its ability to gather information and the resulting autonomy in decision-making. Independent capabilities also permit the country to conceal its areas of interest and to gather information unhindered. To achieve this independence, Israel has been building its space program, especially the capability to develop and launch satellites. The main rational for this undertaking can be found, for example, in a parliament report published in March 2004. The members of the Steinitz Commission recommended intensifying the development of an Israeli reconnaissance satellite system as infrastructure for long distance Visint intelligence. "This system should be built in such a way that it has the ability to respond to threats to the State of Israel in near and distant 'tiers of threat,' and the capability to track down, identify and monitor technological, industrial and military infrastructures" (Knesset Foreign Policy and Security Subcommittee 2004).

### 28.4.6 Space, Military Doctrine, and Force Buildup

Having a presence in space is part of the fundamental components of the military doctrine Israel adopted in the last two decades. This doctrine draws from the American military doctrine known as Revolution in Military Affairs (RMA), which was developed in the early 1990s. RMA has four facets: control of space, dominant maneuver, information warfare, and precision strike. Space plays an important role in each of these areas (Ben Israel 2004; Paikowsky 2005): intelligence, deterrence, navigation and guidance, communications (shortening sensor-shooter loops among the forces), command and control, meteorology, and media. Israel's space program plays an important role in the military doctrine, both in practice and conceptually.

## 28.5 Space: An Opportunity and a Challenge

The description of a rational for Israel's engagement in space activities provided above reveals that Israel (which operates a successful space program on a modest budget) views space as a significant opportunity, especially as a force multiplier projecting the quality of force over its quantity. In the era of the information revolution and the expansion into space (which is an integral part of this process), quantity and mass of ORBAT (order of battle) no longer play such a big role. Israel, as a small country that exploits its features, opportunities, and capabilities, can enhance its power through space in ways it otherwise not possible.

This opportunity is accompanied by significant challenges, especially in maintaining the qualitative gap and preserving Israel's position at the forefront of technology. The significance of space in Israel's strategic conception shapes Israel's perspective on space security.

Israel perceives space as a global commons and therefore aspires to contribute to a secure and sustainable space environment. Israel acknowledges the world-wide use of space for supporting terrestrial military activity, as well as defending, and deterring harmful actions, against space systems. Nevertheless, it seeks greater international collaboration and cooperation, especially among democratic spacefaring nations, in maintaining space as a peaceful environment for the benefit of all.

### 28.5.1 A Growing Reliance on Space and the Sensitivity to Space Sustainability

The increasing reliance on space-based systems for day-to-day activities on Earth, along with the global trend of a growing use of space for military activities, increases the vulnerability of the space domain to hazards and harmful activities. Space is becoming more congested and competitive. The growing number of space security incidents has lead nations to find methods of ensuring their access to space, their freedom of action, as well as proper functioning of their assets there. For example, a growing number of nations now seek to develop space situational awareness (SSA) capabilities and debris removal (DR) capabilities. Improved international SSA capabilities and DR capabilities may have a positive effect on the sustainability of outer space because they would increase transparency. If shared, these systems could also upgrade confidence in the international community, as they would enable better prediction, and prevention, of harmful interference with space assets. Nevertheless, these new developing concepts could also be used for negating the use of satellites. This could have dangerous implications for the space environment.[2] Many spacefaring nations are concerned with these trends, including Israel. Similar to other spacefaring nations which use and appreciate space, Israel too is gradually becoming more reliant on its space activity for day-to-day life. But together with the reliance on space comes the sensitivity to its sustainability and security.

Israel enjoys and suffers from a growing reliance on space systems for its critical national infrastructure. For this reason, it is concerned about the growing global trend of space militarization. Such threats, if realized, could lead to Israel losing its current relative advantages in the realm of space. Therefore, Israel is looking for ways to protect its satellites and achieve a sustainable space environment.

Due to the lack of officially released statements and policy papers on this topic in Israel, an important source of information on Israeli space policy is the various conferences and academic events which take place each year. Presentations by high officials of the Israeli space community offer valuable insight into current trends in Israeli space policy. The following statement was made by Commander of the Israeli Air Force, Eliezer Shkedi, at the 2007 Ilan Ramon Annual Space Conference: "the operational importance of space is increasing constantly. Why is this field critical? There exists a concern that others who recognize its importance will try to attack space assets. We must consider defense measures, against physical harm, jamming, blinding, or any other technique. One of the greatest surprises that can happen in the modern world, in advanced countries with space assets, is a situation in which a country is surprised to find its space assets damaged. This kind of damage can be caused by an enemy nation or a terrorist organization. I suggest that none of us close our eyes, to understand that this is the reality and to confront the situation with eyes wide open. This is a dream scenario for countries that have been left behind by advanced technological capabilities" (Shekedy 2007).

Shkedi's statement is an example of the growing recognition in Israel of the importance of a sustainable space environment and the need to protect space systems. In his annual presentation at the 2008 Ilan Ramon Space Conference, IAF Commander Shkedi addressed the Chinese ASAT test by saying that "We cannot ignore this issue. The issue of dealing with the expanding space capabilities, combined with the increasing dependence of the modern military on space… in my estimation this issue is on 'our table' whether we like it or not. To ignore the matter would be very much incorrect. As one who is concerned with operational aspects, and we must be very concerned with operational aspects, we must understand how to develop space assets and how to protect them so that they will be operational when necessary. I say specifically "when necessary" because apparently a limited conflict will present few threats to space capabilities. However, I have no doubt that as the level of conflict rises, or if an enemy feels that the threat to him is very high, one of the issues that he will find himself confronted

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[2] For further discussion of this issue, please see Levi and Dekel (2011)

with will be whether or not to use, or to attempt to use, methods that oppose land, sea, and air assets, and develop such capabilities against space assets. Most likely space conflict will not be a burning issue in the next year. But looking five years ahead, or 10 years ahead, I feel that it will be a very relevant issue." (Shekedy 2008).

### 28.5.2 Support of the Global Trend to Secure the Space Environment

Besides the ASAT occurrences of the last few years, there have also been several events of satellite jamming and interference.[3] It is too early to determine whether space weaponization is inevitable, and if the use of ASATs will be internationally accepted as legitimate. Having ASAT technology be part of a country's space security capability can serve three goals. First, it allows a military to have the capacity for aggressive action against an adversary; second, it provides a capability to defend against hostile activities; third, it may be used for deterrence against potential aggressive actions. The risk is that ASATs for aggressive actions will be developed under the excuse of deterrence and defense reasons.

As long as this trend of a growing military use of space is followed by responsible and cautious actors, it is not a cause for immediate alarm. If these technologies proliferate and fall into the hands of irresponsible actors and rogue states, space may evolve into a dangerously unpredictable arena. This process would have significant implications for the national security of all the "space club" members,[4] including Israel. For this reason, advocates of non-weaponization of space often argue that declarations and actions to develop ASAT capabilities increase the potential for a space arms race (Milowicki and Johnson-Freese 2008).

A different approach, based on the democratic peace theory, in which democracies rarely go to war with one another, suggests that democratic nations involved in space security actions and ASAT capability development will not act against one another. For this reason, their aspirations and actions should not be perceived by other democratic and responsible nations as threatening actions. Democratic nations, such as Israel, should not be overly concerned by other democratic nations developing such capabilities. It is in this context that Israel supports efforts of other democratic and reliable allied countries to develop space security capabilities.[5]

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[3] An important example is the case of Iran's satellite jamming activity against BBC broadcasts, which was widely criticized and condemned by leading European Union countries and the UN-ITU. Theodoulou M Tehran told to end satellite jamming. The National. http://www.thenational.ae/apps/pbcs.dll/article?AID=/20100322/FOREIGN/703219849/1002/FOREIGN. Accessed 22 March 2010.

[4] For a definition and discussion of the nature of the space club, see Paikowsky (2009) and Paikowsky (2009)

[5] For a more detailed discussion, see Paikowsky and Ben-Israel (2011)

The democratic peace theory is based on the philosophical idea of Immanuel Kant in his book *Perpetual Peace* (1795). In the discipline of international relations, this idea has been examined since the 1960s and even empirically tested by several scholars in the 1990s.

As a spacefaring nation that utilizes space assets on a daily basis in the defense field, and even more in the civilian and commercial fields, Israel is interested in a space environment that is safe and secure, expects other countries to act responsibly in space, and will act in cooperation to achieve this goal.

Recent years have seen a number of international initiatives and agreements being advanced by countries interested in space sustainability. The European Union proposed an Outer Space Code of Conduct.[6] Russia and China have suggested the draft treaty on prevention of placement of weapons in space (PPWT).[7] In 2008, the UN passed a series of guidelines for debris mitigation (UN Debris Mitigation Guidelines). Years before these proposals, a resolution calling for the prevention of an arms race in outer space (PAROS) has been debated within the UN Conference on Disarmament. The United States and Israel oppose PAROS.

The United States is concerned with the binding nature of such proposals. It is especially concerned with the lack of transparency and enforcement that would enable irresponsible countries and actors to take advantage of those abiding by the treaties. This could result in responsible actors losing their relative advantage, their freedom of action in space, and their ability to defend their space assets. Therefore, the United States supports non-binding agreements which would serve as confidence building measures.

Israel favorably views these legally non-binding efforts towards space sustainability. In Israel there is an understanding and belief in the need for international cooperation to ensure that space remains accessible and sustainable for the future.

### 28.5.3 An Emerging Threat: Space and Cyberspace Security

The growing dependence of the global economy on space systems creates a common concern regarding debris and other threats in the space environment which threaten space systems. As part of this process, recognition is gradually increasing that physical damage to satellites is not worthwhile and should be avoided because it may damage other satellites indiscriminately. Additionally, the likelihood of soft interference in the operation of space systems by jamming or cyber attacks is rising. This was also recognized by many in Israel who perceive a direct link between cyber threats (Levi and Dekel 2011; Levi and Dekel 2012) and assuring the security and safety of space systems (Ben-Israel 2012).

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[6] For the updated version of the European initiative of the Outer Space Code of Conduct (2012)

[7] For more information on the PPWT

## 28.6 Conclusions

Israel's space program was launched in response to national security needs. Over the years, with Israel's development and evolution as a country, its needs and capabilities have also evolved. Today, Israel has commercial, scientific, and civilian space assets and is expanding its involvement in international space cooperation. These developments, combined with increasing reliance on space for day-to-day activities and the nation's continuing security issues, make space security a concern for Israel.

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# Space Security-Relevant International Organizations: UN, ITU, and ISO*

# 29

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## Contents

**Abstract**

The rapidly expanding use of space comes with growing challenges to ensuring the safety and security of space assets. As recognition of the many challenges has spread, there is increasing interest by nation states in the development of multilateral approaches. At the same time, there is not any one international organization that is fully mandated to address the risks and threats to space assets – be they commercial, civilian or military or a combination. Instead, the effort to develop multilateral governance regimes for outer space is complicated by the plethora of bodies with individual remits, bureaucracies and political histories. Thus, while there is now momentum for progress in developing

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multilateral approaches to space security, the actual achievement of progress faces not only competing state interests but also potentially competing bureaucratic interests that may prove difficult to overcome.

## 29.1 Introduction

Over the last 50 years, global space activities have not only increased in number but also in importance to economic development and human security. There are now some 1,100 active spacecraft on orbit and more than 60 states and/or commercial entities owning and/or operating satellites.

However, the growing use of space comes with growing challenges to ensuring the safety and security of space assets. For example, the amount of uncontrolled space debris – which is poses collision dangers for active satellites – has exploded. In addition, there is greater competition for the limited resource of frequency spectrum, particularly for satellites in the geosynchronous (GEO) orbital belt (36,000 in altitude where satellites in essence stay over the same spot on Earth as they rotate). The past two decades have also seen the ever increasing use space technologies for military applications, such as weapons targeting and real-time imaging, thus raising the specter that satellites will become a target during warfare.

As recognition of the many challenges has spread, there is increasing interest by nation states in the development of multilateral approaches to ensuring space security.

At the same time, there is not any one international organization that is fully mandated to address the risks and threats to space assets – be they commercial, civilian or military or a combination. Instead, the effort to develop multilateral governance regimes for outer space is complicated by the plethora of bodies with individual remits, bureaucracies and political histories.

These include three United Nations-related bodies – the Conference on Disarmament (CD) in Geneva, the Committee on the Peaceful Uses of Outer Space (COPUOS) in Vienna, and the International Telecommunication Union (ITU) in Geneva – as well as the International Organization for Standardization (ISO) in Geneva. In addition, the UN General Assembly has been active on the issue under the First Committee, most recently with the 2010 creation of a so-called Group of Governmental Experts on Transparency and Confidence Building Measures in Outer Space, which commenced its work in New York in July 2012. This chapter will look at functioning and roles of each of these instruments, as well as lacunae among them in regard to the development of an international space security regime.

## 29.2 Conference on Disarmament

The Conference on Disarmament is the UN-related body with the most direct potential impact on traditional, or ‘hard,’ security in space. The CD was established by the General Assembly in 1979 as the only multinational forum dedicated to the negotiation of arms control and disarmament treaties and agreements. The CD has

65 member states and about 40 observer states; it holds three sessions each year and decisions require consensus. The CD began consideration in 1985, under a formal ad hoc committee, of the "Prevention of an Arms Race in Outer Space (PAROS)". After years of circular debate, the committee was disbanded in 1994; since then, CD discussions of PAROS have been on an informal basis.

Since the 1980s, the primary champions of the PAROS issue have been China and Russia. Both countries have long been worried by the on again/off again interest in the United States in space-based missile defense systems, which Moscow and Beijing see as a threat to their nuclear deterrence capabilities. Although the CD's PAROS mandate is not so specific, both governments thus have interpreted it as primarily focused on the development of a ban on space-based weapons.

In June 2002, Russia and China introduced into the CD a joint working paper, "Possible Elements for a Future International Legal Agreement on the Prevention of the Deployment of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects." The paper stated: "Only a treaty-based prohibition of the deployment of weapons in outer space and the prevention of the threat or use of force against outer space objects can eliminate the emerging threat of an arms race in outer space and ensure the security for outer space assets of all countries, which is an essential condition for the maintenance of world peace."

In February 2008, Russian Foreign Minister Sergey Lavrov, on behalf of Russia and China, formally presented a draft treaty: *Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects* (PPWT).

The PPWT aims to "keep outer space as a sphere where no weapon of any kind is placed," and defines "weapons in outer space" as "any device placed in outer space, based on any physical principle, specially produced or converted to eliminate, damage or disrupt normal function of objects in outers space, on the Earth or in its air, as well as to eliminate population, components of [the] biosphere critical to human existence or inflict damage to them." Signatories of the PPWT would "undertake not to place in orbit around the Earth any objects carrying any kind of weapons, not to install such weapons on celestial bodies, and not to station such weapons in outer space in any other manner; not to resort to the threat or use of force against outer space objects; not to assist or encourage other states, groups of states or international organizations to participate in activities prohibited by the Treaty."

Moscow and Beijing called for the immediate launch of negotiations on the proposed treaty, and asked fellow CD members to submit preliminary comments and questions.

While there is general sympathy within the CD for PAROS and a widespread concern about the concept of weapons being placed on orbit, the issue is really only of primary importance for the CD's agenda to a few states besides Russia and China, namely the United States. (Most of the CD's membership is focused on issues related to nuclear disarmament.) While the U.S. government was supportive of the creation of the ad hoc committee on PAROS in 1985, Washington was overtly hostile to any discussion of the issue during the administration of

President George W. Bush (which was intent on pursuing space-based missile defense as well as anti-satellite capabilities to maintain U.S. "dominance" in space). The administration of President Barak Obama has taken a much lighter approach, and has quietly backed away from any support of space-based missile defense. The 2010 U.S. National Space Policy, in a complete U-turn from the 2006 Bush policy, stresses the need for multilateral cooperation – including the development of transparency and confidence-building measures (TCBMs) – and pledges that the United States "will consider proposals and concepts for arms control measures" if they are equitable, effectively verifiable, and enhance the national security of the United States and its allies. Further, Washington has signaled its willingness to address the PAROS issue at the CD under a discussion mandate.

That said, the Obama administration remains opposed to the PPWT language as the basis of formal negotiations at CD. In particular, the U.S. government frets about the lack of specific language in the document covering the development, testing and use of terrestrially based anti-satellite weapons, such as have been tested in the past by the United States, Russia and China. In addition, the U.S. national security community has qualms about any effort to define a "weapon" in space, due to the inherent dual-use capabilities of most, if not all, space technologies. Indeed, the current U.S. government consensus is that a ban on weapons in space is inherently un-verifiable. Finally, the Obama administration has shown some reluctance to directly take on the small phalanx of right-wing Republicans in the Senate and House of Representatives who view any multilateral agreements regarding space as threatening to U.S. national security; and who are vocally opposed to any new space security treaty.

While serious PAROS discussions or negotiations within the CD on PPWT would most directly impact military space assets and hard security in space, unfortunately, the Conference is headed into its 15th year of failure to even launch a program of work. This is due to the linkage of several issues within the CD's remit – including nuclear disarmament and non-proliferation – that have different priorities for different governments. The current source of the stalemate is the refusal of Pakistan to discuss the issue of a treaty designed to cap or cut stockpiles of fissile materials used in nuclear weapons fabrication; but this impasse in only the latest in a long string of major political disagreements about what the Conference ought to be doing. Partly, the problem can be traced to the use (and often abuse) of the consensus rule that in effect allows one nation to veto the desires of the rest of the group. Partly, it can be traced to political differences among nations possessing nuclear weapons – both inside and outside the Nuclear Non-Proliferation Treaty regime – non-nuclear weapons states, and those perhaps wishing to build arsenals either covertly or overtly. Another factor is the inability of many nation states to see international security as benefitting their own national security; rather viewing the establishment of international rules as coming at the cost of national sovereignty. In any event, there is no end in sight to the CD's stalemate at this point in time – diminishing its relevance in the current search for a multilateral path forward on space security.

## 29.3 Committee on the Peaceful Uses of Outer Space

COPUOS was established in 1959 by the General Assembly to promote the peaceful use of space, research, information sharing, and international cooperation (including development of UN programs); and address legal issues regarding the peaceful use of outer space. It is the only multilateral organization empowered to negotiate international space law. There are 74 member states, plus a large number of non-governmental and intergovernmental organization observers. COPUOS activities are undertaken within two subcommittees – the Scientific and Technical Subcommittee and the Legal Subcommittee. The subcommittees meet annually and report to the annual meeting of the full committee. The last full committee session took place on 12–21 June 2013. COPUOS decisions are taken via voting by member states, although consensus is usually sought. Those decisions are then reported to the General Assembly for consideration and endorsement.

COPUOS has a strong focus on information sharing, education, and capacity building in developing countries – seeking to bring the benefits of the use of space to all nations. While the benefit to space security may be indirect, the value of vesting more nations in the protection of the space environment – precisely because they are reaping benefits from its use – is high. The fact is that all space-faring states must understand the need for best practices on orbit, because the physics of objects on orbit mandate that what any one actor does in space has the potential to affect all others, whether positively or negatively.

COPUOS has over the past several decades made slow progress in addressing technical challenges to the space environment. Perhaps the most far reaching success in recent years was the development of a set of voluntary guidelines for space debris mitigation adopted by COPUOS in 2007, and subsequently endorsed by the General Assembly in January 2008. The guidelines represent a small, but significant, step forward for space security. Most relevant is Article 4, which pledges nations not to deliberately create long-lived debris – which in turn could be read as a pledge not to test destructive ASAT weapons. In its 2009 report, the Scientific and Technical Subcommittee agreed that "implementation of the voluntary guidelines for the mitigation of space debris at the national level would increase mutual understanding on acceptable activities in space, thus enhancing stability in space and decreasing the likelihood of friction and conflict."

The COPUOS work on the debris issue cast a light on myriad other problems facing the safety and security of outer space, and raising to a political level the long-held concern of space experts and practitioners about the need to create better international governance and management systems for space activities. In February 2010, COPUOS launched a new Scientific and Technical Subcommittee working group on "long-term sustainability of outer space" to focus on identifying problems and finding solutions. The group has been mandated to produce a proposed set of voluntary "best practice guidelines" for activities in space, including launch, on-orbit operation and disposal of satellites. In effect, this mandate addresses the issue of space traffic management in an increasingly crowded environment.

The group's objective – as laid out in the terms of reference codified in General Assembly Resolution A/AC.105/C.1/L./307/Rev.1 of February 21, 2011 – is to produce "a set of guidelines that could be applied on a voluntary basis by international organizations, non-governmental entities, individual States and States acting jointly to reduce collectively the risk to space activities for all space actors and ensure that all countries are able to have equitable access to the limited natural resources of outer space."

The work of the group has been detailed to four expert groups: A. Sustainable Space Utilization Supporting Sustainable Development on Earth; B. Space Situational Awareness (SSA) and Debris Mitigation; C. Space Weather; and D. Regulatory Regimes and Guidance for Actors in the Space Arena. The four expert groups began work at the last Scientific and Technical Subcommittee meeting in February 2012.

The working group's current mandate runs through 2014, with a draft report to be provided to the Scientific and Technical Subcommittee at its 51st session in February 2014. The Subcommittee in turn is to report to the full COPUOS in June 2014.

While COPUOS technically has no remit to address military or security issues, the scope of the working group includes addressing activities that should be recognized as de facto TCBMs, and that would necessarily affect dual-use, military and intelligence space assets and activities to some degree if they are to be effectual. Among these are orbital data collection, sharing and dissemination; notification of re-entry of satellites (or large pieces of debris); pre-launch and maneuver notification; and adherence to existing treaties and principles on the peaceful uses of outer space. Indeed, these activities are also reflected in a paper on TCBMs provided to the CD by the Russian Federation in 2009 – highlighting the difficulty of separating discussions of space governance between "peaceful" uses of outer space and security/military uses.

Nonetheless, there remain many delegations within COPUOS who oppose "tainting" its work with security issues; for example, even opposing a visit by the President of the CD to Vienna. This is already creating problems for the European-proposed Code of Conduct on space activities, which contains both civil and military/security related measures – in that while it is apparent that COPUOS's work on long-term space sustainability has overlaps with the proposed code, there is an unwillingness – from both sides – to launch a dialogue at COPUOS on the code proposal. This somewhat artificial insistence on keeping COPUOS's activities "politically correct" will, if not tempered, hamper the body's ability to impact progress on space security and at the same time deny the vast technical and legal experience housed at COPUOS to the security debate.

## 29.4 UN General Assembly First Committee

Since 1990, annual UN General Assembly resolutions emanating from First Committee (which handles security questions and meets every October in New York) stress the importance of TCBMs for reducing risks and bolstering security in outer space.

Between July 1991 and July 1993, a Group of Governmental Experts appointed by the UN Secretary-General worked on a "Study on the application of confidence-building measures in outer space." The final report detailed potential TCBMs, such as exchanges of information about space systems, but also revealed strong differences of views about the imperative for action. The report was transmitted by the Secretary-General to the General Assembly at its 48th Session in October 1993. However, almost no follow-up ensued for many years.

In 2005, Russia reengaged on the TCBM issue and since then has been the key sponsor of an annual General Assembly Resolution calling on states to support the creation of TCBMs ideas. The Russian initiatives have been widely supported – with the exception of the United States which voted against the annual resolutions from 2005 to 2008. In 2009, the Russian resolution asked governments to submit concrete proposals for TCBMs and asked the Secretary-General to submit a report on the proposals to the October 2010 session of the First Committee. Under the new administration President Barak Obama, Washington switched its no vote to an abstention.

In 2010, resolution, A/Res/65/68, was adopted at the General Assembly's 65th Session and instructed the Secretary-General to create a new Group of Governmental Experts (GGE) on "Transparency and confidence- building measures in outer space activities." One hundred and eighty three nations voted for; the United States again abstained. However, during the First Committee debate, U.S. officials made clear that the vote did not reflect a lack of support for the development of TCBMs, instead the concern was the resolution's linkage of TCBMs with the PPWT. In fact, the 2010 U.S. National Space Policy specifically pledges the United States to support space-related TCBMs. It reads: "The United States will pursue bilateral and multilateral transparency and confidence-building measures to encourage responsible actions in, and the peaceful use of, space."

The GGE includes 15 representatives of UN Member States, chosen on a basis of geographic balance. These are: Brazil, Chile, China, France, Italy, Kazakhstan, Nigeria, Romania, Russia, South Africa, South Korea, Sri Lanka, Ukraine, United Kingdom and the United States. Russia chairs the meeting, and the United Nations Institute for Disarmament Research (UNIDIR) based in Geneva provides expert consultants to assist the chair. The GGE held its first session on July 23–27, 2012, in New York. Two more sessions took place on April 1–5, 2013 (in Geneva) and July 8–12, 2013 (in New York). The group agreed by consensus to a report for the Secretary-General making recommendations for how to proceed on development of a TCBM regime for space. The Secretary-General should transmit the final report to the First Committee in October 2013.

Russia already has put forward a proposal on a possible space TCBMs, which was presented to the CD in 2009. The proposal sets out three types of TCBMs that might be applicable to the space domain: measures aimed at enhancing more transparency of outer space programs; measures aimed at expansion of information on outer space objects in orbits; and measures related to the rules of conduct during outer space activities. More specific measures proposed include:

### 29.4.1 Exchange of Information

- The main directions of the states' outer space policy
- Major outer space research and use programs
- Orbital parameters of outer space objects

### 29.4.2 Demonstrations

- Experts visits, including visits to space launch sites, flight command and control centers and other objects of outer space infrastructure on a voluntary basis
- Invitation of observers to launches of spacecraft on a voluntary basis
- Demonstration of rocket and space technologies

### 29.4.3 Notifications

- The planned spacecraft launch
- The scheduled spacecraft maneuvers which may result in dangerous proximity to spacecraft of other states
- The beginning of descent from orbit of unguided outer space objects and the predicted impact areas on Earth
- The return from orbit into atmosphere of a guided spacecraft
- The return of a spacecraft with a nuclear source of power on board, in case of malfunction and danger of radioactive materials descent to Earth

### 29.4.4 Consultations

- To clarify the provided information on outer space research and use programs
- On ambiguous situations as well as other issues of concern
- To discuss the implementation of the agreed TCBMs in outer space activities

### 29.4.5 Thematic Workshops

- On various outer space research and use issues, organized on bilateral and multilateral basis, with the participation of scientists, diplomats, military and technical experts

In addition, some elements of the European Union's proposal (the latest draft of which was released in June 2012) for a "Code of Conduct for Outer Space Activities" are quite similar to some in the Russian proposal, for example: provisions on notification of launch and maneuvers; sharing of information on space policies, strategies and "basic objectives for security and defense related activities in outer space;" and development of consultation processes. The United States, after months of interagency discussions, announced in January 2012 that it intended to work with the European Union to refine and internationalize the code proposal. In fact, a number of the proposed code's provisions – such as orbital data sharing and debris mitigation – already are featured in the U.S. National Space Policy.

Transparency and confidence-building measures are traditional tools of security in many realms, designed to improve understanding among states and reduce tensions and risks of conflict. While many TCBM regimes are focused squarely on hard-security parameters (i.e., information exchange about number of weapon systems), any regime for space will require measures that cross the somewhat artificial divide between commercial/civil and military activities. This again points to the need for the various forums involved in space security efforts to work in tandem and not at cross purposes.

## 29.5 International Telecommunication Union

The ITU is the successor to the International Telegraph Union, begun in 1865 to coordinate cross-border usage of the telegraph. It is a treaty-based organization comprised of governments who join as member states, as well as industry groups who join either as "sector members" or "associates" and may participate in ITU activities, but do not have voting rights. There are 191 member states (that is almost all UN Member States) and more than 700 sector and associate members.

The Radio Frequency (RF) spectrum and satellite operational positions on orbit (known as "slots") are legally considered limited natural resources that all states have equal rights to use. Each state manages use of the RF spectrum within its borders, but international coordination is required when signals cross borders, as is the case for all satellites. The ITU began coordinating space radio-communications in 1963.

The legal framework for the ITU was established in 1992 with the signing of the *Constitution of the International Telecommunication Union*, which entered into force in 1994 as a legally binding treaty based on the major principles of efficient use of and equitable access to the spectrum and orbits. Among other things, the constitution empowers the ITU to:

> "a) effect allocation of bands of the radio-frequency spectrum, the allotment of radio frequencies and the registration of radio-frequency assignments and, for space services, of any associated orbital position in the geostationary-satellite orbit or of any associated characteristics of satellites in other orbits, in order to avoid harmful interference between radio stations of different countries;
> b) coordinate efforts to eliminate harmful interference between radio stations of different countries and to improve the use made of the radio-frequency spectrum for radiocommunication services and of the geostationary-satellite and other satellite orbits";

Member states of the ITU are also bound to abide by the "Administrative Regulations" that govern use of the spectrum, operations of telecommunications facilities, and coordination to avoid harmful interference with other operators. The specific regulations that govern spectrum and orbital band usage in order to avoid harmful interference are contained in the Radio Regulations, administered by the Radiocommunication Sector and the Radiocommunication Bureau.

Member states must apply to the ITU for the rights to use frequency bands and orbital slots before launching a new satellite or satellite constellation, as well as for new terrestrial satellite command, control and communications stations. All commercial and civil satellites are covered by ITU regulations and procedures. Military installations are exempted from the ITU rules. However, states are urged to comply with the rules, especially with the requirement for avoiding harmful interference. Most states actually do hold their military satellites and operating facilities to the ITU rules.

ITU policies, including revisions to the constitution, are decided at ITU Plenipotentiary Conferences, which are held every 4 years. The next one will be held in Busan, South Korea, October 20-November 7, 2014. World Radiocommunication Conferences (WRCs) are held in Geneva every 3–4 years to review and revise the Radio Regulations and the Table of Frequency Allocations, the latter of which identifies what portions of the spectrum can be used by specific types of communications systems whether based on the ground, at sea, in the air or in space. The last WRC took place January 23 to February 17, 2012. These meetings serve as forums for resolving disputes about spectrum/orbital slot allocations, rules and regulations, the implementation of technical standards and incidents of interference. Each country gets one vote at the Plenipotentiary and WRC conferences, although consensus is sought.

The ITU system has been successful in managing use of the limited resources of spectrum and orbital slots to avoid conflicts among users, and in resolving problems of interference. This is partially because satellite owners and operators are usually aware that avoiding interference is in their own interests, but also because the ITU considers itself a technical rather than a political body. It is important to point out, however, that while the ITU treaty is legally binding, the ITU administrative bodies have no enforcement powers – disputes and interference incidents are usually resolved by mediation among the parties.

Most interference is caused by technical problems or operator error. However, over the past several years, the ITU has witnessed a dramatic increase in satellite interference and jamming, including deliberate interference by nation states and non-state actors for political reasons. This is obviously a question that impinges on the security of satellites, as well as national and international security of states.

One of the most longstanding problems involves alleged Iranian jamming of European satellite television broadcasts in Persian and Arabic, primarily carried by Eutelsat and Arabsat satellites. The jamming began in December 2009 and has been continuing off and on since. In January 2010, French officials asked the ITU's assistance to resolve the problem; European Union foreign ministers in March 2010 demarched Iran to cease and desist. In an extraordinary move, on March 26, 2010, the ITU's radio regulations board publically called Iran out as in violation of their ITU obligations: "In this case there is evidence that there is a deliberate attempt to block the satellite transmissions … . This is prohibited under the regulations." However, the ITU bureaucracy can do nothing to force the issue, and Iran has not admitted to the jamming despite being provided with technical evidence that the jamming signals are emanating from its territory.

Because of the increased concerns, the issue of jamming was addressed at the 2012 WRC. The resulting changes to the ITU regulations, however, were minimal due to the political sensitivities – and do little to help the satellite operators being blocked by Tehran. The WRC reiterated that deliberate interference was a violation of the ITU constitution, and the regulations were changed to state: "If an administration has information of an infringement of the Constitution, the Convention or the Radio Regulations (in particular Article 45 of the Constitution and No. 15.1 of the Radio Regulations) committed by a station under its jurisdiction, the administration shall ascertain the facts and take necessary actions."

It should be obvious that if many states begin to ignore the ITU rules for political reasons, the entire system – which is essentially based on the good faith of the member states – will be at risk. This will imperil the operations of all satellites and create a major threat to space security and to human security on the ground given the global reliance on satellite services for every day functions such as banking and communications.

## 29.6 International Organization for Standardization (ISO)

The ISO, a non-governmental agency, is a network of 163 national standards institutions – both from governments and private industry – headquartered in Geneva. The ISO produces technical and industrial practice standards; the ISO Catalogue currently includes more than 19,000 standards. The work of the ISO in standard development is broken out into various technical committees based on the type of standard involved, which are made up of experts from the industrial, technical and business sectors involved, as well on occasion governments, laboratories, NGOs and academics. There are currently 269 technical committees, including information technology and aircraft and space vehicles.

Overarching ISO policy is based on a Strategic Plan, which is approved on a five-year basis by members. Membership is divided into three categories: Member bodies (full members), correspondent members and subscriber members, only the first category can vote. The ISO General Assembly meets annually, and comprises the ISO principle administrative officers (who are voted into position) and delegates nominated by member bodies. The General Assembly deals with the ISO annual report, the Strategic Plan, and finances. Day to day governance, however, is undertaken by a Council which meets twice a year and is based on rotating membership. Operations of the ISO are delegated by the Council to the Secretary-General. There is also a Technical Management Board that oversees the technical work of the various committees.

The technical committees, which meet based on individual work schedules and in various cities all around the world, base their work on business plans developed internally to each committee but overseen by the Technical Management Board. The Technical Management Board develops so-called Directives that govern the creation of standards to ensure quality, ethics and legal requirements are met. New standards are proposed by industry sectors, and the work assigned to a standing technical committee if there is one. If not, a new committee may be formed.

ISO has no legal standing to enforce the implementation of standards developed; however many member states routinely adopt the standards into their regulatory frameworks.

ISO standards related to space mostly fall under technical committee 20, Aircraft and Space Vehicles. There are two major subcommittees: SC 13 on Space Data and Information Transfer System and SC 14 Space Operations. There is also a working group on debris mitigation. The standards are, in general, highly technical and specific – although there are also macro-standards that cover issues such as program management and quality control. In the space operations arena, there is an emphasis on safety issues. For example, ISO 26872:2010 covers safe disposal of satellites operating in GEO.

ISO standards contribute to space security in several ways. First, scientific and technical cooperation amongst space-faring nations serves as a baseline transparency and confidence-building measure – by ensuring a level playing field of knowledge and encouraging collective efforts. For example, SC 13 and 14 are developing standards (ISO CD-16158 Avoiding Collisions with Orbiting Objects and CCSDS 508.xx Orbit Data Messages) for best operational practices and data exchange that will improve the ability to avoid collisions, but also to allow a wider-spread capacity to detect undesirable activities in space.

Second, the creation of standards to underpin best practices will improve safety of space operations and thus the security of space by mitigating against accidents that could be mistaken as deliberate actions. For example, ISO 24113 Debris Management essentially operationalizes the COPUOS guidelines and ISO work on the issue is covering debris mitigation from cradle to grave. These standards therefore build credibility for the norm of debris mitigation and promote self-regulation by space operators, which reduces risks to satellites.

On the other hand, ISO standards are created only upon the initiative of operators – and are not necessarily linked to political considerations or perceived security threats. Thus, they cannot alone serve to set the boundaries of acceptable and unacceptable behaviour in space, as perception management as well as political considerations will also be crucial in establishing stability among space actors.

## 29.7 Conclusions

The numerous initiatives regarding space security now facing the international community are testimony to a growing sense of urgency among many states about the need to reduce risks in the ever-more crowded and tense space environment. While movement continues to be slow, especially within UN-related structures, points of coalescence of interests are emerging.

However, the multiplicity of proposals also reveals continued differences among states about just what must be done, including with regard to whether a voluntary or a legally binding approach is best. There also remain questions about “buy in” – even to the currently weak structures of international space governance – by states less vested in the space domain. This can lead to unproductive political horse trading in the best case; and to outright undermining of what few norms and best practices exist in the worst case.

Finally, progress toward mitigating security risks continues to be hampered by political friction among the various forums involved, and the artificial division, fostered during the Cold War and embedded in the COPUOS-CD structure, between the commercial/civil sector and the military/security sector. This issue in particular must be addressed head on if headway is to be made ANY of the venues. It would be a shame if “not invented here” sentiments and/or bureaucratic politics were to be allowed to thwart the current momentum. It will behoove state actors to recognize that national security in space is dependent on international security in space; i.e., without collective action, no state’s space assets will be secure.

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# Part III

# Space Applications and Supporting Services for Security and Defense

# Space Applications and Supporting Services for Security and Defense: An Introduction

# 30

Denis J. P. Moura and Jacques Blamont

## Contents

**Abstract**

Use of space started with the Cold War, and even today the links between space technologies and military ones are still close. However, it has also contributed to peace. With time, space activities have become more and more oriented towards civil applications, while the ones dealing with military ones were enhanced. In this section of the handbook, the applications directly or indirectly connected to security and defense are exposed by specialists of each field.

## 30.1 Past Context and Current Situation

The interest for space rose in the middle of the twentieth century from the motivation to demonstrate the ballistic missiles capacities and thus consolidate the credibility of the nuclear deterrence. Very soon however, the operational use of space emerged in front of the limitations of the ground and airborne assets used

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so far. In that frame, space has been used to progressively offer services in the fields of Earth observation, telecommunications, and positioning.

Today, as this section demonstrates, numerous space operational applications routinely deliver indispensable fast and reliable services for security and defense, all dealing with **information**: observational and geographical data and telecommunications. In addition, a limited number of countries have developed other applications such as detection of missile launches or eavesdropping (see ▶ Chap. 6, "The Laws of War in Outer Space"). The final aim of all these services is always to **ease and multiply the effects of non-space assets**.

However, due to the associated large costs, only a few countries (about ten) have purely military systems out of about 50 having today's space assets. In addition, the sovereignty issues limit the cooperation and these assets are developed mainly in national frames. It is thus important to note the **contribution of the civil space services**, developed primarily as powerful tools to support the economic growth on Earth: in most of the cases, they are also largely used for security and defense applications, and some dual-use systems have been developed to provide both commercial and governmental services.

In terms of applications and services, space is indeed essentially the main global way of collecting, transmitting, and distributing information. This is the reason why it has become, in the communication age, a major component of the security and defense systems, as demonstrated by the articles of this section.

## 30.2 Space for Security and Defense: Services and Threats

Space allows to **collect information** for remote sensing purposes offering two types of applications for intelligence, surveillance, and reconnaissance (see ▶ Chaps. 1, "Introduction to International Space Security Setting" and ▶ 2, "Defining Space Security"). On the one hand, they have a strategic function. They can support, for example, diplomatic discussions in providing data on facilities related to nuclear weapons and verification of arms limitations agreements. In the civilian area, they can help to mitigate risk in identifying in advance potential critical situations. On the other hand, imaging satellites have an operational, or tactical, function since their sub-metric resolution, now available to many stakeholders, opens the possibility to permanent refreshing on the status of a given situation as well as on troop or rescue team deployments for the benefits of military users as well as for the management of natural resources.

Communication satellites are indispensable tools for **transporting information** to support command and control between a limited number of users (see ▶ Chaps. 3, "Obstacles to International Space Governance" and ▶ 4, "Security Cooperation in Space and International Relations Theory") and, therefore, are heavily used in military operations, requiring unique requirements for protected communications. The security operations also require such reliable communication services but without the same level of protection and thus rely on commercial services. The interpenetration of the military and civilian space communication services, however, increases with, on the one hand, the needs to connect mobile assets such as unmanned aircraft and network ground forces requiring large bandwidth and, on the other hand, the growth of the commercial market, driven by the demand for broadband Internet services and video distribution. Indeed, the Pentagon is today the largest user of commercial capacities, and the European Defence Agency has launched a program to pool the national demands for commercial services.

**Distributing widely information** by space telecommunications between a very large number of users is also a basic service, and the most glaring example is direct television broadcasting. But in the recent years, satellites have been used for a new type of information distribution related to the users themselves: their own localization (see ► Chap. 5, “Spacepower Theory”), thanks, for example, to the Global Positioning System, initially reserved to military users, which benefits today to more than 800 million people. This classified system is now beneficial to the crowd, and mastering the distribution of localization is now viewed as a sovereignty issue. As a consequence, various space localization systems have been developed by Europe, Russia, and China in an uneasy cohabitation with GPS.

The current challenge is the operational merging of the previous basic services to provide **integrated applications**, delivering at user’s level more reactive and complete services (see ► Chap. 7, “The Role of Space in Deterrence”). This requires a new approach based on the notion of system of systems, where the integration of the space systems with ground-based ones is a key element. Special attention is to be paid on the possible use of these powerful integrated services for illegal purposes, as demonstrated by the 2008 terrorist attack on Mumbai where images provided by general public portals, positioning data, and direct TV signals have been used by a very limited number of terrorists.

Unfortunately, space-based services are facing two important threats (see ► Chap. 9, “Space and Cyber Security”). The first one, particularly critical for military applications, is the possibility of **attack of the associated assets**. Planned destruction of spacecraft has been achieved since 2007 by China and the United States, and there is no doubt that various methods exist to eliminate an unwanted spacecraft. This capacity was well understood already in 2000, when Donald Rumsfeld warned the United States against the possibility occurrence of a spatial Pearl Harbor. The question of antisatellite warfare has to be considered as an unsettled worry. Therefore, some countries have developed strategies and means to secure their own space assets and to counter, limit, or deny the use of space-based services to potential hostile entities (see ► Chap. 8, “Responsive Space”). The second threat comes from the **growing number of debris**, fragments of launchers, and satellites staying in the frequently used orbits for a long time (see ► Chap. 10, “Space as a Critical Infrastructure”). Since 1957, about 20,000 tons of materials have been placed in orbit and 4,500 tons are still there. Collisions between such objects initiate a snowball effect generating an explosive increase of the number of debris. Furthermore, the number of active spacecraft is planned to augment with large fleets of small and tiny satellites launched in constellation and clusters. The presence of these millions of debris could completely ban access to space in future.

In the very long term, whatever is then the political context, **space will still continue to play a key role as long as the debris issue is under control**. Indeed, in a situation of international tensions, the need of information superiority will be high while, in a situation of international peace, a large flow of information will be required for the surveillance of the application of the associated treaties, without speaking about the impact on security of the scariness of natural resources or global warming.

## 30.3 Conclusions

We can predict with a correct level of reliability that in the short and medium terms space military applications will be widely developed by a larger number of countries, with the risk to transfer in space the tensions occurring on the Earth. At the same time, rivalries for accessing to limited resources such as frequencies and orbital positions will be also increasing, adding another element for tension. However, these trends could be impacted by the worrying increase of space debris, today slightly under control by nonbinding guidelines. Within that frame, our hope is that it will not lead to one of the two following extreme cases: a real weaponization of space or a non-sustainability of space limiting de facto its use and impacting directly all mankind.

# Earth Observation for Defense

# 31

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Vittoria Piantelli, Giorgio Sciascia, and Ignazio Rana

## Contents

**Abstract**

Regardless of specific defense applications, one of the most important features requested to a spaceborne Earth observation system for defense is to perform

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with high flexibility in order to assure the satisfaction of defense exigencies whenever and wherever they arise.

Further, in a military contest, it is of fundamental importance that the data availability, once requested to the system, is assured with a probability close to 100 %.

Last but not least, important aspect in the frame of defense application is the assurance of the confidentiality and integrity of the information; it is in fact of vital importance to be sure that only those who have requested the data can be able to use it and in addition that the data have not to be alterable by external entities.

All the above mentioned aspects involve system design features that have to be taken into account in order to answer to military exigencies.

## Abbreviations

| | |
|---|---|
| ASI | Italian Space Agency |
| AIS | Automatic Identification System |
| BPD | Boundary Protection Device |
| CAPP | Controlled Access Protection Profile |
| CC | Common Criteria |
| COMPUSEC | Computer Security |
| COMSEC | Communication Security |
| COSMO-SkyMed | Constellation of Small Satellites for Mediterranean basin Observation |
| DAC | Discretionary Access Control |
| EO | Earth Observation |
| GIS | Geographical Information System |
| HW | Hardware |
| I&A | Identification and Authentication Mechanisms |
| IEM | Industrial Equipment Manufacturing |
| ISLR | Integrated Side Lobe Ratio |
| IT | Information technology |
| ITSEC | Information Technology Security Evaluation Criteria |
| LEO | Low Earth Orbit |
| MAC | Mandatory Access Control |
| MOD | Ministry of Defence |
| NSA | National Security Agency |
| PSLR | Peak to Side Lobe Ratio |
| SAR | Synthetic Aperture Radar |
| SW | Software |
| TASI | Thales Alenia Space Italia |
| TC | Telecommand |
| TEMPEST | Telecommunications Electronics Material Protected from Emanating Spurious Transmissions |

| | |
|---|---|
| TRANSEC | Transmission Security |
| TM | Telemetry |
| VPN | Virtual Private Network |
| WAN | Wide Area Network |

## 31.1 Introduction

Satellites are used in lots of fields that imply Earth observation and in all use that implies telecommunications, i.e., overseas calls, satellite TV, mobile phones, Internet, and meteorology, with the purpose, for example, to provide the study of the Earth's atmosphere and natural phenomena that occur within it influencing the weather and climate or in navigation like pointing to ships and aircraft the right routes to take; moreover, for other military purposes, satellites are used for tasks such as spy satellites, antisatellite systems, and other important applications.

The user's needs, in particular for defense, are related to achieve complex satellite systems which allow to communicate with each other by exchanging real-time thousands of data or may transmit to the ground station the information they have obtained with their powerful means of recording and analysis of the environment around them or even can spread from moment-to-moment lighted regions of the signals received from the Earth.

The success of the technology using Earth observation satellites lies in the fact that satellites can cover wide areas of the planet, even a whole continent in a few moments, using reliability communications at high speed by saving installation on the ground of several cables or repeaters; also they allow to see our planet from a totally different point of view by arranging a huge amount of information and data in a very minimal time. In addition they have often little maintenance in orbit and a long life, and in most cases the power exploited is basically the solar energy (solar cells).

Technologies for Earth observation, historically developed from the earliest photographic aircrafts for military purposes, only afterwards have seen their use and evolution on satellites because such space systems include numerous techniques for the acquisition and processing of information of various nature related to planetary surfaces which often would be not otherwise achievable.

Today, Earth observation is a constantly evolving field, in which the areas of application are expanding in parallel with the progress of technology research. The resolutions of observation are arriving to very high levels, and the electromagnetic spectrum uses sensors capable of sampling with a resolution variable reflective spectra and submissiveness of Earth areas and whose high-resolution spectrum sampling allows to measure with precision the location to get more and more accurate measurements and to better monitor the parameters descriptive of important phenomena.

For military applications or for any particular satellite tasks that require high-resolution images of a very specific area, such as the monitoring of a glacial lake or mapping of buildings destroyed by an earthquake or war reasons, a high-resolution sensor is needed. A sensor of this type generally has a width of scanning reduced, and it is installed on a LEO satellite, that is, in “Low Earth Orbit.” In an orbit of this type, it is not possible to continuously monitor the same area due to the relative motion of the satellite in relation to the Earth, and the images of a specific area can only be acquired when the satellite passes over it.

In this chapter, it is presented the Earth problematic for satellite systems and examples of their applications starting from a technical point of view, by describing the engineering features and system designs at the base of such technologies and, only after, to show some of the major satellite missions for Earth observation applications focusing on military aims. The Earth observation for defense is a real need especially for essential services to be supplied to the community in particular for environmental monitoring and enforcement of citizen’s security.

These typologies of systems are very complex and are composed by subsystems which are distributed both on ground and in space (ground and space segment), and they are strategic assets for defense and are used for the observation of lands on a global scale.

Examples for the global environmental monitoring and citizen’s security enforcement could include the aims of the national and international entities to improve situation awareness or crisis prevention through the use of technologies such as simulation or specific training, ongoing management, and postcrisis assessment. This technology can monitor the environmental parameters on large territories (i.e., region or global scale), and their applications are mostly intelligence, surveillance, and reconnaissance.

The observation systems can gain some important and multilateral uses for defense, civilian institutional, and commercial and in both national and international context achieved by the use of sensors and observation, communication networks and services, and navigation systems and services, which provide enabling technologies and service capabilities to handling and/or generating sensitive or confidential information and data.

## 31.2 Earth Observation (EO) System Features

### 31.2.1 Earth Observation System Architecture

Earth observation system is a very complex system used to acquire, process, and disseminate optical or radar images of the Earth.

Technically, each of this kind of space systems can be split in the following two main segments:

- The Satellite Segment which is composed by one or more Low Earth Orbit (LEO) Satellites orbiting around the Earth
- The Ground Segment which is composed by the following system subcomponents:

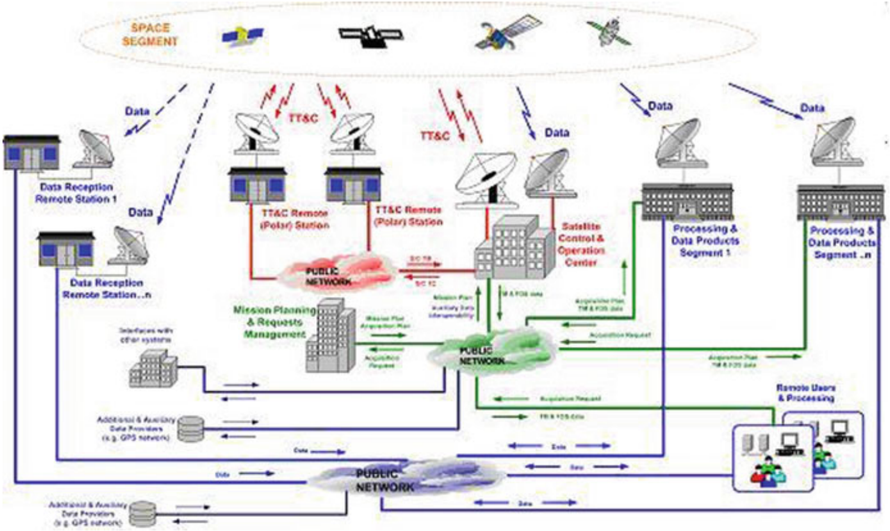


Fig. 31.1 Earth observation system architecture

- The Satellite Control Center for the control of the orbital position of the satellite constellation
- The Mission Control Center for the mission planning in relation to the user's requests
- The data acquisition stations for the downloading of images from the satellites, which is further made up of the following substations:
  - Data Processing Station
  - Remote Reception Data Station

Figure 31.1 shows an example of Earth observation system architecture with the indication of the main components and of their link interconnections, while the differences between architectures and features of dedicated defense, civilian, or dual systems are highlighted in the next sections.

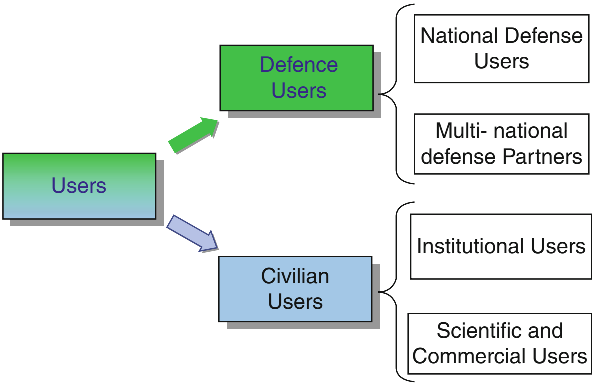
### 31.2.2 Earth Observation System Typologies and Assets

The Earth observation systems shown in the above paragraph, in Fig. 31.1, can be classified in three major families in relation to the user typologies exploiting the system itself:

- Defense systems
- Civilian systems
- Dual systems

Classification is based on the user's needs as follows (see also Fig. 31.2):

**Fig. 31.2** User typologies



- Defense systems fulfill the needs of defense users that can belong to a single nation, i.e., “national users,” or to many countries, i.e., “multinational defense partners.”
- Civilian systems, on the other hand, fulfill the needs of civilian users that can belong to institutional, scientific, or commercial communities.
- Dual systems integrate the features of both civilian and defense systems simultaneously coping exigencies of both these user classes.

In relation to the systems typologies defined above, different architectures have to be identified and taken into account during the design of a space borne Earth observation system. The major differences among these kinds of architectures reflect the user’s need to protect the sensible data managed by the system in terms of confidentiality, integrity, and availability, in conjunction with needs of system performances and functional and operational requirements; then the security ones result to driving factors for the identification of the system architecture suitable to fulfill the user need.

Dedicate defense or civilian uses of the system, in an end-to-end system, view the most important requirements and features of the systems in the domain of security, in particular on:

- Security of the infrastructure
- Security in the signal transmission
- Prevention from illicit use of the service

Earth observation space systems and security are synergic and effectively integrated as long as the space systems are the elective instruments to develop nowadays technologies and improve and provide strategic infrastructures and state-of-the-art applications for security items, while security is an enabling technology for implementing, correctly and coherently to the customers’ requests, end-to-end space systems for each kind of usage, i.e., dual and/or multilateral use.

### 31.2.3 Security in EO Space Systems

The observation space systems are, indeed, very complex information technology systems; they are distributed on ground and in space and are strategic assets

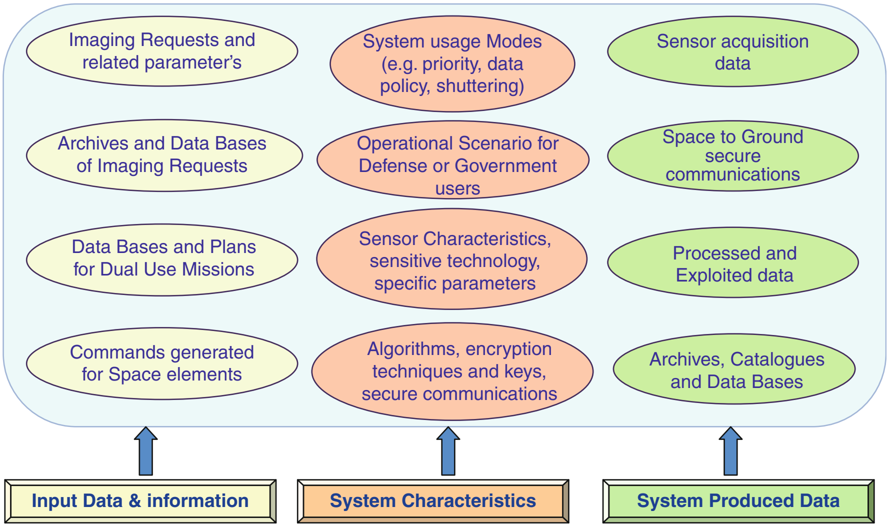


**Fig. 31.3** System data assets

(Stuart 2011; Giuseppe et al. 2010). An example of key asset is the ground segment and infrastructures, which is extremely critical both for space system security and for security applications.

Figure 31.3 shows an example of typical data assets in observation systems:

Two major drivers are demanding security in space systems:

- The system use, especially when institutional related
- The data policy, of primary interest to protect data produced and handled by the system

Security shall effectively contrast threats to ensure system's assets: observation systems can have critical information assets, due to high resolution combined with accurate geolocation capability, worldwide access, integrity and service availability to be guaranteed, and sensitive technology (for both sensing and communication infrastructure).

### 31.2.4 EO Sensitive Items and Their Protection

As defined above, the major concern for security engineering on a spaceborne observation system is the protection of the sensitive data (Consultative Committee for Space Data Systems 2006, 2007).

Sensitive data for a space borne observation system are, regardless of the user typology, the following:

- Satellite telecommands (information sent from the Earth to the spacecraft for commanding purposes)
- Satellite housekeeping telemetries (information sent by the spacecraft to the Earth about its status)
- Raw images (data acquired by the sensor(s) and downloaded to ground stations)

Telecommands and telemetries are sensible data in relation to the possibility for intentional or unintentional threats to damage the satellite, to take the control of the satellite compromising satellite service integrity and availability, to know the observed zones, or to monitor the satellite status compromising satellite service confidentiality. The sensitivity characteristics of these data are independent from user typologies.

A raw image, in its turn, is a sensible data in relation to the user typologies managing that information.

Specifically:

- In case of a civilian user, the sensitivity of a raw image derives from the potential commercial use the image will be used for.
- In case of a defense user, the information sensitivity can derive both from the specific information contained in the raw image and from the related tactical information associated with it.

In case of a defense user, indeed, in addition to the raw data itself, all the tactical information related with the request can become sensitive; it means data such as the authority requesting the raw images, the time at which the images are requested, and the information relative to the acquisition location.

It can even happen that an image itself is not classified (i.e., image of a forest or of a desert), but it becomes classified when associated to the information of who requests that image and when.

The protection of sensible data within an Earth observation system depends on the observation system typology and then on the user involved.

In particular, while the sensible data types are independent from the observation system typologies, their protection differs in case of defense, civilian, or dual system.

Specifically, for a defense system, in case of multinational defense partners involved, the protection of sensible data can be in charge to more than one authority. Therefore, in this case, in addition to a data protection related to their classification (i.e., restricted, confidential), also caveats (i.e., need-to-know restriction) have to be defined for specific data, if these data are considered as national use only.

Therefore filtering and fire walling techniques have to be implemented in the system in order to cope with caveat restriction.

On the other hand, in case of national defense system (only a defense partner involved), the protection of sensible data is managed by only one authority in charge of protecting sensible data in relation to its classification. Therefore in this case, no caveat (i.e., no need-to-know restriction) is associated to the sensible data since they are protected, managed, and used by only one authority.

The protection of sensible data defined above is performed at all levels (i.e., at ground and satellite segment levels and within the interfaces between these two entities).

At ground segment level, the protection is mainly performed by means of personal and procedural countermeasures in response to possible intentional or unintentional threats coming from users accessing the system.

At satellite segment level, the protection is principally performed by means of onboard software test (COMPUSEC, Computer Security) and electromagnetic emanation control (TEMPEST, Telecommunications Electronics Material Protected from Emanating Spurious Transmissions).

Data protection is also achieved in the onboard–ground radio link, in which connections are used to exchange telecommand, telemetries, and raw images data between the satellite and the ground stations, by means of ciphering systems (COMSEC, Communication Security).

### 31.2.5 Threats, Vulnerabilities, and Countermeasures Associated with EO System

The security design shall be managed as an end-to-end system process especially for services applications for defense users: security measures shall contrast threats to project a safe and trust system. All the aspects must be considered to achieve a system design ensuring the assets in terms of confidentiality, integrity, availability properly balancing acceptable risks with project schedule, and cost constraints where availability, integrity, and confidentiality of assets mean that the resources and data are available at any time they are required (availability), the resources and data can be modified or deleted only by the owner (integrity), and the resources and data can be accessed only by authorized users (confidentiality).

Any system has some vulnerabilities. A vulnerability is a security weakness in a system or in a product which can be used by an attacker to extend a threat and endanger an asset or defeat a countermeasure (Stuart 2011; Consultative Committee for Space Data Systems 2006).

The two major vulnerabilities in observation space system and in general in any complex system are:

- The "construction vulnerabilities" which take advantage of some property of the system introduced during its construction, e.g., the failure to clear a buffer
- The "operational vulnerabilities" which take advantage of weaknesses in nontechnical countermeasures to violate the security of the system, e.g., the disclosure of one's password to someone else

There are also potential vulnerabilities which are identified from analysis aimed to establish the correctness of security design. Vulnerability assessment is a key step to decide whether they are exploitable or not.

The residual vulnerabilities are the results of an analysis of the security design process, while the risk analysis identifies these as exploitable and correlated with significant threat.

The model of the risk analysis is aimed to predict the effectiveness of security measures in complex systems and the residual risks factors.

The model considers threat level as a function of the attack capability, of the exposition of the system assets, relevance (ranking) of assets (physical and data), and the assets exposed to threats in terms of confidentiality, integrity, and availability of data and infrastructures.

The Quantitative Risk Analysis Model is developed in two forms, due to complexity:

- Technology Risk Analysis, risk evaluation of all the security measures (technical, physical, organization) provided by the security system
- Geographic Asset-Based Risk Analysis, considering the geographical distribution of security system and political risk factors to establish the threats scenario

Methodology is derived from information security standards and expertise and extended/customized as necessary to assess systems geographically distributed, threats, and security measures of a complex system.

Concerning the security measures, they are necessary to reduce system vulnerability and impacts. They can be identified in technical (or IT) measures or nontechnical (or non-IT) measures, the first are the security enforcing functions and mechanisms of the IT system (i.e., they are implemented by HW and SW functions), while the second are physical, personnel, and/or procedural.

Satellite observation systems, as told before, mostly rely on a LEO satellite constellation in which use requires specific countermeasures to cope with architectural characteristics related to the data management.

Specifically the scarce size of mass memory available onboard the satellite for the storing of raw images acquired requires the use of several remote reception ground stations located all over the Earth for the downloading of images and their subsequent forwarding to the data processing station. Ground acquisition stations are therefore not located within the national territory and most often not under the control of the same organization/authority. Therefore specific countermeasures have to be implemented in order to guarantee the confidentiality of data within foreign organization/authority.

Moreover, the forwarding of data from the acquisition station to the central management center requires the application of countermeasures, like crypto system to ensure communication and data exchange channels, for the transmission of data through public or dedicated networks. In some cases, the use of a data relay satellite, in higher orbit, may improve this situation in avoiding the need of this several acquisition stations.

To design end-to-end system that initially has no security requirements in a secure, safe, and trust system used for strategic government and defense users, it shall be applied hereafter sensitive system items in secure environments, equipments, links, services communication, IT systems, etc.

Secure onboard and on-ground HW and SW equipments shall be managed by an access control policy, operating systems, and database management systems, while a security environment shall be implemented by a system high, multilevel secure IT, DAC, or MAC.

The space–ground links shall be NSA (National Security Agency) approved for Transmission Security (TRANSEC), a proprietary encryption, and by using a strong authentication.

The links interconnection shall be protected by BPDs (boundary protection devices) which provide domain and environment separation, hardened VPN, firewalling, and secure gateways. This BPD could be used also on a WAN to protect data exchanges on the Internet by applying Internet boundary protection like double BPD structures, DMZ, network cuts, or air gaps. These solutions are especially useful in an observation system in case of exchange of raw image data from remote reception data station to the data processing station.

The communication services architecture is established onto layers (model ISO/OSI):

- Application and transport: including management, policy, firewalling, and log collection/storing
- Network: IP addresses separation in networks with different security (e.g., domains)
- Data link security: encryption and strong authentication
- Physical link security: TRANSEC and TEMPEST

To ensure network, the cryptography is not sufficient for whole network protection: it would not ensure availability nor auditing; this is the reason for which firewalls and secure gateway are needed for overall network protection.

The security devices which connect space system components to a network shall usually provide acceptable security level by applying the following typology of measures:

- Access control to grant of permission to perform an action only to allowed users
- Identification and authentication to ascertain the identity claimed by a party
- Accounting and auditing to include access logging and allowing data flow control
- Non-repudiation such as digital signature for integrity of a message and identity
- Typical secure architecture for information system protection uses
- Trusted operating system
- Trusted Database Management System
- Identification and authentication mechanisms (I&A)

### 31.2.6 Satellite System Security Architecture Design

The architecture of a space observation system takes into account security constraints, as identified previously. This section focuses on the onboard and ground system sensitive component architecture and features.

From comparison with a generic observation system architecture (see Fig. 31.1), it can be highlighted that this architecture is characterized by several security measures such as:

- Router/switch firewall for every external interconnection (i.e., interconnection between different components composing the overall system)
- Implementation of VPN within secure domains

Moreover, ciphering systems are implemented in the onboard/ground radio link communications to gain, from a conventional system like that shown in

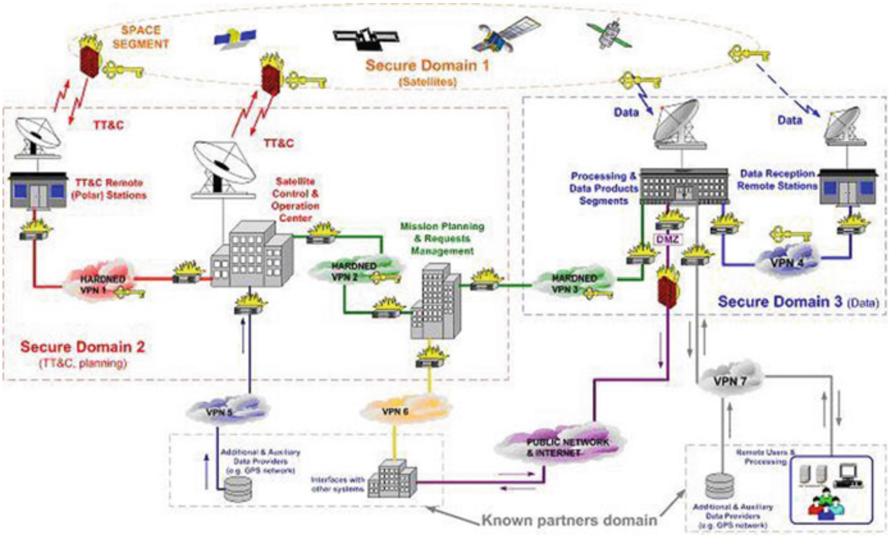


**Fig. 31.4** Ground segment security architecture for EO systems

Fig. 31.1 to a secure system as the following Fig. 31.4 (Consultative Committee for Space Data Systems 2007; Giuseppe et al. 2010).

Furthermore, within the space segment, specific security measures are implemented.

Figure 31.5 shows the security architecture of a satellite managing sensible data in a dual (defense/civilian) environment. As it can be seen, dedicated encryption related to civilian or defense data is implemented in the satellite architecture. Moreover, satellite components managing sensible data are TEMPEST (Telecommunications Electronics Material Protected from Emanating Spurious Transmissions) certified in order to prevent sensible data to be unintentionally retransmitted on ground.

These security onboard components are installed on standard reconfigurable multi-mission satellite platform which includes thermo mechanical structures, electrical power system, the integrated control system, and propulsion; the platform provides satellite agility, robustness, and resources necessary to sustain the very high operational profiles, for example, the number of images and side viewing of system.

### 31.2.7 Security Mode of Operation for EO Systems

The security in an observation space system could implement the dual operation mode which consists in a separation of domains with high security level from one or more domains with lower security. This scheme guarantees the achievement of higher security standard required for government, defense, and dual-use system applications.

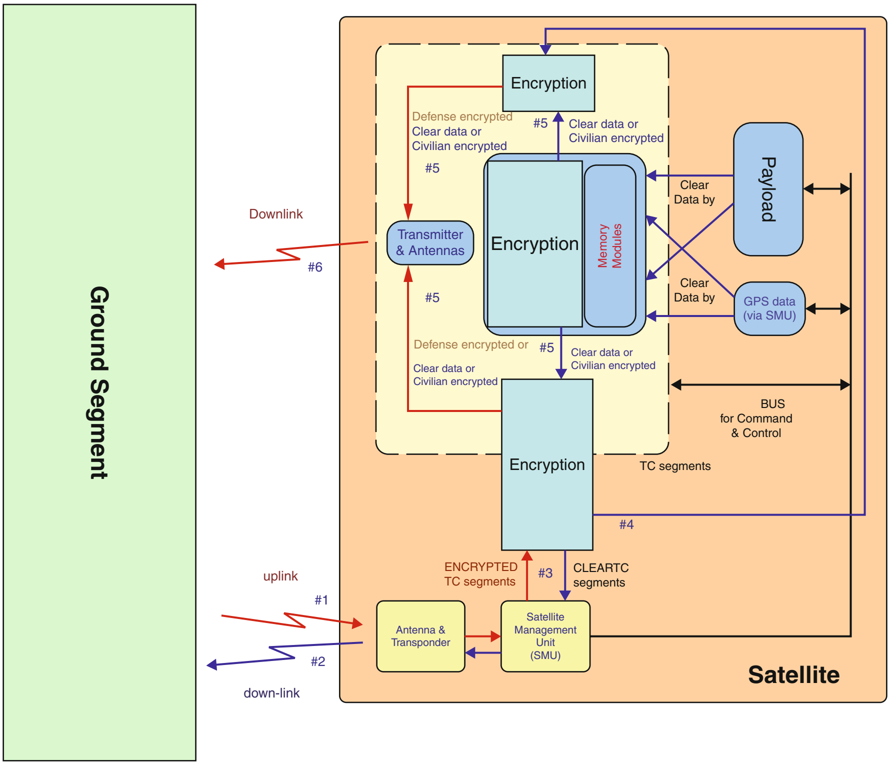


**Fig. 31.5** Satellite security architecture

Specifically the implementation of multi-domain concept is suitable to larger user communities for various applications, simultaneously fulfilling civilian and defense needs.

In general terms, the approach for multi-domain keeps separate the two (“open” and “secure”) domains, duplicating their implementation (e.g., center, databases). Within secure domain, the “system high” security operational mode imposes user clearance at the highest classification level; the access control to specific assets and resources is discretionary on the basis of need to know of each user. System high operational mode could be implemented through the ITSEC DAC (Discretionary Access Control) or Common Criteria CAPP Access Control (Controlled Access Protection Profile) inside each domain, and these domains shall be connected between each other through approved cross-domain solutions with Common Criteria certified with EAL Assurance Class.

Alternative security approach like MAC (Mandatory Access Control) could be implemented when using DAC which raises some difficult issues and deals with coalitions such as:

- Who creates the roles?
- Who determines permissions (access)?

- Who assigns users to roles?
- Are there constraints placed on users within those roles?

The MAC could be used in international system applications (e.g., multinational defense system) when different countries have different security requirements, so the need to apply also different security labels to security objects making translation between sensitivity levels is a problem for dynamic coalitions.

The multi-domain system concept will be the "system security concept" to be adopted for dual and defense applications, also for international cooperation.

Space observation systems implemented with multi-domain are systems that can guarantee high level of security.

Another typology used for space observation systems is the multilevel operation mode; it consists in a single domain, security classification of assets, and resources at multiple levels; it provides the advantage to avoid duplications of system elements and resources that may not be able to guarantee higher security, in particular where certifications are required to follow in multiuser contexts – nongovernment.

A multilevel security principle can be adopted for accessing data and information through adaptive (rule-based) mechanisms, providing access level adequate to the typology of users, information content, and operational context. This operation mode allows clearance at different classification levels, while the access control to assets and resources is discretionary on the basis of classification level and need to know of each user. Specific application can be adopted in general in those systems conceived to serve multiple user categories.

## 31.3 Earth Observation Applications for a Space System

This section, after an overview about the main Earth observation applications allowed by a spaceborne system, presents COSMO-SkyMed that, thanks to its dual-use nature and consequent design, effectively supports both defense and civilian needs.

### 31.3.1 Dual-Use Applications

The field of applications can be divided into two main families, those related with defense needs and those related with civilian ones.

The current space market tendency, also in order to save money, is that to realize spaceborne systems managing at the same time both the exigencies (i.e., dual systems).

Hereafter some generic examples of applications belonging to these two families have been reported:

- Land monitoring for Territory Risk Management
- Territory strategic surveillance for Intelligence and Homeland Security
- Specific defense purposes
- Management of environmental resources
- Maritime and shoreline control and law enforcement

- Topography
- Scientific applications for institutional entities and academics
- Application for commercial organizations (e.g., pipeline monitoring)

The generic category of civilian needs comprises several exigencies:

- Those belonging to scientific community
- Those related to urban planning and technical cartography
- The risk monitoring and prevention
- The emergency management

Scientific community needs, in which Earth observed data are nowadays vital, are, for example:

- The ocean and ice observation aiming, respectively, to pollution and to glaciers melting monitoring
- The monitoring and management of forestry and agricultural resources aiming to deforestation and biomass trend observations
- The monitoring and management of coastline and inland waters aiming to perform evaluations about shoreline erosion

As for technical cartography and urban planning exigencies, the Earth observed data are used for GIS (Geographical Information System) applications as additive information layers and for urban area development control (change detection, e.g., for identification of unauthorized buildings).

Earth observed data are also vital for risk monitoring, prevention, and management of various emergencies typologies.

Interferometric SAR data are, for example, very useful in disaster prevention through the monitoring of volcanoes or landslides movement or through the monitoring of city permanent scatters (e.g., buildings' roof) allowing to identify risky situations (buildings' collapse precursors).

Earth observed data can be also fruitfully used in first aid management in case of postcrisis situations, for example, allowing identifying the areas most damaged by an earthquake or the best way for rescues.

SAR data are also essential in sea environment care, thanks to the particular oil behavior; in fact, these data allow detecting oil spill and help in its postcrisis management.

Always in maritime field, another application of Earth observed data is the use of these as ancillary information for maritime surveillance purposes; together with AIS (Automatic Identification System) data, EO ones allow detecting non-collaborative ships.

In the frame of security and defense applications, current Earth observation systems have to be considered as strategic assets given that they can satisfy medium- and long-period exigencies.

These kinds of assets allow in fact applications like border surveillance for unusual troop movement's detection or critical site monitoring (military site, port, airport, or in general target of interest) for retrieving information about habits and military forces engaged.

As example of a spaceborne system that answers to the exigencies of both civilian and defense users class, the following paragraphs provide the description of the CSK system and then detail its design versus dual-use applications.

### 31.3.2 The COSMO-SkyMed Dual-Use System

COSMO-SkyMed is the first spaceborne Earth observation system implementing a dual-use architecture (for civilian and defense needs satisfaction in both national and international contexts), and it has been commissioned and funded by ASI and MoD in 2003 to TASI (Thales Alenia Space Italy) as prime contractor.

The system design and development has been led by TASI in collaboration with a large industrial team comprising many other small- and medium-sized Italian companies mainly belonging to Finmeccanica group (e.g., Telespazio, responsible for the development of the user ground segments and of the control center).

The dual nature of the system can be retrieved already in its mission objectives relaying mainly on the capability to provide information and services useful for a large number of activities and applications in both civilian and defense contexts, such as:

- Risk management
- Cartography and planning
- Agriculture
- Forestry
- Hydrology
- Geology
- Marine domain
- Archeology
- Defense and intelligence applications (Fig. 31.6)

COSMO-SkyMed system consists of a space segment composed by a constellation of four Low Earth Orbit midsized satellites, each carrying a multimode high-resolution Synthetic Aperture Radar (SAR) instrument operating in X-band frequencies and a full featured global ground segment allowing a proper exploitation of space capabilities (Fig. 31.7).

Both ground and space segments are conceived to support dual use, the space segment thanks to an antenna granting a wide spread of resolutions and swaths, whereas the ground segment thanks to the duplication of its key elements (CUGS Civilian User Ground Segment, DUGS Defense User Ground Segment) and a series of rules and procedures granting a secure data circulation (see Fig. 31.8 for details).

The success achieved by this spaceborne mission is testified by the interest that it has generated in other countries and that has lead ASI (Space Italian Agency operating as a procurement agency for the French defense administration) to assign, on December 2005, an additional contract to TASI for the provision of an integrated Defense User Ground Segment located in France (i.e., the French User Ground Segment, F-DUGS) in order to allow the French defense receiving and generating the COSMO-SkyMed system products.

The COSMO-SkyMed French Defense User Ground Segment is today fully operative, and according to Italian and French government partnerships, a bilateral image-trading protocol has been established: COSMO-SkyMed SAR

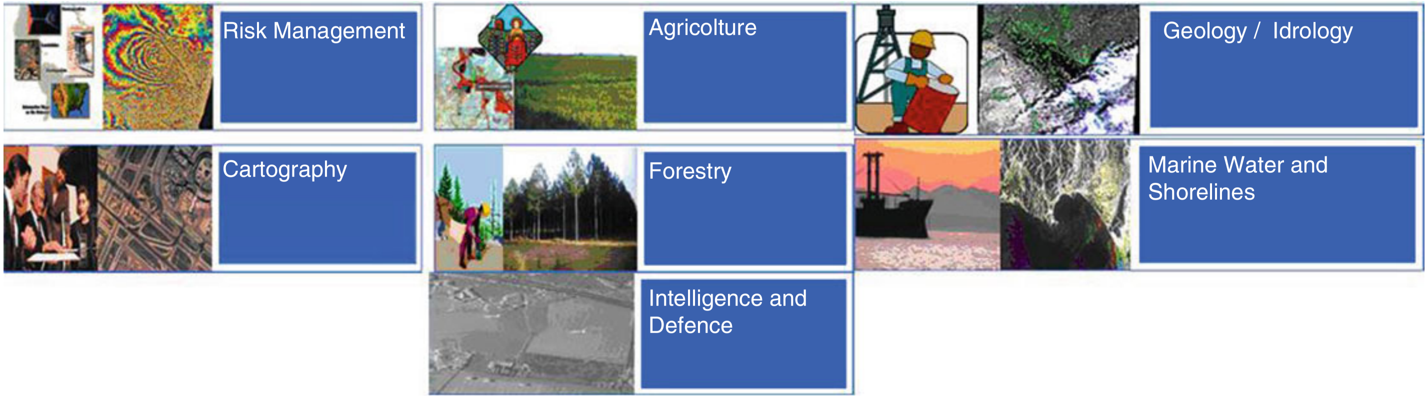


**Fig. 31.6** COSMO-SkyMed main application

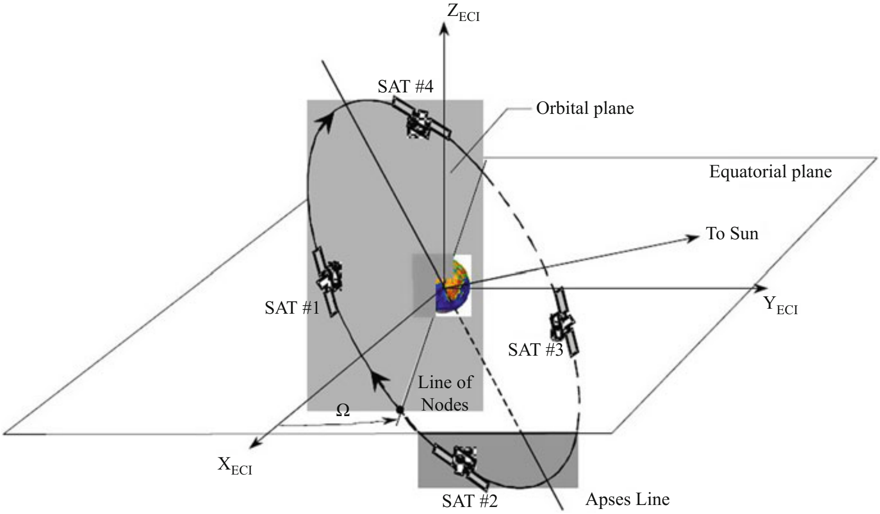


Fig. 31.7 COSMO-SkyMed space segment

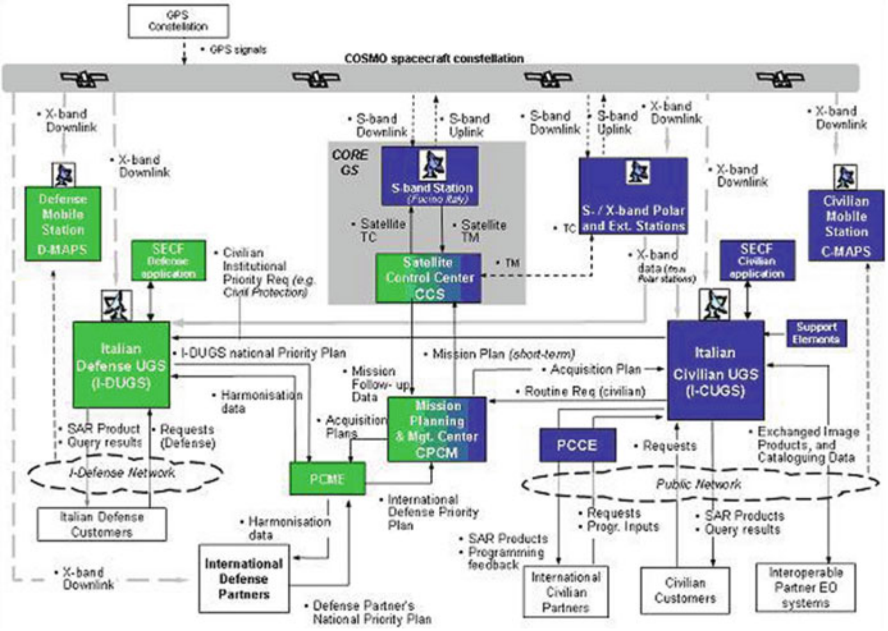


Fig. 31.8 Dual system architecture

image products are exchanged with Helios 2 optical image products to support institutional defense applications.

This scalable approach in integrating a new UGS in its architecture has been possible, thanks to the flexibility versus external interfaces with which COSMO-SkyMed has been designed and developed.

The COSMO-SkyMed scalability has been also exercised through the integration of other mobile acquisition station and processing center in the system.

In addition to scalability, COSMO-SkyMed is also designed according to the IEM (Interoperability–Expandability–Multi-sensoriality) approach described hereafter:

- Interoperability: ability of exchanging data and information with external heterogeneous systems according to agreed modalities and standards and irrespective of internal design of the cooperating parts.
- Expandability: ability of system architecture to embody mission-specific components “imported” from partner’s EO systems.
- Multi-sensoriality: ability to request, process, and manage data related to different observation sensors. Such a feature is architecturally and procedurally based on abovementioned interoperability and expandability concepts.

### 31.3.3 COSMO-SkyMed System: Key Performances and Capabilities for Dual-Use Applications

The design and development of COSMO-SkyMed system has been driven for support of dual use already starting from the high-level requirements that have been imposed on it and that have brought to the following needed performances:

- Large amount of daily acquired images
- Satellites worldwide accessibility
- All weather and day/night acquisition capabilities
- High-frequency refresh information (i.e., short revisit time)
- Short time interval between satellite data acquisition and product availability for delivery at user (i.e., short information age)
- Short time interval between user request submission and release of the remote-sensed product (i.e., system response time)
- Very fine image quality (e.g., spatial and radiometric resolution, controlled PSLR, and ISLR)
- Possibility of image spatial resolution trade-off with size, at most possible extent including also submeter resolution
- High geolocation capability (i.e., small error difference between the measured location of the target in the SAR image and the its true location)
- Capability to generate DEM (Digital Elevation Model)
- 3D object applications

In the following the above mentioned performances and capabilities have been detailed, and the bounds with user applications have been highlighted.

#### 31.3.3.1 Large Amount of Daily Acquired Images

The abovementioned requested performances have brought COSMO-SkyMed to be currently the most complex spaceborne imaging SAR system designed and built in Europe; its four satellites allow a very high operational capability and flexibility, granting up to 1,800 images per day (450 per satellite – 375 wide field and 75 narrow field).

Such a large operative capacity allows the system to avoid resource saturation in many operative conditions.

#### 31.3.3.2 Satellites Worldwide Accessibility and All Weather Acquisition Capabilities

These 1,800 images, thanks to the sun-synchronous polar orbit, can be acquired worldwide and in all weather conditions (feature granted by the use of X-band).

The worldwide acquisition capability allows accessing and monitoring any country in the world giving a great strategic advantage to the system owner for intelligence and monitoring purposes; further, the all weather acquisition capability gives an additive great advantage to this system with respect to optical ones often blinded by cloudy weather.

#### 31.3.3.3 High-Frequency Information Refresh (i.e., Short Revisit Time)

The revisit time is defined as the time between two consecutive satellite passages (coverage gap) which allow a given site anywhere placed on the Earth to be sensed by the (SAR and/or optical) instrument, independently from the satellite of the constellation accessing the site and from the access geometries (e.g., different incidence angles, ascending or descending satellite passages).

As more than one access couple exists over each site during the orbital repeat cycle, the revisit time is a statistic concept, and so this performance has to be further specified in terms of average or maximum values.

COSMO-SkyMed, thanks to its four satellites and to a high instrument access area ([20°–59.5°] incidence angle), is characterized by a revisit time in order of hours, a performance much better than that of other previous and concurrent systems composed by one or two satellites.

COSMO-SkyMed system assures an average revisit time performance of about 6 h in the worst case (see Fig. 31.9); this means that a sensitive site could be monitored in average once every 6 h giving so the possibility to sample it more frequently looking for suspicious behaviors.

Figure 31.9 reports also the maximum revisit time performances of COSMO-SkyMed system that is in the order of 12 h in the worst case during the whole orbit repeat cycle.

#### 31.3.3.4 Short Time Interval Between Satellite Data Acquisition and Product Availability for Delivery at User (i.e., Short Information Age)

Information age is defined as the time elapsed from the observed data sensed and stored onboard up to the product availability at the processing center for the delivery.

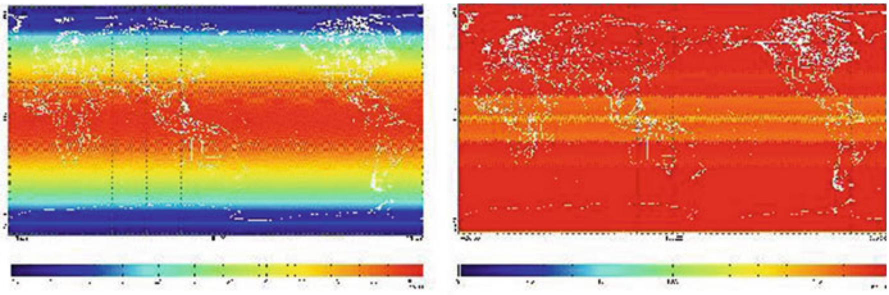


**Fig. 31.9** Average and maximum COSMO-SkyMed revisit time

This key performance depends mainly by the ground station distribution over the world and by the processing time necessary to process the data downloaded on ground.

This key performance indicates to the user how old the image seen is at the moment at which he visualizes it.

If enough is reduced, such key performance would allow the user to organize and put in place response actions to particular threats detected opportunistically on the image and having an evolution in a time scale comparable to that of the information age.

Current COSMO-SkyMed system information age spreads from about 7.6 h in the worst case up to 1 h in case of direct visibility with the ground station (this happens, e.g., on the Mediterranean area in direct visibility with Matera ground station).

#### 31.3.3.5 Short Time Interval Between User Request Submission and Release of the Remote-Sensed Product (i.e., System Response Time)

System response time is defined as the time elapsed from the user request submission up to the availability of the relative data product at the processing station.

This figure of merit depends both by geometrical features of the system (orbit, access area, ground station distribution) but also by the system chronology (time schedule of all the operation necessary to handle the request in a first time and then the data on ground).

This key performance indicates to the user when, after the request submission, the image product will be available to him.

A short response time answers to the need to manage quickly crisis situation when these arise and to have shortly clearer situations awareness, thanks to satellite SAR imaging (e.g., after an earthquake or a bombing).

COSMO-SkyMed, depending by the seriousness of the situation that has to be monitored, can operate in three different ways that allow reducing response time, thanks to an optimization of system chronologies:

- Routine is a synchronous system operation mode working on a 24 h time span, and it is used as default operation mode in normal condition; the requests are submitted once a day.

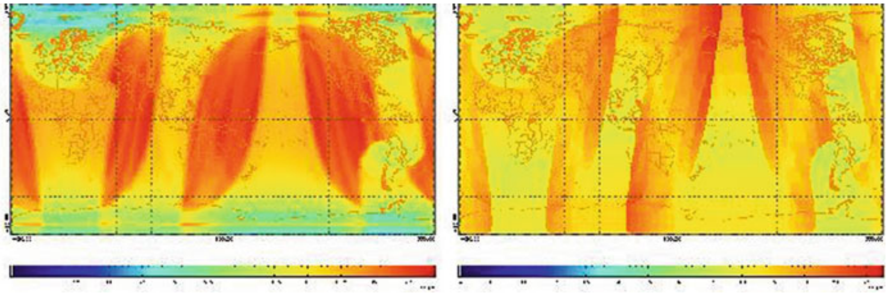


**Fig. 31.10** Average and maximum COSMO-SkyMed response time V.U

- Very urgent is an asynchronous system operation mode working on demand; the request is submitted as soon as the emergency arises.
- Crisis is a synchronous system operation mode working on a 12 h time span, and it is used to monitor the evolution of emergency situation; requests can be submitted twice a day.

Figure 31.10 reports colorimetric maps of average and maximum response time performances.

#### 31.3.3.6 Very Fine Image Quality (e.g., Spatial and Radiometric Resolution, Controlled PSLR, and ISLR)

The image quality concept comes from the control of a set of simpler properties, different depending by the sensor considered, that as a whole give a measure of image quality.

In particular, dealing about SAR sensor, these properties are:

- Resolution – in azimuth and range – is the distance between two objects on the ground at which the images of the objects appear distinct and separate (it is measured 3 dB down from the top of the main lobe of the impulse response).
- (PSLR) peak to side lobe ratio – ratio between the returned signal of the main lobe and that of the first side lobe of the point target.
- (ISLR) integrated side lobe ratio – ratio between the returned energy of the main lobe and that integrated over several lobes on both sides of the main one.
- Geolocation accuracy is the difference between the measured location of the target in the SAR image and its true position.

All these properties, adequately controlled through a set of requirements appropriately engineered from user ones, allow obtaining images of high quality, simplifying and improving the image interpreter work in both cases; it is finalized to a civilian or defense purpose.

#### 31.3.3.7 Possibility of Image Spatial Resolution Trade-Off with Size at Most Possible Extent Including Also Submeter Resolution

One of the major evidence of COSMO-SkyMed dual-use destination is the versatility of the SAR instrument, the true enabling core of this system, capable to provide image products with different resolutions and sizes (Italian Space Agency),

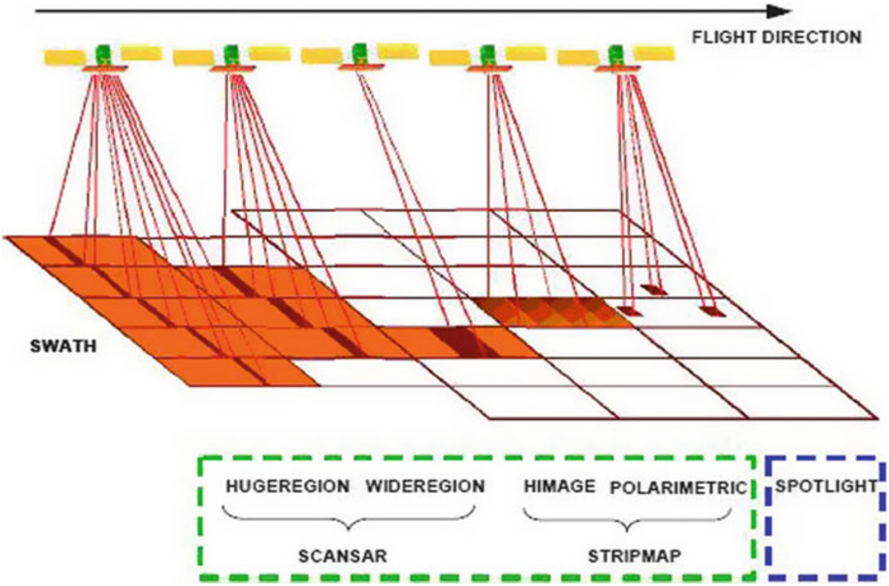


**Fig. 31.11** Cosmo-SkyMed SAR acquisition mode

**Table 31.1** Swath and resolution COSMO-SkyMed SAR operative modes

| | Himage | Ping Pong | WideRegion | HugeRegion | Spotlight-2 |
|---|---|---|---|---|---|
| **Swath [R Km × A Km]** | 40 × 40 | 30 × 30 | 100 × 100 | 200 × 200 | 10 × 10 |
| **L1A on ground res. [R m × A m] Single look** | 3 × 3 | 15 × 15 | 6 × 21 | 22 × 30 | 1 × 1 |
| **L1B on ground res. [R m × A m] Multi look** | 5 × 5 | 20 × 20 | 30 × 30 | 100 × 100 | 1 × 1 |

spanning from narrow field/high resolution throughout very huge field and mid-/low-resolution images satisfying, respectively, defense and civilian needs (Fig. 31.11, Table 31.1).

Defense usually needs very high-resolution product in order to perform target recognition; the reduced swath dimensions (see spotlight case) are due to limits of the technological status of the art.

Civilian users, on the other hand, usually need the monitoring of larger areas at medium–low resolution for environmental analyses purposes.

#### 31.3.3.8 High Geolocation Capability (i.e., Small Error Difference Between the Measured Location of the Target Detected in the SAR Image and Its True Position)

A particular consideration shall be dedicated to the geolocation capability; this figure of merit is very important for defense application allowing to avoid misleading target detection and recognition (e.g., within complex scenarios).

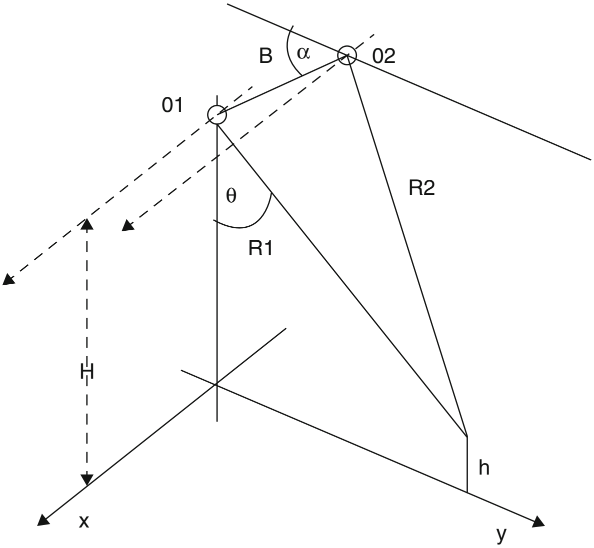


**Fig. 31.12** Interferometric acquisition geometry

Civilian geolocation requirement asks for an accuracy of 15 m, but system performance results to be much better than requirements asked.

The system geolocation capabilities have been assessed by third parties (United States National Geospatial-Intelligence Agency) confirming what certified during the four system commissioning, i.e., a performance geolocation in the order of about 4–5 m and less.

### 31.3.3.9 Capability to Generate DEM (Digital Elevation Model)

The availability of a DEM is of fundamental importance for defense applications; it is simple to understand in fact that the precise knowledge of terrain topography gives high advantages to a defense user in planning its strategies.

The Digital Elevation Model can be obtained through the processing of two interferometric acquisitions.

Thanks to properties of an image SAR product, each pixel is in fact characterized by two information (one related to the energy backscattered by the target, modulus, and another related to the target distance, phase).

Two images acquired on the same area and opportunely co-registered allow generating interferograms (i.e., products where each pixel highlights the phase difference) from which it is then possible to retrieve a Digital Elevation Model (DEM); a simplified approach to the DEM retrieving is reported in the formula below (Fig. 31.12).

$$h = H - \frac{\left(\frac{\lambda\Phi}{4\pi}\right)^2 - B^2}{2B\sin(\theta - \alpha) - \frac{\lambda\Phi}{2\pi}}\cos(\theta)$$

where B is the satellites baseline, Φ is the phase difference, and λ is the wavelength (Dongchen et al. 2004).

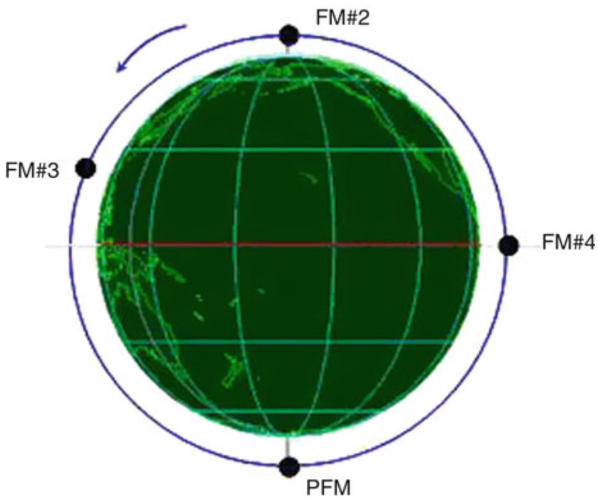


**Fig. 31.13** Current COSMO-SkyMed 1-day interferometry "tandem-like" configuration

These two images shall be acquired with quite the same geometry, and the acquisitions can be contemporary or displaced in time according to two main operative configurations:

- "Tandem" configuration, i.e., the two satellites are shortly displaced in time and space, and the two acquisitions are highly correlated in time.
- "Tandem-like" configuration, i.e., the two satellites replicate quite the same acquisition geometry at higher time spans in the order of some days; the two acquisitions in this case result less correlated in time.

COSMO-SkyMed system can support both configurations, but it is currently deployed in 1-day tandem (or tandem-like) configuration (see Fig. 31.13) that allows the satellites FM#2 and FM#3 of the constellation, displaced of 67.5° in true anomaly, to pass over the same area and with the same acquisition geometry at a time span of 1 day.

Other CSK satellites, thanks to the particular orbital design, pass over the same area and with the same acquisition geometry at larger time spans; the whole sequence passage in the 16-day orbital repeat cycle is the following:

- FM#2 on day 0
- FM#3 on day 1
- FM#4 on day 4
- PFM on day 8

Here below, as exemplificative case of logical sequence that leads to DEM generation, it is reported in Fig. 31.14 in which all the passages from the two interferometric acquisitions up to Digital Elevation Model generation have been depicted; the particular DEM is referred to Etna Volcano.

Another significative evidence of COSMO-SkyMed interferometric capabilities is reported below (Fig. 31.15) and is referred to Spotlight 2 interferometric acquisition of October 2007 on Cairo and in particular on pyramids.

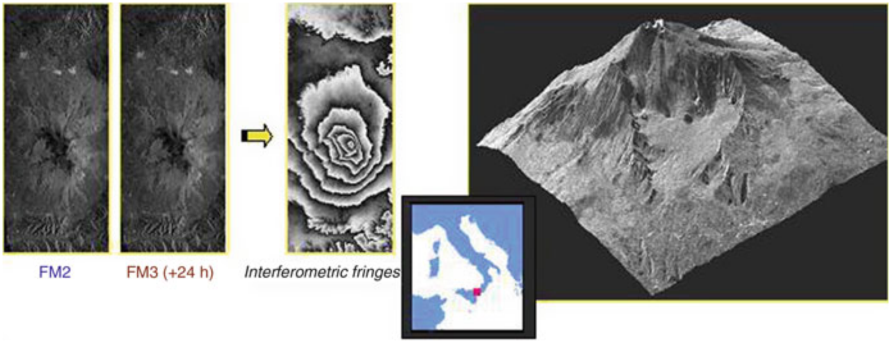


**Fig. 31.14** Etna Volcano DEM generation

**Fig. 31.15** Spotlight 2 interferometric acquisition on Cairo

### 31.3.3.10 3D Objects and Applications

A further application can be achieved by exploiting the fusion between optical and SAR data with Digital Elevation Model; this application allows 3D visualization and an improved interpretation of high-resolution data (Fig. 31.16).

Modern spaceborne SAR sensor systems, like COSMO-SkyMed, provide geometric resolution in the order of one meter.

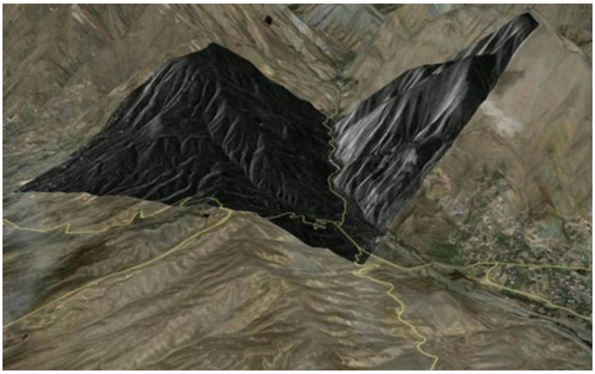


**Fig. 31.16** DEM/SAR/optical data fusion

However, because of the side-looking SAR sensor principle, layover and occlusion issues inevitably arise in undulated terrain or urban areas. Therefore, SAR data can be difficult to be interpreted even by senior human interpreters.

As seen, SAR interferometry from pairs of such images allows obtaining Digital Elevation Models of the same grid spacing.

The fusion of optical, SAR data, and DEM simplify the interpreter works, and thanks to data fusion, many features of urban objects become visible.

## 31.4 Conclusions

This chapter analyzes the main technical features of space observation system in order to provide an overview of their capabilities (with particular attention to defense and dual systems) and security engineering issue since these two elements have to be interactive and complementary to achieve the user's goals and a trusted and usable system.

This chapter starts with the description of the security methodologies that have to be applied to implement a safe and secure satellite system, and then it presents a section focused on some Earth observation spaceborne application with particular focus to defense exigencies.

As explained in this chapter, the overall system architectures, the management of the sensible data, and the operating mode of the system itself are deeply driven by users which need secure and safe design features to enable the system to be operable in real contexts. This goal is more felt in particular by defense for the more restricted requirements they need, like the exigency to operate in a dangerous context or to protect strategic assets.

Nowadays the current Earth observation systems context answers also to civilian and commercial needs, so the possibility of cooperation among different users typologies (defense and civilian) is being investigated by the industries and institutions. The current space market tendency, indeed, is that to realize spaceborne systems managing at the same time both defense and civilian exigencies (i.e., dual systems). These dual spaceborne Earth observation systems are an interesting and emerging typology which gives the opportunity to a large variety of entities to obtain Earth observed products exploiting the same system to its maximum extent with a consequent money saving for the entities involved.

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# Earth Observation for Security and Dual Use

# 32

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## Contents

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**Abstract**

After a recall of the genesis of Earth observation from space, the article deals with the issues linked with dual use of space imagery. After an attempt to define duality, some examples of dual-use systems are exposed. The objectives, benefits, but also blocking issues are then addressed through some study cases and analyses.

## 32.1 Introduction

In the scope of security, defense but also management of state, to monitor what was happening over a limited area or country, has always been of main importance. As soon as the end of the eighteenth century, the use of balloon created a revolution in the way to monitor: it became possible to monitor the things with the same vision of a bird. At the beginning of twentieth century, it became more obvious with “aeroplane” that getting this bird’s-eye vision was an asset for military missions. In the middle of the twentieth century, to survey USSR without overflying it, imagery satellites became the solution.

Since the 1990s the world seems more stable, and the technology of imagery satellites developed so fast that it became possible to use them regularly for civilian mission with Landsat and Spot. In the beginning of the twenty-first century, civilian technology (high-resolution imagery) was developed enough to be used also in the security field: management of crisis, protection of citizens and infrastructure, maritime surveillance, and border monitoring.

The shrinking of military budget after end of the Cold War or in 2012 during the world economic crisis will push forward the cooperation between military people and civilian people for the use of such expensive tools in order to save money. Duality in using or building high-resolution imagery satellites is becoming the standard. All around the world different solutions of funding are tried to make this duality real:

- Funding them in cooperation between the MoDs and the ministries in charge of security
- Funding them on a dual mode: mainly military funding and commercialization for security and other business in order to access new users and thus decrease the overall cost

Nevertheless, whatever the financial and operational rationale, it is also obvious that in some countries the mind-set and even the constitution are not in favor of involving military means within civilian security. Future will tell us if it was possible to continue to separate HR satellite imagery between two different parts, military and civilian, or if at the end HR satellite imagery will become the standard.

## 32.2 Genesis of the Earth Observation from Satellite

Either in kingdoms, empires, dictatorships, and democracies, throughout history, the knowledge of the situation behind the borders has always been one of the main targets of all the governments.

To achieve such objective, human intelligence with ambassadors, national traders, journalists, and spies has always been one of the core means.

As soon as 1783, the French industrial Giroud de Villette lobbies the royal army and promotes the use of balloons for military/intelligence purposes, mainly for observation of enemy armies.

In June 1794, the French Revolutionary armies of the North operationally used balloons to observe enemies during the battles of Charleroi and Fleurus, with success. This is the first organized use of the third dimension for military purposes with the creation of the military company of "aerostiers" (Fig. 32.1).

During the First World War, the use of balloons was generalized in order to:

- Update the military maps
- Support the artillery for firing beyond the line of sight
- Provide permanent observation of enemy's lines with immediate information to the headquarters using telegraphy (at that time the armies are close together in the military trenches)

**Fig. 32.1** Use of l'Entreprenant during the battle of Fleurus, 26th of June 1794 (Copyright Ecole Polytechnique)

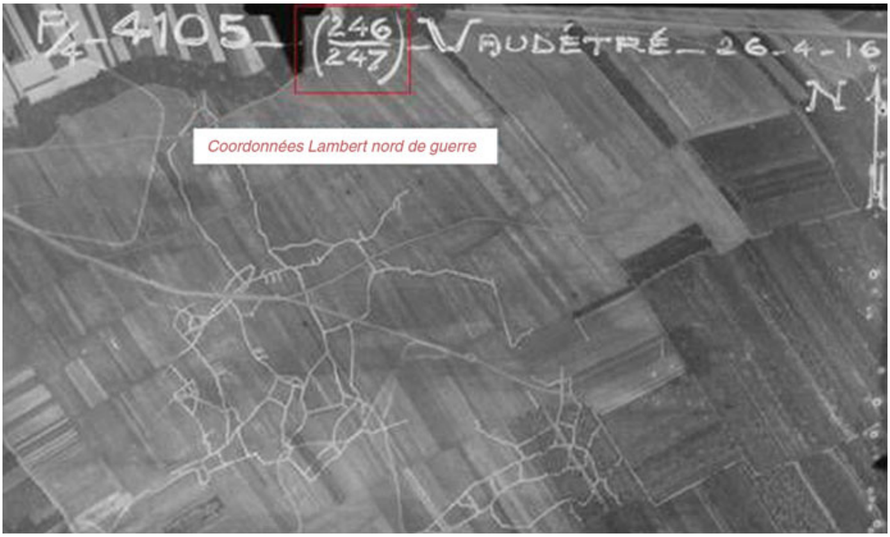

**Fig. 32.2** Aerial photography of Vaudétré (France, 51) the 26th of April in 1916 – Collection SHAA (Copyright numérisationterrain.fr)

In that period, the military sector showed also interest in the use of aircrafts. Before that time, aircrafts were only used as a sport for the rich. The use of aircraft enhanced the provision of information/intelligence about what is happening far from the lines of combat... Moreover the air recognition aircrafts using cameras provide vertical images which can be used by the "aerostiers" in the balloon to provide coordinates of the targets to artillery (Fig. 32.2).

Observation of the Earth from air is then of main interest for military purposes. It is achieved by using the vectors such as balloons (permanent observation) and aircrafts (beyond the combat line).

During the Second World War, the way to operate changed: despite the French defensive "ligne Maginot," armies were not anymore static. Therefore, when the headquarters accepted this fact, the observation balloons were out of interest.

That period was the apogee of air recognition which is of main importance to:

- Define targets for all the bombing
- Assess the damages
- Survey movement of troops along lines
- Detect targets in define areas
- Create maps for tactical and strategic decisions

After the World War II, USSR tried to develop nuclear bombs and missiles at an incredible rhythm. The Central Intelligence Agency developed the U2 aircraft flying at very high altitude which became operational as soon as 1956. Such an air reconnaissance system provided a riskless observation of the Chinese and USSR territories. It must be noted that at that time, military people believed that no missile or aircraft was able to intercept such an aircraft flying at 21,000 m.

At the same period the RAND institute started to imagine and promote a robot flying outer of the atmosphere around Earth, which could take photographs of the enemy's countries without intrusion since no authorization is needed to fly objects in space.

In 1957, with the success of Sputnik, it became clear that USSR was be able to develop ICBM and the CIA and Air Force started to develop projects to observe USSR territory with a spacecraft, a robot flying in space (respectively, Corona and SAMOS projects).

On the 1st of May 1960, the U2 piloted by Gary Powers was shot down by USSR and the pilot was captured. In July 1960, although it appeared that USSR was increasing the gap regarding the number of ICBM, US President Eisenhower stopped all flights of U2 over USSR. This way, since photographic satellite projects were not successful yet, USA was left without any reconnaissance means.

Financial and organizational measures were taken, like the creation of the National Reconnaissance Office which merged the dedicated teams of Air Force, CIA, industries, and other governmental organizations dealing with space reconnaissance. As soon as 1961 the first Corona missions are successful and NRO is able any part of the world including USSR with satellites named Key Holes.

The Key Hole satellites had the following missions:

- Collection of the national intelligence/information plan
- Detection of nuclear facilities
- Mapping of enemy's territories for Strategic Air Command
- Surveillance of deployment of air defense systems

Those reconnaissance satellites were rapidly recognized as a nonintrusive technical means of verification. Then both parties recognized them as contributors to stability and confidence building. In the 1970s, ABM and SALT agreements didn't interfere with satellites of reconnaissance/observation.

In June 1978, in an attempt to set the difference between military and civilian imagery, President Carter issued the PD/NSC-37 which allowed the distribution of commercial imagery with resolution such as Landsat to 10 m (Florinini, p. 100).

As soon as the late 1970s, in order to keep a strategic independence, France decided to develop the access to this strategic observation mean with the program SAMRO "SAtellite Militaire de Reconnaissance Optique." The project was stopped in 1982, although approximately 250 M€ were spent. This decision can be explained by the following reasons:

- A political change occurred in France.
- Technical performance of SAMRO (10 m of resolution) was not at the level expected by military people (at least 6 m) and too much linked with the nuclear strategy (cities became nuclear targets).
- SAMRO was at that point too expensive for the sole French Defense budget since Germany refused to participate to the funding and France preferred to secure the budget for the satellite telecommunication program SYRACUSE).

Nevertheless, France decided to use the research done and to launch a demonstrator: the civilian satellite SPOT 1 "Système Probatoire d'Observation de la Terre" (Probative system for Earth observation). The development and launch were done under the responsibility of scientific people from the French Space

Agency (CNES). Moreover, in order to disseminate the information and to try to generate some revenues, the company Spot Image is created in order to promote and distribute the images of SPOT. It is the first private company (even if the main shareholder was the French State via the CNES) in the world to commercialize satellite imagery with a resolution of 10 m. In 1986 satellite imagery is not only a military product but also a commercial and civil one.

At the same time, with the successful development of SPOT1, France decided to launch a military observation satellite with better performance (resolution ~ 1 m), in cooperation with Italy and Spain, the Helios system which will be launched in 1995 and will cost around 2–3 b€.[1] As soon as 1986, it was decided between CNES and the Ministry of Defence that the fourth generation of the SPOT satellites and the Helios satellites will use the same platform.

It has to be stressed that the imagery of SPOT was initially commercialized mainly for economic reasons.

In the beginning of the 1990s, with the explosion of the USSR, it became clear for the US satellite firms that developing missions and application depending only on the US Defense budget only was not possible anymore. Also the SPOT example had shown that satellite imagery could be used by the civilian market, providing income that could be used as an important source of growth. The relevant US industry made a strong lobby, and in 1994 President Clinton issued the presidential decision PD-23 which allowed unlimited resolutions for commercial imagery satellite systems and then firms to develop and launch high-resolution satellites and sell the images. Also, the US government has been committed to using commercial imagery satellites, in order to save money and help ensure the health of the domestic industry. However, this directive forced the US companies to request authorization before building satellite and to be able to turn off access to high-resolution imagery in case of conflict (shutter control).[2]

Even today, satellite-operating companies must get commercial imaging satellite-operating licenses by the National Oceanic and Atmospheric Administration (NOAA). NOAA is coordinating satellite-imaging applications among several governmental agencies, in order to ensure that any license is compliant with all US national security and foreign policy concerns and with all international obligations of the USA. Some of the rules and constraints that the companies must comply for granting the operational license are:

- Positive operational control of the specified satellite systems must be maintained from a location within the USA at all times.
- Restriction from disseminating panchromatic imagery with a resolution better than 0.5 m or multispectral imagery with a resolution better than 2.0 m within 24 h of collection to anyone other than the US government.

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[1] The total cost of Helios program was estimated around 10 bFr in 1995 which can be considered as 2–3 b€ of today.

[2] Conflict has to be understood as a period when national security, international obligations, and/or foreign policies may be compromised.

- The companies are requested to obtain DoC approval before implementing "significant or substantial" agreements with foreign nations, entities, or consortiums (foreign persons) to protect the national security and foreign policy interests and international obligations of the US government. Transfers of "significant or substantial" agreements also require DoC approval, such as customer agreements for high-resolution imagery collection and distribution, operating agreements, and agreements relating to equity investments in the company of at least 20 % of the total outstanding shares, and entitle a foreign person to a position on our Board of Directors. Foreign persons entering into "significant or substantial" agreements with the US satellite operator are required to comply with the DoC license imagery collection and distribution restrictions and are subject to the US government's exercise of "shutter control," which could adversely affect the ability to collect imagery products for distribution to foreign customers.
- The US government reserves the right to exercise "shutter control" – the interruption of service by limiting imagery collection and/or distribution as necessary to meet significant US government national security or foreign policy interests or international obligations.
- Restriction from disseminating imagery of the state of Israel with a resolution better than 2.0 m. An amendment was passed in 1997 by the Congress, and after protestations by Israel in 1998 when the VHR imagery sales were allowed, it is still applicable.

Moreover, satellite-operating companies that have classified US government-related business are required certain facility and personnel security clearances. Standards for the protection of classified information released or disclosed to industry in connection with classified US government contracts are provided in the National Industrial Security Program Operating Manual (NISPOM). NISPOM also expresses restrictions to non-US ("foreign") ownership, control, or influence, or FOCI, over a US citizen performing classified work for the US government, prohibiting this way investments by non-US entities or individuals prior to a review by the US Department.

Besides that, President George W. Bush in the new policy of April 2003, "US Commercial Remote Sensing Policy," strengthens the role of the commercial satellite providers since it required that US governmental agencies "rely to the maximum practical extent on commercial remote sensing capabilities for filling imagery and geospatial needs." The goal was "to advance and protect U.S. national security and foreign policy interests by maintaining the nation's leadership in remote sensing space activities, and by sustaining and enhancing the U.S. remote sensing industry." Therefore, all US government agencies are asked to rely, "to the maximum practical extent," on US commercial capabilities for "filling imagery and geospatial needs for military, intelligence, foreign policy, homeland security and civil users."

Different companies such as Space Imaging, Orbimage, Orbital Sciences Corp., Earthwatch, and WorldView imaging were created for this purpose. Their shareholders were coming mainly from the satellite industry (Boeing, Lockheed Martin, Ball Aerospace...).

This decision created a major change in the access at the satellite imagery. Moreover, arguing the cheapest price of commercial imagery versus military imagery, the US MoD started three major successive programs called ClearView, NextView, and EnhancedView, to secure the acquisition of high-resolution imagery by the NGA from the US commercial providers. Those budgets allowed these US companies to build the new generation of high-resolution satellites. In 2011 there were only two US companies left, DigitalGlobe and GeoEye, which are the two main satellite-imagery companies in the world but with a turnover depending up to 80 % from NGA contracts. During the year 2012, due the defense budget restrictions decided by the Obama administration, the merging of those two companies was decided.

Under this trend, the gap of performance, for example, in terms of resolution, between military and civilian optical imagery satellites is today decreasing: from 1/80 in 1972, 1/20 in 1986, and 1/3 in 1999 to 1/2 in 2014, as seen in the next table (Fig. 32.3).

| Satellite | Usage | Launch date | Best resolution (m) |
|---|---|---|---|
| CORONA | Mil | 1960 | **6** |
| KH 9 | Mil | 1971 | **1** |
| Landsat 1-3 | Civ | 1972 | **80** |
| KH 11 | Mil | 1976 | **0,6 ?** |
| Landsat 4 | Civ | 1982 | **30** |
| SPOT 1-4 | Civ | 1986 | **10** |
| KH 12 | Mil | 1992 | **0,3 ?** |
| HELIOS 1 | Mil | 1995 | **1 ?** |
| Ikonos | Civ | 1999 | **0,82** |
| Landsat 7 | Civ | 1999 | **15** |
| Quickbird | Civ | 2001 | **0,6** |
| SPOT 5 | Civ | 2002 | **2,5** |
| DMC 1 | Civ | 2002 | **32** |
| OFEQ 5 | Mil | 2002 | **0,8 ?** |
| Crystal bloc IV | Mil | 2005 | **0,15 ?** |
| HELIOS 2 | Mil | 2005 | **0,35 ?** |
| Cartosat | Civ | 2005 | **2,5** |
| ALOS | Civ | 2006 | **2,5** |
| Worldview 1-2 | Civ | 2007 | **0,5** |
| Geoeye 1 | Civ | 2008 | **0,41** |
| Rapideye | Civ | 2008 | **6,5** |
| DMC 2 | Civ | 2009 | **22** |
| OFEQ 9 | Mil | 2010 | **0,15 ?** |
| Pleiades 1&2 | Dual | 2011 | **0,5** |
| SPOT 6 | Civ | 2012 | **2,2** |
| Geoeye 2 | Civ | 2017 | **0,33** |
| Worldview 3 | Civ | 2014 | **0,3** |
| CSO | Mil | 2016 | **0,15 ?** |

**Fig. 32.3** Some examples of evolution of the resolution of optical satellite imagery since 1960

**Fig. 32.4** SPOT 6 imagery over "Bora Bora" island in September 2012. Resolution of this commercial imagery is sufficient to analyze maritime activities between airport and hotels (Copyright Astrium Services)

Moreover, according (Risen 2012) to the retired Gen James E. Cartwright former vice chairman of the Joint Chiefs of Staff, "*The technology of the current satellite architecture is pretty much at its limit, and the commercial satellites are producing just about the same thing at a much lower cost*."

Today, "*Most studies show that about 90 % of what the military needs can be solved with commercial (imagery)*."

The commercial satellites such as SPOT 6 (France), GeoEye (USA), WorldView (USA), TerraSAR-X (Germany), and Radarsat (CAN) provide images which are used for different purposes such as reference images for Google Earth, cartography, monitoring of the environment, pollution, emergencies, agriculture, subsidence monitoring, and military purposes (Fig. 32.4).

Shortly, history has shown that imagery taken from Earth observation satellites, although initially designed for strategic military purposes, became useful for multiple applications of interest by the civilian market and users. In 1986 France created the first commercial company in order to distribute those images on a new market. At the beginning of the twenty-first century, the market of commercial imagery is growing up to 9 % per year and should be able to fulfill 90 % of the military needs.

## 32.3 What Does One Mean by Duality or Dual Use?

Clearly, the terms “duality” and “dual use” have multiple meanings especially in the field of satellite imagery, making it quite difficult today to define it. Hereafter, some definitions of the duality are presented.

### 32.3.1 European Commission

According to the Council Regulation (EC) No 1334/2000 of 22 June 2000, regarding the setting up of a community regime for the control of exports of dual-use items and technology, any products, software, or technology that can be used for both civil and military purposes are considered to be dual-use items. The same approach is followed by the USA through the ITAR (International Trade in Arms Regulation).

It is clear that Earth observation satellites are considered as dual-use items and that their commercialization or part of their technologies is submitted to governmental agreement.

For example, each company who wants to launch and operate a satellite to distribute its data has to request the authorization of its own government (USA, DEU, FRA, ESP. . .). Nevertheless, after the agreement is obtained, the company will have to go through national regulations for the imagery distribution. It has to be understood that even in Europe, up to now, some countries have their own regulation control process. As examples:

- Regarding US missions, commercialization of imagery above 0.5 m of resolution is generally authorized with the exception of imagery over Israel over which all imagery must be resampled to 2 m resolution. Specific authorization for dissemination for imagery of resolution between 0.25 and 0.5 m must be requested.
- In Germany the regulation control is in force as soon as the imagery satellite resolution is better than 2.5 m. A quite automatic but very restrictive process is existing, limiting the commercialization of imagery (SatDSiG).
- In France, the current regulation deals with different limitation and specifically controls the distribtion of optical images with a resolution better than 2 m. Over a list of sensitive areas, pre-authorisation should be requested before delivery.

### 32.3.2 Wikipedia

According to Wikipedia, *dual use can refer to any technology which can satisfy more than one goal at any given time. Thus, expensive technologies which would otherwise only serve military purposes can also be utilized to benefit civilian commercial interests when not otherwise engaged such as the Global Positioning System.*

It is clear that satellite imagery is definitely fitting with this definition: satellite imagery commercialized today is of dual use.

This definition of the "use" of the goods seems too general. A road is used either by civilian or military trucks. So a road paid by civilian budget is of dual use. SPOT 5, financed by civilian budget, is used by military people; it is also of dual use. Pleiades financed only by military research and development budget is used by Spot Image in order to distribute the images on the commercial market. Indeed, in the current taxonomy only Pleiades is considered as dual-use satellite.

### 32.3.3 Personal and Professional Experiences

According to the author's experience, the duality reflects a simultaneous presence of civilian and military entities, here in Earth observation satellites programs, and/or developing Earth observation technologies, and/or using or possessing a satellite Earth observation system.

The military entities cover usually what is dealing with the Ministry of Defence, which is quite simple to express in practice (see ▶ Chap. 44, "Russian Space Launch Programs (TBD)").

But civilian entities are not so easy to define. The civilian sphere covers usually the institutional needs and the ones of the commercial market. Those two fields are quite different indeed. The price and data policies might very well be different and it becomes more complex when we take into account the existence of private funding.

Security is also an issue. This need is usual for the defense and institutional users. Nevertheless, commercial providers could also deal with defense and security markets which make the notion more complex to define in practical terms.

Thus, it appears that the duality concept for space imagery has to be considered not from the use of the images but much more from the funding and the ownership of the systems: funding can be civilian or military or mix, see below.

1. Institutional funding: ESA in the scope of COPERNICUS, using European Commission budget, is funding the satellites called Sentinel. The satellites Sentinel 2 and 3 which are of interest to describe the environment of military or security operations are funded by EC, built by ESA, will be operated by private industries for EC and their images will be distributed for free according the data policy of COPERNICUS. Whatever the policy of ESA and EC is, those images will be used for environment and security but also for defense purposes (e.g., as it is already the case for information like meteorology).
2. Private funding: Astrium (an Airbus Defense and Space company) is funding the satellites SPOT 6 and 7 for the commercial market but also for the cartographic needs of defense. Those satellites will be very helpful for security purposes like maritime surveillance.
3. Military funding: German defense funded alone the radar satellites SAR-Lupe for exclusively military intelligence purposes. French defense funded with other MoDs (ESP, ITA, BEL, GRC) the military Helios satellites which could be used for security purposes. Nevertheless, even if the possibility was given to use those

satellites for security purposes, the fact that they are operated in a military environment and the lack of knowledge of security services concerning the use of space imagery limited the use to some experiments (forest fires, detection of illegal gold extraction areas…).

4. Mix (military/private) funding: Italian Defence and Telespazio (a Finmeccanica company) co-funded the COSMO-SkyMed radar satellites. The images with the best resolution are used by Italian Defence. Others are commercialized be e-Geos, one of the subsidiary of Telespazio. Clearly due to the fact that the satellites are dually operated, it is easier for the private company to promote the use of this imagery to the security services for emergencies or for maritime surveillance.

It is clear that, according to the funding, the case 4 is a clear understandable example of what we can call dual-use system.

Nevertheless, there are some cases more complex where duality is effective without falling into the above fourth category:

- The French satellites Pleiades,[3] which has been funded by common (military and civilian budget) R&D budget delegated to CNES, is considered as a full dual satellite system: Spot Image funded its ground segment and got the right to commercialize part of the Pleiades images in the scope of public service delegation. Part of the image acquisition capability of the satellites is reserved for military actors (satellites are tasked via a military channel). The other part is commercialized by Astrium.
- The US satellites GeoEye and WorldView are built by the company DigitalGlobe[4] using specific contracts from the National Geospatial-Intelligence Agency, known as “Enhanced View” contracts, in which NGA requests to the company to provide imagery for military purposes over a specific period of time. Payments occur before the images are delivered in order to give DigitalGlobe the money for building and launching the satellites GeoEye 2 and WorldView 3. NGA will use only a limited part of the resources of these satellites, DigitalGlobe will sell the rest. Due to the high accuracy and the good resolution of those images, they are also commercialized for security services outside the USA. For example, they have been very useful during the Haiti and Italian earthquakes: their usefulness for such emergency purposes has been demonstrated in the scope of G-MOSAIC and SAFER projects funded by the European research and development budget.

Pleiades, GeoEye, and WorldView systems can thus be considered also as dual-use systems.

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[3] Pleiades is a constellation of two heliosynchronous satellites. P1 was launched in December 2011 and the launch of P2 is expected in December 2012. Resolution of the imagery products provided by the system is down to 0.5 m using a specific algorithm of CNES to enhance the quality of the raw images with a 0.7 m resolution.

[4] DigitalGlobe and GeoEye companies decided to merge in 2012.

Duality is thus a consequence of the funding and operations of the satellites:

- If a satellite like Helios is funded and operated only by MoDs, it is definitely a military satellite. Even if the MoU between the Helios partners gives the possibility to use such a satellite for security, due to its military flavor, it is quite never the case.
- Other satellites, even funded with military budget, but operated by civilian/ commercial entities (like Pleiades or GeoEye), are of dual use.

This fact demonstrates the importance of understanding the funding and operating scheme of the satellite Earth observation missions.

## 32.4 To Whom Do Imagery Satellites Belong?

At the beginning of the space age, 50 years ago, the space systems were developed by single nations (and sometimes with a strong competition between them, like during the moon race), under military control or derived from a military asset (the development of the launchers has started with the WW2 German V2 rocket) and using public funding. The space systems have evolved, and this evolution can be measured and characterized on three axes to answer basically the question: to whom does it belong?

1. **System owners and financing institutions** are somewhere onto the axis **civil-military**. We are using here the criteria of ownership and financing rather than the use. Let's take an example: a road can be used by civilian or military trucks; therefore, a road is dual use, but it has not to be paid by nor belongs to a military entity. Similarly, we shall find many systems that have been totally financed by civilian budgets but are used for military purposes (Galileo, SPOT 5...). We may also find some specific military requirements such as cryptography and secure tasking, on top of civilian needs, and the military shall pay for that. The level of financing and ownership is therefore much more illustrative than the duality in use.
2. **Financing** can be a mix **public-private**. Obviously private investment should be mobilized as and when opportunities for profit can be identified (European Space Policy: Frequently Asked Questions). This is linked with the existence of a commercial mark: the end user customers might be civilian or military, private or institutional. This criterion is therefore totally independent from the nature of the end users. Many variants exist and are developed below.
3. Asset can be **national or multinational**. This is induced either by a political will (e.g., European joint staff) or financial constraints (e.g., to share the nonrecurring costs).

   Of course when the budgets are not sufficient to cover the complete systems, a multinational cooperation may lighten the burden.

   Multinational assets can be developed either through a procurement agency (OCCAR, EDA, ESA...) or by a single country with delegation (Helios) see (Fig. 32.5).

Duality is one of these axes, but those axes are not totally independent. The analysis of duality cannot thus be done by ignoring the other components.

**Fig. 32.5** The three axes of the ownership of space systems

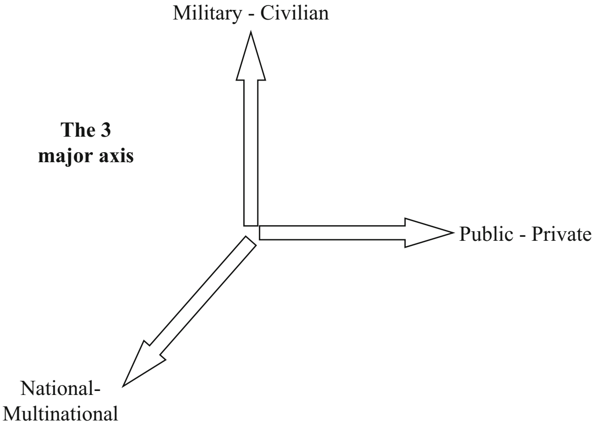
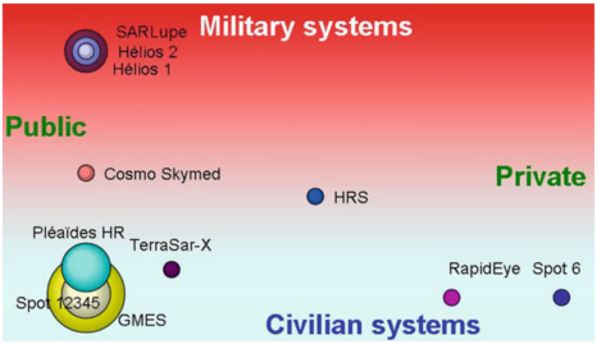


**Fig. 32.6** Representation of the ownership of some European space systems (HRS is an instrument on board SPOT 5, see below § 4.3)



The following figure illustrates the position of various programs (relative positions are only illustrative, without scale) (Fig. 32.6).

The private-public criterion is horizontal, the civil-military criterion is vertical, and the size of the bubble is the number of nations involved in the program.

With this representation, evolutions can be viewed easily.

Considering all those definitions, it is clear that today high-resolution satellites which are not purely military funded and operated are generally of dual use, under dual governmental control, and funded mainly by public funds.

## 32.5 Some Examples of Existing Systems Known as "Dual"

### 32.5.1 COSMO-SkyMed

The Italian COSMO project started in 1996, with general studies about an optical and radar imaging space system (see also ▶ Chap. 44, "Russian Space Launch

Programs (TBD)”). In 1997 the phases A and B started and concluded that the cost of a simultaneous development of optical and radar technologies was too high compared to the national financial availability. In this context the international cooperation agreement signed in 2001 between the Italian and French governments resulted into a reciprocal benefit for both Italian and French dual-user communities. This fact determined the suppression of the Italian optical branch in favor of a cooperation with the French optical program, which resulted in the definition of activities jointly performed. Some months later an MOU was signed between CNES and ASI (see http://smsc.cnes.fr/PLEIADES/GP_actualite.htm),[5] and, in March 2003, the contract for the development, launch, and operations of COSMO-SkyMed system based on a four SAR satellite constellation was granted to Thales Alenia Space (See ASI website).

The COSMO-SkyMed system is able to take images of anywhere on the Earth’s surface with a 12-h revisit time with the four spacecraft on an ~600 km altitude orbit. Like Pleiades, they will have a 20 km wide swath width. Each COSMO-SkyMed satellite is capable of producing 75 images per day in high-resolution mode and more than 350 per day in the lower-resolution mode. Therefore, the complete system is designed for 1,800 images per day Lopinto and ASI (2006).

Each satellite weighs around 1,700 kg and is able to store up to 300 GB of data and transmit at 300 Mb/s.

Italian Space Agency (ASI) estimates that COSMO-SkyMed has a cost of about 1 billion euros, a sum that covers satellite construction and launch as well as the ground segment. Initially, the Italian Defence Ministry has committed about 150 million euros to COSMO-SkyMed in return for 20 % of the satellites’ viewing time.

The ownership ratio of COSMO-SkyMed is thus about 25 % for defense.

### 32.5.2 Pleiades

The French Pleiades program started in 2000 with workshops to characterize the users’ needs, following the binational agreements signed between France and Italy and between ASI and CNES in 2001 (see above).

The B phase study started immediately and the satellite preliminary design review has been performed in April 2002. The definitive C/D contract has been granted in October 2003 to EADS Astrium.

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[5] A memorandum of agreement was signed in June 2001 between the Centre National d’Etudes Spatiales (French space agency) and the Agenzia Spaziale Italiana (Italian space agency) for the definition phase of a dual system with an Earth observation capability using optical satellites, radar satellites, and an associated ground segment. The dual system to be developed is composed of the following elements:

- An optical component composed of two satellites and the corresponding ground functions, developed under French control
- A radar component composed of 4 satellites and the corresponding ground functions, developed under Italian control
- A user ground segment developed jointly by France and Italy

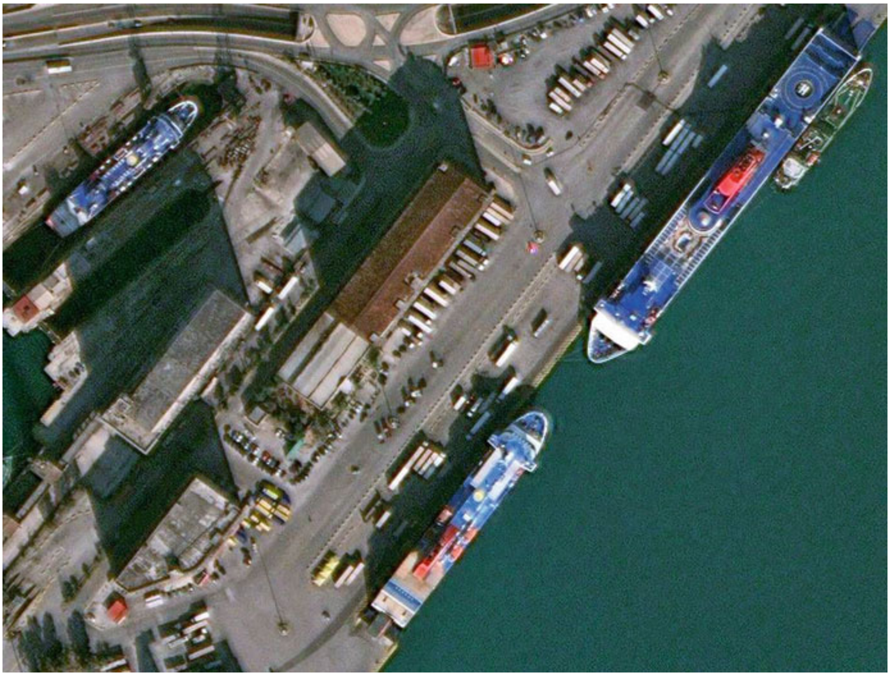

**Fig. 32.7** Extract of Pleiades image over Piraeus port in Athens, Greece. Copyright CNES 2012 – Distribution Astrium Services/Spot images SA

Each Pleiades spacecraft has a swath width of 20 km with a basic ground resolution of 70 cm[6] and carries an onboard memory system capable of storing 600 gigabytes of data and transmitting images to Earth at a speed of 450 megabits per second. Power available to the payload will total 1 kW, for a mass around 1,100 kg.

The first Pleiades satellite was launched in December 2011, with the second to follow a year later. The Spanish Defence Ministry has agreed to take a small stake in the program and the civilian space agencies of Austria, Belgium, and Sweden drive the total of the non-French role in Pleiades to 10–15 % of the total.

Pleiades, expected to cost about 600 million euros including its ground segment and launch, is designed to provide optical images for defense and civil/commercial customers.

The Pleiades program is fully financed by the CNES, with the common (civilian and defense) R&D budget.

Pleiades is operated by the military and civilian operators (from Astrium GeoInformation Services, ex Spot Image) with two independent ground segments. Military requests have the highest priority and represent around 10 % of the total of the requests (Fig. 32.7).

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[6] The basic resolution of the imagery is 70 cm, but the processing system uses a specific algorithm to provide a product ortho rectified with a ground resolution equivalent to 50 cm.

### 32.5.3 HRS Instrument

The instrument high-resolution stereo (a stereo camera) has been developed as a passenger of the French SPOT 5 satellite, launched in April 2002. Primary goal was to realize digital elevation models (with a high defense interest), covering almost one fifth of lands (30 million km$^2$) in 5 years (lifetime of SPOT 5).

The instrument cost was ~20 M€ (EC 2000), shared between CNES (46 %) and industry (54 %).

The operating/distribution costs (~30 M€ over 5 years) are shared between defense (46 %) and industry (54 %).

The breakeven has been achieved thanks to the export market, in 5 years.

Due to the performance of the DEM (level 2 in 2002), a data policy set of rules has been established by the French authorities to keep control over the exportation.

Programming is done only by the commercial operator who takes into account the requests of the military, the common requests, and the pure civilian ones. It appears that most of the requests were indeed common.

In fact, a meeting between MoD and Astrium takes place every three months for defining prioritization and schedule for the production of the DEM over the areas of interest. Since the DEM processing is a slow process, the schedule foresees the AOIs for the next year.

## 32.6 The Use of Satellite Imagery: What for?

### 32.6.1 Imagery Satellite: What for in the Area of Security?

During the last 10 years, in the scope of the definition of the European Commission GMES services, several studies and projects[7] have been done to define and validate how Earth observation from space could help in the scope of security. They have been funded by ESA and EC in the scope of FP6 and FP7 but also by national institutions and governments like the French Ministry of Interior.

Security usually covers (at least):

- Protection of the citizens
- Protection of the infrastructures and networks, food and energy supplies, secure transportations
- Border security, maritime surveillance, immigration control
- Crisis management, help actions, natural disasters early warning and monitoring
- Exterior security actions, humanitarian actions
- Disarmament control, site monitoring
- Illegal culture detection (to defeat terrorism funding)

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[7] Using R&D funds from the FP7 and FP6 framework program, EC funded a lot of projects to define what could be the use of space imagery for security and emergency: G-MOSAIC, SAFER, MARISS.

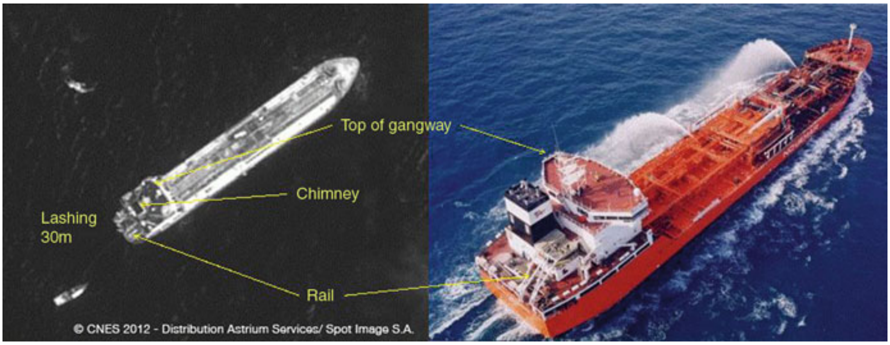

**Fig. 32.8** Use of Pleiades imagery to track "Enrico Tivoli" which was attacked by pirates in January 2012

All these missions are extremely different. A single system cannot thus handle all of them.

In the scope of the GMES program, it is currently agreed that security is dealing with:

- Border surveillance support
- Maritime surveillance support
- Support of the EU external actions in the scope of CSDP (Fig. 32.8)[8]

Missions concerning the internal security mainly done by customs and police request today are performances that the EO satellites are not able to reach in terms of:

- Resolution to detect, recognize, identify people
- Persistency (capability to survey a point anytime and not only once a day)
- Clouds and night independency

Nevertheless, even if such performances are only available today with UAVs and aircrafts, satellite imagery can be useful in support of operations where it is difficult or not possible to send surveillance aircrafts over isolated areas, specifically for drug trafficking and illegal gold or diamond extraction, terrorism threat. . .

It is also agreed that in case of emergency (floods, earthquake, forest fires. . .), satellites with VHR resolution are helpful for assessment of the situation and deployment of first responders. Those missions also can be considered as security missions.

Under these considerations, can we still speak about a military-civilian duality?

Definitively yes, because the defense world has strong specificities that enable to distinguish whether there are present or not, to qualify a system. For each mission it is easy to analyze whether or not there are military people and/or military means involved. If yes, the system is dual.

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[8] The European Common Security and Defence Policy or CSDP is a major element of the Common Foreign and Security Policy of the European Union (EU). This covers essentially external operations using police or military means and troops (Petersberg missions). Part of the "S" of the CSDP is thus covering also military sphere.

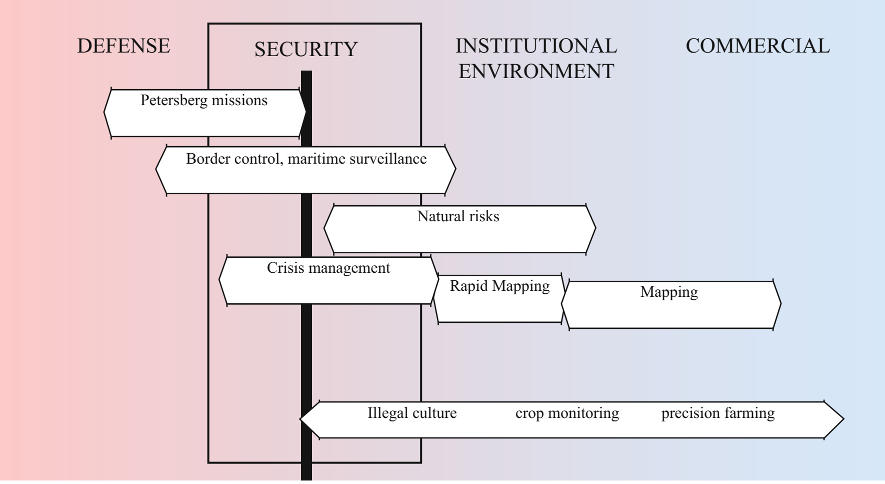

**Fig. 32.9** Positioning of some typical space-related missions dealing with security

Going back to the above illustration, the frontier could be drafted right in the middle, between the so-called Petersberg missions and illegal culture detection (Fig. 32.9).

### 32.6.2 The Use of Imagery Satellite: What for in the Area of Defense?

The use of space imagery in the military world moved from strategic intelligence to very operational imagery purpose.

Military imagery purposes can be defined as follows:

- Strategic intelligence (surveillance of nuclear activities, detection of unforeseen military activities, armament control. . .)
- Intelligence for military activities (location of troops, detection of enemies activities . . .)
- Description of environment (cartography, digital elevation models, urban maps, 3D models. . .)
- Navigation for cruise missile
- Localization of targets (coordinates, 3D models)
- Battle damage assessment
- Surveillance of areas (at sea, in wide or noncooperative areas)
- Detection of activities (at sea, in wide areas)

Those military uses lead to some specific requirements such as:

- Performances; in general the highest performances of a dual-use system will be reserved for the military purposes (highest resolution, best localization, agility. . .). This induces a specific data policy and system architecture.

- Robustness against denting, disablement, jamming, interception: security and confidentiality usually require specific links, specific cryptography algorithms, even specific hardware.
- Availability and responsiveness should be extremely high, which could lead to multiple redundancies as well as specific operating procedures. Reliability should be extremely high due to the fact that space imagery, even if used regularly in operations, continues to be considered in some cases as strategic. This explains why there is reluctance for military people to rely only on commercial satellites and providers.

## 32.7 Duality: What for?

The answer is straight and simple: duality is sought to reduce the cost at users' level, by sharing technologies and/or the development and/or the operations.

> synergies with the civil sector (. . .) must be looked at as far as possible, in order to optimize funding efficiency on common interest topics (2007 French Finance Bill 2006, Extracted and Translated).

- If the military budgets were sufficient to develop all the needed capacities to fulfill the military needs, these capacities would be developed in a pure military mode, with no duality.
- If the civilian budgets were sufficient to develop all the technologies and techniques needed to fulfill the civilian needs, then it will be developed with civilian or commercial funds.

But let's be serious, we are not living in such a theoretical world; the search for multiple sources of financing space systems is definitively needed to lighten the financial burden. This is a normal tendency, for improving the efficiency of the national budgets.

There are two reasons that very high-resolution imagery space systems have turned to duality for:

- The shrinking of military resources
- The fact that the high performances of VHR imagery satellites is now of interest for security missions

## 32.8 How to Build the Duality?

- **Dual Technology**: for what concerns the space domain, it is easy to say that almost all the technologies needed are basically dual. Of course we could find a few specific military technologies rare. On the other hand, all the civilian ones are intrinsically dual. This fact is well known and sometimes used by military staffs to justify an absence of direct investment in space technologies. This is especially true for what concerns the technologies related to access to space and launchers.

- **Dual Development/Procurement**: such as Key Hole/Hubble or more seriously, in France, Syracuse 2/Telecom, SPOT 4/Helios 1, and SPOT 5/Helios II. The joint developments of a civilian and a military system can be phased, so that many commonalities can be found. The cost reduction is important since many equipment, software, procedures, and ground support equipment can be shared. Of course such co-phased developments suppose.
- Harmonized client and industrial organizations for both programs, to enable and ease the trade-offs and arbitrations that will be numerous. In the case of SPOT/Helios, EADS Astrium was priming the two projects and the first-level client was the CNES in both cases.
- Harmonized sources of financing, not to hamper one project because the other is lacking money. This can cause a lethal malfunctioning.
- **Dual Use**: this is the most wide and complex domain, because, as technologies, everything can be dual use since everything can be used by a civilian or a military end user. The two good examples are **Galileo** and **Pleiades**: both programs are developed under strict civilian funding, and both programs are well known to be dual use, but we cannot say that they are dual programs.
- **Dual** Vocation: under this definition, one should put systems that have been from the beginning developed with a co-financing, a joint program team, a common industrial organization, and will be operated by two separate bodies. This encompasses the dual development and the dual use together. The perfect example is COSMO-SkyMed.

With these definitions, we can rephrase some statements:

- SPOT 4 or SPOT 5 are dual-use civilian programs, associated to military programs.
- SPOT4/Helios 1 and SPOT5/Helios 2 are dual vocation programs.
- Pleiades is a dual-use system and dual program.
- COSMO-SkyMed is a dual-vocation system (dual use and dual program).
- GeoEye is of a special dual program (funding done by military in advance but development done purely by private companies which commercialized imagery mainly for security/defense missions).

## 32.9 Duality for Defense and Security: The Blocking Points?

### 32.9.1 Different Mind-Set Concerning the Military Status Versus the Civilian

In Europe the citizens of the different countries don’t have the same relation with the military actors.

In France the military actors are involved in military missions but also in security and emergency missions. The French Military Marine is part of the security mission of the state at sea. Specifically the French Marine helps the customs or police in their security mission. “Gendarmerie Nationale,” even if it is a military organization, is under the control of the Ministry of Interior in charge of security of citizens and police. So definitely, in France, the use of military assets for civilian/security/police missions is fully understood and accepted.

In Germany the constitution establishes a clear position: the German military people can't be involved in any police missions. This is certainly the reason why it is difficult for German people to imagine that their military satellites, such as SAR-Lupe, could be also used for civilian security missions.

France and Germany are today the two biggest European countries involved in space activities[9] and their approach to the duality of military means is not the same.

According to the nation, the relation between citizen and their militaries could be a showstopper in the scope of duality, particularly for high-resolution Earth observation systems.

## 32.9.2 Sharing the Resource

Main difficulties of sharing the satellite resource will happen only during crises over limited areas. Let's assume a crisis requiring partially the satellite's capabilities. During the rest of the time, when imagery is neither considered as defense confidential nor secret, there are no major difficulties to share the resources between defense and security.

Let us address now three main types of crisis:

### 32.9.2.1 War, Military Operations...

When a war (Iraq 2003) or real military operations (Libya 2011) happen, it is quite clear for everybody that the images which are taken by satellites over the area of operations are for the military purposes and go to defense actors. It is observed that even priority tasking for non-defense applications, e.g., agriculture, that was accepted and planned by the satellite operators before the crises may be "rescheduled" if they are located in the wider area of conflict and task plan may be modified even at the last possible minute.

The satellite operators (either commercial, dual, or military) are tasked by military actors and deliver their information mainly to them. Clear responsibility chain exists: the military people are in charge of the operations and have the highest priority.

### 32.9.2.2 Emergency, Earthquake, Humanitarian Crises...

When security crises happen (fire, earthquake, ...), the images should go first to security actors, which is indeed currently the case, except for those from the military satellites which can't share their capacity. The main reason is usually the

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[9] In 2009 the space budget for France was $2.7 b and $1.6 b for Germany, compared to $972 M for Italy and $474 M for UK. "Space economy at a glance 2011, OCDE July 2011"

confidentiality of data, but the fact that such sharing is not implemented on regular basis kills in practice every tentatives to do so. But we don't have to forget that in a large number of countries, military actors are also involved in such crisis and they usually request to their military or dual operators images over the area of operations. In that case, some conflict may clearly happen in the use of the satellites when they are considered as dual. Nevertheless, such conflict can be solved on a win-win base. Communalization of requests can be easily done by the satellite operators: it is clear for military people that the images they need are also needed by the security actors under whose responsibility they will act. This makes also clear for the security actors that the military troops who will be deployed to support them need to have the information. Clear responsibility chain exists: "security" (usually civilian) people are in charge of the operations.

#### 32.9.2.3 Growth of Crises Which Can Create War or Trigger Military Operations

When an international crisis happens such as Syria 2012, it is not clear who needs to have the priority for the satellite images. Until war or military operations are decided, a lot of civilian actors dealing with emergencies and security have the legitimacy to request such images. But military people who have to prepare themselves to war operation are full legitimacy to request priority for the tasking of satellites. Moreover, there is a clear power game between the different intelligence actors, military but also civilian, to be the first one to provide the good image or information to their own political power. Then definitely, during the growth of such a crisis, conflict between defense and security actors happens. Then the criteria concerning to whom the satellites belong are usually used. Solving conflict needs to be addressed case by case at the highest level. Imagery satellite becomes again a strategic asset which is used as political tool. Common use of images between defense and security will be addressed depending on the will and knowledge of political people but also of satellite imagery end users and operators (military, civilian, commercial). The last one can usually solve 90 % of the conflict at their level when confidence has been built. Crisis doesn't happen yet so the responsibility is to the diplomacy who received input from defense and civilian actors for security, each one playing in his field of responsibility.

Even if in 95 %[10] of the cases during the life of the satellite conflicts on resources can be solved between defense and security actors in win-win situation based on regular exchange and communalization of tasking, some major resource conflicts between them will continue to happen. Those 5 % unresolved conflicts are the consequence of a political will to use the satellite imagery as a strategic asset. This is indeed the reason why men invented the satellite imagery in the middle of the twentieth century.

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[10] Figures are author's personal estimation due to his professional experience (military and civilian) after more than 20 years in the area of satellite imagery.

## 32.10 Conclusions

According to what has been explained above, it is clear that high-resolution satellite imagery is not anymore only of strategic interest for intelligence but also for military purposes such as mission preparation, targeting, battle damage assessment, but also environment description and cartography. National defense will thus continue to invest in such tools and services.

Nevertheless, it is clear also that for security purposes such as border monitoring, support to external actions, reaction to natural emergencies (like floods, earthquake…), satellite high-resolution imagery is needed. We could also foresee that, if in the future the resolution of such satellite imagery is able to reach the same resolution as aerial imagery, i.e., 10–20 cm, then those images will be also very helpful for internal security applications.

Indeed, there are only minor differences between the needs of security and defense of high-resolution imagery satellites.

Up to now military people were able to finance their own military satellites and the security branches were using only commercial satellite with limited performances. Now, it seems clear that the relevant defense budget may not be enough to continue the funding of high-performance military imagery satellites. At the same time it has been demonstrated that civilian security actors have operational interest in using high-performance imagery satellites. But they don't have the budget for building alone such satellites. So it is clear that some synergies could be created by developing no more military satellites but satellites for dual purposes.

This opens two possibilities of funding for such systems:

- Funding them in cooperation between the MoDs and the ministries in charge of security
- Funding them on a dual mode: mainly military funding and commercialization for security and other business in order to access new users and thus decrease the overall cost

In this situation, whatever the funding, in few cases estimated by the author in the range of 5 % or less, some conflict between defense and civilian security actors will happen, mainly for political/strategic reasons. In that case, the one who wants to have the priority has to pay for it. It can be done by increasing the price of priority tasking if the satellite is commercial (SPOT 6). It can be done also by giving priority rights by construction to one of the users when building the system (French Defence in the case of Pleiades). It can be done by using the prime customer right in the case of commercial satellite funded by MoD (NGA in the case of the contact Enhanced View).

Nevertheless, whatever the financial and operational rationale, it is also obvious that in some countries the mind-set and even the constitution are not in favor of involving military means within civilian security.

In Europe, according the authors' perception, the choice is fully open for the coming years. Let's see what will happen with the satellites CSO (next generation of Helios) and the satellites SARah (next generation of SAR-Lupe). The author's guess is that Post CSO satellites will be dual satellites.

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# Telecommunications for Defense

# 33

Louis Tillier

## Contents

## 33.1 Introduction: History of Telecommunications for Defense

Telecommunications evolutions have always influenced battlefields, and the rhythm has recently accelerated. Between 1853 and 1856, during the Crimea War, telegraphy allowed armies to coordinate their movements and inform the political power. In 1905, admiral Togo is informed of every movement of the Russian fleet and wins a decisive victory in the Tsushima straits. In 1940, the tank and plane tandem communicate and coordinate themselves, thus providing an advantage to German troops and panzer divisions. Those three examples illustrate the fact that telecommunications have always given an advantage, from the tactic to the strategic level, to the party that could use it better or earlier than the opposite force.

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DOI 10.1007/978-1-4614-2029-3_8,

Second World War research programs instilled the germs that will able space communications to become reality. Two domains have undergone major developments: microwaves and rockets. Both combined will allow a major step ahead, making possible the use of space telecommunications for defense (Maral et al. 2009).

Telecommunications satellites have often been marked by their duality: civilian and military use. Hence, first communications satellites are seen as civilian satellites transmitting some information of public interest. Sputnik (1957), Score (1958), and TELSTAR (1962) could transmit messages, Christmas greetings from US President Eisenhower, television programs, or telephone calls. Nevertheless, and for the USA, the ARPA was part of Score project, and the satellite was launched by the Air Force Ballistic Missile Division, rapidly allowing the launch of exclusively military communications satellites for operational purposes such as the Initial Defense Communications Satellite Program (IDCSP) in 1962 with 26 satellites launched between 1966 and 1968. Since then, many countries launched communications satellites for military use: the USSR with the Molniya satellite in 1965, UK with SKYNET (1969), France with SYMPHONIE even used by the UN Blue Helmets between Ismaila, Jerusalem and United Nations Head Quarters in Geneva during UNEF II mission (1973–1979), then TELECOM 1 (1985), first step to the SYRACUSE series.

Today, about 60 nations and government consortia operate satellites, being used for defense, security, and civilian purposes.

US satellite programs from 1960 to 1980 give us a good overview on different uses:

1. Long-haul users through DSCS (DoD)
2. Strategic users with high survivability by AFSATCOM (US Air Force)
3. Tactical users served by FLEETSATCOM (US Navy)

Those programs give us the main needs for defense. Linking strategic and isolated users, such as operational headquarters and Navy ships, was the priority. The ability to link tactical users has always been limited by technical possibilities. First tactic units fitted with satellite devices were Navy ships, the only assets having the capacity to embed large antennas. Today, satellite antennas and dishes can be embedded on airplanes, UAV, vehicles, or even as manpacks, then completely changing the employment concept.

## 33.2 Limits of Traditional Radio Communications

The first problem that military units have faced is how to overcome distances on the battlefield. Traditional radio communications have always been dependent upon the earth rotundity and atmosphere.

VHF (30–300 MHz) and UHF (0.3–3 GHz) communications, the most easy to embed, are limited to line of sight. A direct radio wave can propagate on a predictable distance which is set by the following formula:

$$D = 2,2 * \sqrt{(h + H)}$$

with D in nautical miles and h and H the respective heights of transmitting and receiving antennas in meters. As an example, an aircraft carrier as the older French ship Clemenceau has antennas 25 m above sea level. It will be able to keep contact with its escort, destroyers with 15 m high antennas, at a range of 14NM, and meanwhile sail 600NM in a day.

One alternative is to use lower frequencies, from HF to VLF, hence relying on refraction in the ionosphere. This alternative has three limits:

1. The refraction will, theoretically, allow any station on earth to receive a signal of any other station wherever it is. In practice, propagation conditions keep changing, depending on different cycles (daily, seasonal, and 11-year sunspot) affecting the ionosphere refraction's capacity, making it difficult to rely on a stable channel.
2. The size of equipments to transmit signals in low frequencies, especially in LF (30–300 kHz) and VLF (3–30 kHz), forbids any two-way communications with tactical and mobile units. For instance, submarines usually have the capability to receive VLF signals but have no mean to transmit back in those wavelengths.
3. The transmittable information is quite poor due to the small bandwidth available. A 10 kHz channel will be available to transmit a few decades of kbit/s, which is fairly good in terms of spectral efficiency but cannot answer to increasing needs pulled by intelligence, surveillance, and reconnaissance (ISR) systems and network-centric warfare (NCW) concepts.

Hence, militaries have investigated satellite communications as an alternative. The frequency issue is a major trend to able specific governmental use.

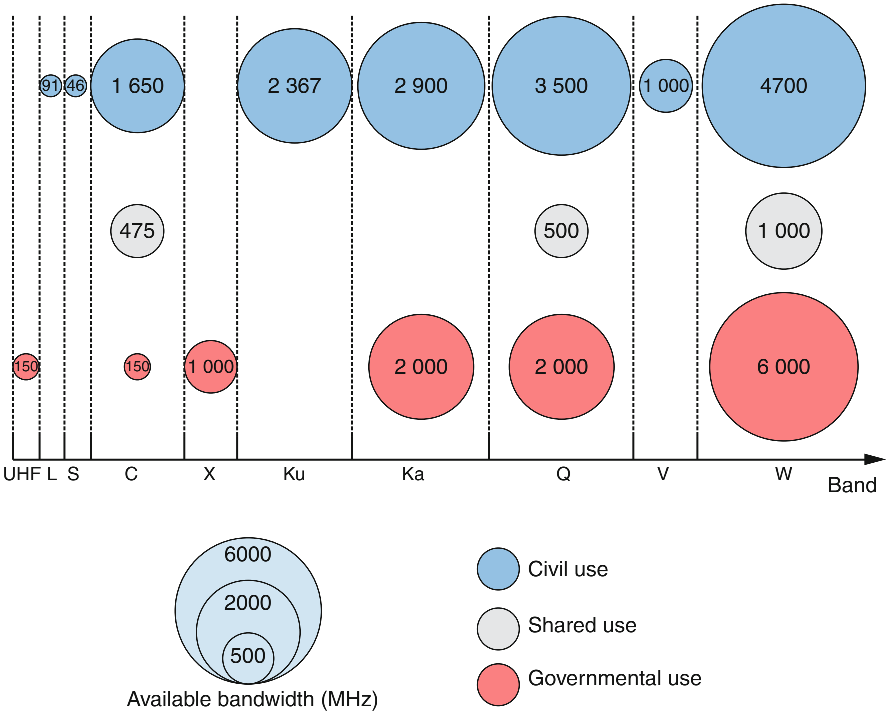
## 33.3 Specific Defense Needs

### 33.3.1 Frequencies: A Rare and Coveted Resource

Since ITU was founded in Paris in 1865, governments have played an active role and secured access to the radio-frequency spectrum for defense needs. Bands reserved for defense, security, or governmental use have always been an important issue for countries. Today, the SATCOM frequencies are divided between defense and civilian uses. Some bands are exclusively operated by commercial enterprises (C band, L band), some are exclusively used by defense (X band), and some are divided between defense and civilian uses (Ka band in NATO countries).

As Frequency Allocation Tables (FAT) are nationally transposed in National Frequency Allocation Tables (NFAT), it is possible for some countries to restrict the use of part of frequencies for defense needs. For example, NATO countries have

**Table 33.1** Total bandwidth available (MHz) for civil, governmental, and shared use



reserved some UHF and Ka frequencies for defense use, a practice that is not always applied by all countries.

The following table gives us a quick overview on the available frequencies for satellite communications in France, which is a good example of how a European country (ITU region 1) and NATO member state is using its national radio spectrum (Table 33.1).

Today, military systems mainly rely on X band, with some specific and seldom uses in Q band (also known as EHF band, even if it is a language abuse). Increasing demands for datarates should be answered through either the improvement of the spectrum efficiency of already used bands, either the use of new bands (Ka and Q bands).

### 33.3.2 Hardened Satellite Communications

The need to deliver the service even under degraded conditions pushes requirements to be more ambitious. Military requirements usually involve the following issues:

- Nuclear hardened satellites
- Anti-jamming capabilities

- Protected telecommand/telemetry and ranging
- Resisting to cyberattacks
- Protecting the confidence of communications

Such requirements cover a wide scope that not all countries will seek to fulfill.

For instance, a nuclear aggression affects both the satellite vehicle and the communications. In 1962, the USSR undertook three nuclear explosions in space over Kazakhstan. Those explosions, creating a high-altitude electromagnetic pulse (HEMP), affected satellites (i.e., the solar panels) and all radio communications through the ionization of the channel for a few minutes. Typically, having nuclear hardened satellites is a requirement that will be fulfilled by countries that have the will to resist and retaliate against a nuclear attack, hence having a nuclear deterrence force. An easier access to nuclear weapons, or weapons that could create an EMP, could nevertheless extend this requirement to non-nuclear countries.

The other requirements should be basic requirements for all countries, as they are an answer to asymmetric threats that could be acquired by any State or even terrorist groups. Some jamming occurrences targeting private satellite operators have already been related through press releases those last years, mainly located in countries as Iran or Syria.

> **AFP Press Release: 18 October 2012**
> LONDON — The BBC said Thursday its services in the Middle East and Europe were being deliberately jammed, along with those of other broadcasters – with the interference coming from Syria. (. . .)
>
> The jamming of Eutelsat satellites affected BBC television and radio services in English and Arabic, the British Broadcasting Corporation said.
>
> The French-based satellite provider Eutelsat said the interference was coming from Syria.

Those threats are taken into account for defense communications through a number of parads as frequency shifting techniques, on-board anti-jamming, crypto algorithms, and geolocation of jammers that able a retaliation if necessary.

Finally, protecting satellite telecommunications links does not only involve attacks on the frequency spectrum (jamming) or on software (cyberattacks). Physical aggressions, apart from a nuclear explosion, should not be neglected as the Chinese People's Republic destroyed a Chinese LEO satellite with a missile (11 January 2007), followed by the USA destroying 1 year later one of their satellites (20 February 2008). It proved that it was possible and affordable. Hence, physical aggressions on the geostationary orbit cannot be cleared without a precise study, even if today's international rules, especially the 1967 Outer Space Treaty, limit the use of weapons in outer space.

As a consequence, developing military satellites has a cost due to those specific requirements that affect missions, clients, and solutions. The process from conceiving the satellite to operating it is all the most protected and long-lasting. It is also enforced as military operations get more and more dependent to satellite communications. This is part of the strong threat analysis that is fulfilled when developing any military satellite.

### 33.3.3 Availability of Communications When and Where Required

Second, the tempo in shifting from normal to crisis conditions has nothing to compare with the tempo needed to define and build a satellite. Contrary to commercial satellite fleets that are continuously renewed and benefit of the last mature technologies, a country's military communications satellites are renewed every 10–15 years. The procurement process should be able to foresee next technological breakthroughs and even anticipate them as the next performance level to achieve. The process is long and complex. A country's strategic and political ambition is declined in military missions and capabilities (navy, air, land, communications systems, for instance). For communications satellites that should be operating between 2020 and 2035, the procurement process should be able to foresee a need for midterm (2027) with the technological stakes that are tied to it. One of the main drivers will be the flexibility of the satellite, able to adapt to a constant changing world, as military operations bring their part of uncertainty. It is part of the sovereignty required by each nation, being able to intervene whenever and wherever, in unpredictable conditions but with strong communications needs.

On the other hand, decisions to intervene are made in a much more short time frame: first hits in Afghanistan were made by the US Navy four weeks after 9/11. In Mali, first troops stepped in airplanes a few hours after the French President François Hollande has decided it. Very quickly, in both examples, needs for satellite communications increased rapidly. They were made possible because capabilities have been defined 15 years ahead. They were continuously optimized and adapted through operational feedbacks. They were finally operated without any time constraints after a political decision that can be taken anytime and anywhere.

### 33.3.4 Acquisition Schemes

Hence, one recurrent question has been whether the assets should be owned by states or could it be rented as a service? And if it is rented, how the availability can be guaranteed? This question is today a major trend among Army staffs and procurement agencies.

Acquisition of satellite communications assets has followed two main schemes: patrimonial acquisition, which is the main procurement scheme, and privately financed initiatives (PFI) with an example through UK and the Paradigm contract. Another relevant factor is the part of commercial contracts to complement the whole need for space communications as military satellites are one part of the answer. In the last decade, fortuitously coinciding with a wider use of drones and imagery, the USA brought to commercial operators an important part of commercial bandwidth. For FY10, the DoD spent $960 M in military satellite communications and $640 M in commercial satellite communications, putting the trend at 60/40.

**Fig. 33.1**

Hence, a wider approach has been developed with complementary levels of communications divided into three main assets:

- The core and hardened capacity for the exclusive use of a nation's armed forces, which is sovereign, always available and resistant to a number of various aggressions such as jamming, high-altitude nuclear explosions, cyberattacks, and physical aggressions on the satellite (aka MILSATCOM)
- The guaranteed capacity build on civil standards but for the exclusive use of governments, ready to be used upon operational needs (aka MILSATCOM or GOVSATCOM)
- The commercial capacity bought by national agencies to civilian operators and that complements the needs, mainly in only civilian frequency bands (Ku band for drones, L band for small terminal as BGAN) (aka COMSATCOM)

They are often represented as three concentric services, with the hardened part in the center and the commercially bought service at the periphery (Fig. 33.1).

Reaching the optimum trade-off between hardened satellites communications and purely commercial-bought capacities has always been a challenging question, with public and private lobbying. There is today no model that is naturally imposing itself to all countries, but different models adapted to different approaches. Hence, governments and procurement agencies are pressed between different strategies. The first one, relying on commercial bandwidth and expected cost efficiency, cannot guarantee its availability nor robustness, thus jeopardizing the political will to intervene (bandwidth saturation over Iraq in 1991, defense needs challenging media needs over the Middle East). The other one, relying on defense-owned assets, is guaranteeing access to hardened bandwidth at a presumed higher cost, even if its real cost could and will be long debated.

Today, economic models try to optimize the investment through tier-parties participations, either directly in other countries' programs as Australia, the Netherlands, or Denmark in the WGS program in exchange of access to the service or directly by selling part of the over-capacity to other actors (Paradigm or Hisdesat).

If we go back to our US example:

- The core capacity is supplied through 6 AEHF satellites worth \$6.9 billions.
- The guaranteed capacity is supplied through the WGS program, with eight satellites funded by the USA at \$6 billions and two satellites funded by some allies (Australia, Canada, Denmark, Luxembourg, the Netherlands, and New Zealand).
- The MUOS program fills the need for tactical communications.
- The commercial capacity is bought by operators.

Those expenditures do not take into account user terminals programs, nor systems and networks, mainly supported today by the Navy Multiband Terminal (Q, Ka, and X band) program for Navy units and the Ground Multiband Terminal (X, C, Ku, and Ka band) program for Army units.

## 33.4 Satellite Communications in Support of Network-Centric Warfare

### 33.4.1 Netting All Assets

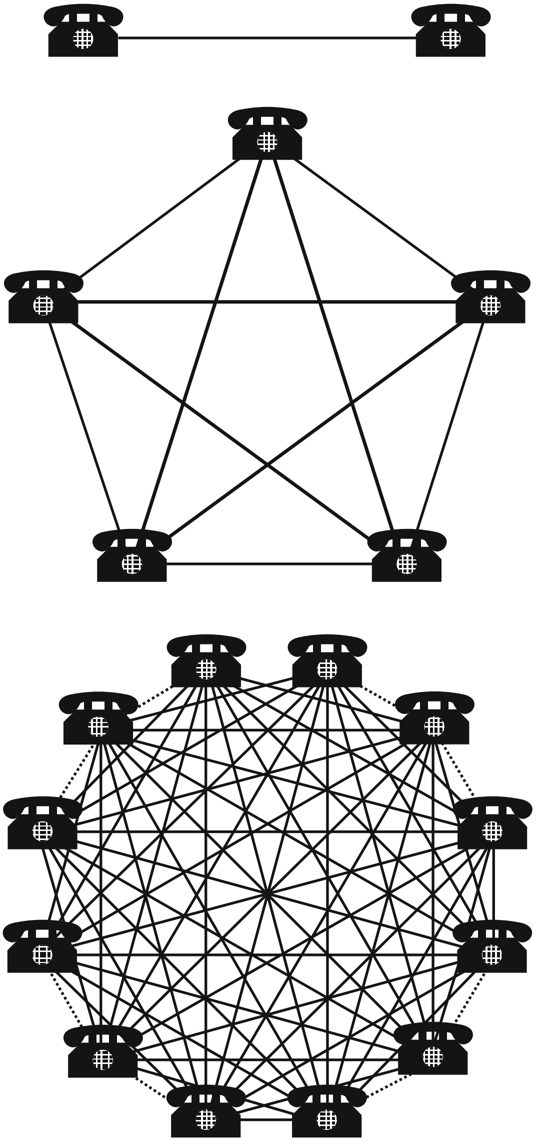
If satellite communications have been a need for militaries since the 1960s, it has been stressed those 20 last years with the emerging concept of network-centric warfare (NCW). One of the founding concepts is explained in the *Command and Control Research Program* (CCRP) book on NCW. It details the concept of information superiority and the prerequisites it needs. A few principles should be backed. First of all, Metcalfe law is saying that the value of a network is proportional to the square of the number of connected users of the system ($n^2$) (Fig. 33.2).

Linking those nodes requires setting up communications in between them, considering the assets are various in size, autonomy, and moving speed. The aim is to build and share information that is relevant, accurate, and timeliness in order to gain "information superiority." There are two aspects of this superiority: gain information for friend forces and deny information to the opposite forces. The latter one explains the need for hardened communications. The first one requires an infostructure which can be seen as the entry fee but will never be sufficient to itself. Satellite communications are the key assets in the Beyond Line-Of-Sight (BLOS) infostructure, the only one able to provide long-distance and high data rate links.

The following scheme is a description of how information is processed (Fig. 33.3).

The infostructure, supporting communications links, ables netting different sensors (air, Navy, land) and building a common picture. This picture can be value-added by force multipliers (drones, space assets, special forces) and shared back between users. It finally allows better collaboration and synchronization, tending to real time, of allied forces, thus increasing the tempo, responsiveness,

**Fig. 33.2** Metcalfe law



and efficiency of forces. Building this infostructure is a major issue. It relies on traditional radio communications and satellite communications, each one being complementary to the other. There are today two major trends, data rates and mobility, which modern satellite communications can both provide.

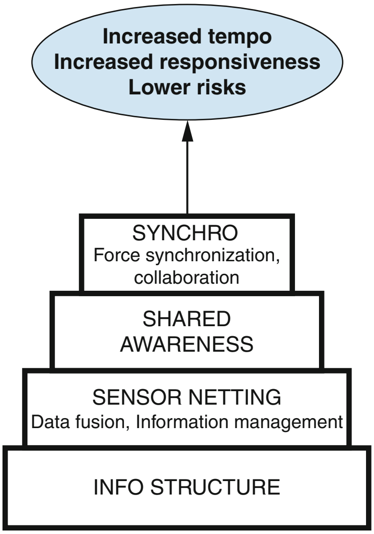


**Fig. 33.3** Network-centric organization

**Table 33.2**

| Assets | Old | Now and future |
|---|---|---|
| Navy ships | Radio communications for voice, tactical data link (plots), and telegraphy | Exchanging data (combat and logistic information systems) on IP networks |
| | | Netting sensors and exchanging raw data |
| Land units | Manpack radio communications assets (voice) | Digitalization of soldiers and armored vehicles |
| | Use of radio relays on heights | SATCOM radio extension offering on-the-move (OTM) communications (i.e., Soldier Network Extension for the USA, VENUS for France) |
| Air units | Airborne radio communications (voice, data link, telegraphy for strategic and transport units) | Netting embedded sensors |
| | | Transmitting full motion video (UAV) |
| Space assets | None | Imagery needs follow the increase in imagery resolution |

## 33.4.2 Increasing Data Rates

See Table 33.2.

The need for data rates is increasing, pulled by the new employments quoted here. They are estimated between 10 % and 20 % per year, which is quite reasonable compared consumed data rates increases through submarine cable between Europe and North America (about 40 % per year between 2000 and 2010) or between Europe and Asia (which recently doubled every year). The following figure gives us an indication of the needs with respectively 10 %, 15 %, and 20 % increases from a base 100 reference in 2013 (Fig. 33.4).

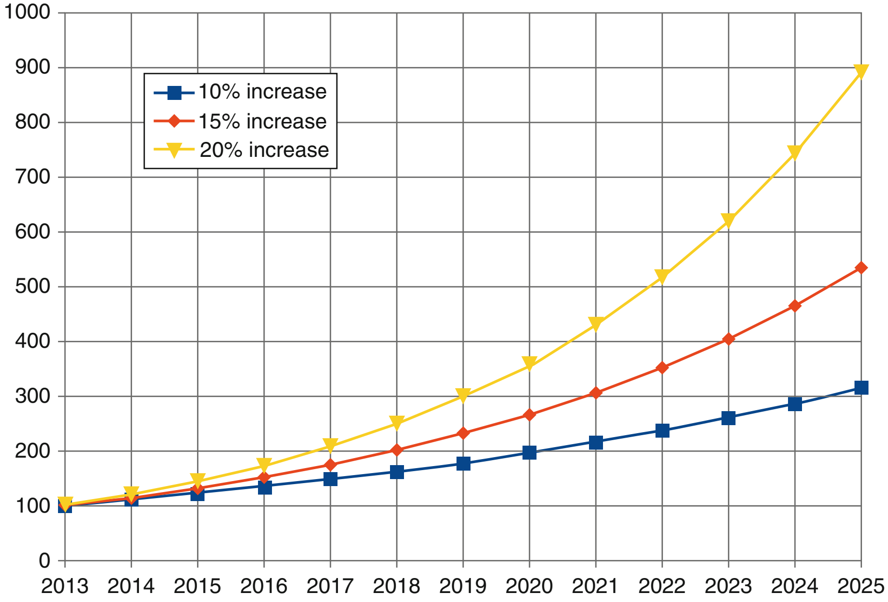


**Fig. 33.4**

The normal slope is around 15 %, with breakthroughs driven by four major evolutions:

- Drone equipments
- Imagery facilities (satellites)
- Digitalization of assets (soldiers, Navy, air)
- Networks' interconnection with operational information systems

Concerning UAVs, in 2011, the USA had 165 Predator and 73 Reaper. Large bandwidths needed can only be provided in higher frequencies as Ku and Ka band, as lower bands are already saturated. For instance, the first WGS satellite, more than symbolically named Wideband Gapfiller System, gave more capacity to US armies than the whole DSCS constellation. Its capacity is 2.4 Gbit/s per satellite with transponders of 125 MHz wide. Today, ten of those satellites are scheduled to be launched and will probably lower the US dependency to commercial-bought bandwidth.

This will to acquire extra bandwidth into higher band is also looked for by France and Italy through the cooperation on the ATHENA-FIDUS satellite in Ka band.

### 33.4.3 Increasing Mobility and Operations Tempo

Providing communications on the move is also a major trend, as it is directly impacting the tempo of operations. The main impact is that through netting the sensors (as listening, looking) and effectors (weapons), the operations tempo theorized by USAF Colonel John Boyd is accelerating. An accelerated "Observe, Orient, Decide, Act" process is allowing increased responsiveness through information superiority.

The major effect of this evolution is a spread of satellite communications assets from the strategic level (between headquarters) to the underneath levels, right down to the soldier in a valley, being able to exchange data with other soldiers, on foot or motorized, or query air support. A major gap step has been made since the first Gulf War (1990) where air planification and support took 3 days, compared to a few minutes in Afghanistan between the moment when a soldier is under enemy fire and the moment he receives air support. He can immediately report any difficult situation with a satellite communications device, being supported by the permanent presence of a UAV to spot the danger, and then receive any kind of armed support.

## 33.5 Conclusion

Satellite communications systems are a major asset providing some C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance) capabilities and leveraging the power of traditional operational effectors (tanks, airplanes, ships). They are the foundations of any military communications and information systems.

They are driven by three main characteristics. The first one is the need to resist to a wide range of attacks and offering protected communications under any condition. Military satellite communications need a high **protection** profile. The second one is the need to answer to radical changing operational conditions of deployments: geographically, environmentally, and overmost operationally. Conducting operations mainly from the sea and air, such as in Libya in early 2012, does not require the same architecture and characteristics than conducting land operations with support from the air such as in Mali in early 2013. Communications satellites need some high **flexibility** to adapt to the uncertainty of war and operational engagements. Finally, military assets would be vanished without guaranteeing the political will to intervene, to know, and to be able to act in consequence, protecting the **sovereignty** of a nation. Only military satellites can fulfill those three main requirements.

In consequence, this capacity is highly strategic. It is highly technical as satellites used to be, but it's far from only being highly technical. It is also and mostly the result of choices that have been thought and supported over many years with consistency. It involves a political will and vision, strong industrial capabilities, and exhaustive operational feedbacks. It finally engages allies towards each other, giving a nation the ability to carry a coalition through a strong command structure. It also ables the delivery of the most accurate information down to the right tactical level, and up to the political decision points, giving an advantage to its owner. It is a capacity that gives coherence and may leverage other capacities. It isn't anymore an option for willing countries.

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Metcalfe figure (source: Wikipedia)
Source: Network Centric Warfare by David S. Alberts, John J. Garstka, and Frederick P. Stein | 1999

# Telecommunications for Security and Dual Use

# 34

Jean François Bureau

## Contents

### Abstract

The military establishment is planning for an increase in need for satellite communications bandwidth and services. The lessons learned from most recent operations demonstrate that commercial satellite operators can efficiently provide the capacity and services needed. A new balance between military and commercial satellite output is coming, which will be considered by all key decision-makers in the United States and Europe, including defense and security organizations like NATO and the EU Common Defense and Security Policy.

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DOI 10.1007/978-1-4614-2029-3_45,

## 34.1 Introduction

In 2011 (Dubaï Air Chiefs Conference 2011), General Palomeros, the then French Air chief of staff,[1] declared: “Planners estimate a large bandwidth is needed because of a ‘multitasking of UAVs (unmanned aerial vehicles)’ with many remote piloted vehicles being operated simultaneously. Some 20 gigabits per second is needed to cope with the growing number of UAVs, which are swamping the current Ku bandwidth available on satellite communications links. Ka band appears to me as an interesting option. . . .A good solution would be to get industry to furnish a dual-band Ku-Ka antenna; this option allows us to benefit from the maturity of the Ku, while anticipating the potential benefits of the Ka band.”

With these few words, General Palomeros gave a sense of the growing importance and attention military planners and decision makers pay to the most recent developments in the field of telecommunications technologies implemented on satellites, and how these groups can envisage a new pattern of relationship with the industry, and parting with the satellite operators.

The telecommunications satellite (satcoms) operators are very much aware of these changes, even if, because of the planned recess of military activities due to the NATO draw down in Afghanistan and elsewhere (Iraq), they are cautious when asked to forecast the development of their activities related to military needs. Hence, attending the same conference, they (Eutelsat, SES, Intelsat, Inmarsat, Astrium Services) mostly considered that until 2015, the risk of reduced use of commercial services for military satellite communications needs would evolve between “no risk” and “low risk” (Euroconsult Conference 2011). This quite unanimous assessment shows that all operators have received the key message: western military forces and defense establishments will build upon satcoms commercial facilities and resources more than ever, and the commercial services and capacities will be very much needed to fulfill the military “hunger for bandwidth.”

However, the shift towards a new balance between market services and capacities and more conventional proprietary concepts will be a long run. Building a new alliance between market pull forces and military push needs will be a challenge, but Western military forces and security apparatuses (such as coast guards, “gendarmeries,” border control units. . .) understand that the technological lead is only meaningful if and when it delivers more efficient and appropriate services and capacities. The spectrum of military and security telecommunications needs is extending significantly, due to the ability to merge data, texts, images, maps, videos (among others) in the same flow of digitalized information, and the increasing ability of commercial satellite

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[1] Since September 28, 2012, General Palomeros is the NATO Strategic Allied Command Transformation (SACT), in charge of strategic planning, training and forecast, which includes the NATO space doctrine.

operators to stick to the most demanding requirements (readiness, availability, flexibility, protection). Both trends could significantly change the usual work process and give more importance to the military–security needs fulfilled by commercial operators. Of course, it will mean that those operators can adjust their organization and processes to ensure the continuity and reliability of the capacities and services they will provide to the military and security establishment.

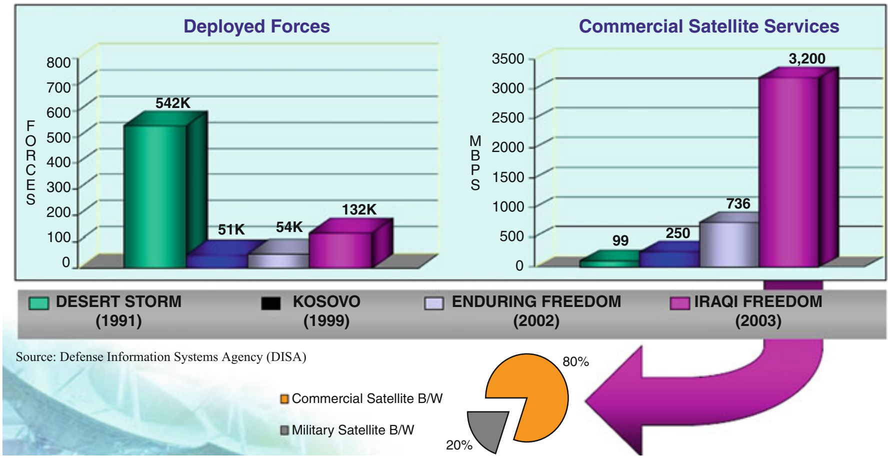
Here is the coming challenge: to build a new alliance between market forces and military-security needs and military establishment, in order to deliver the satcoms resources in a more cost-efficient way, needed to manage long-term, far-away, demanding and enduring operations. At a time of budget crunch, there is no doubt that these tendencies will endure only if they demonstrate that it makes sense to reallocate limited resources from investment (Capex) to operational costs (Opex). However, this shift will not include all types of military needs, and this new alliance will also come from a new balance between "hard core" military needs, which dedicated military telecommunications satellites (milsatcoms) will continue to fulfill for a long time, and other differentiated needs that commercial telecommunications satellites (comsatcoms) will be required to provide.

## 34.2 The Bandwidth Hunger

Two key lasting changes have created the "bandwidth hunger" that all military experts are talking about when they address their coming needs regarding satellite telecommunications:

- The flow of information needed to support highly intensive operations, combining tens and sometimes hundreds of assets of all kinds, e.g., terrestrial mobiles, artillery batteries, air fighters, surface and submarine ships, unmanned aerial vehicles (UAV), command and control centers; and even, in the near future, the individual fighter on the ground. Sharing the appropriate information in real time, in the very challenging operational loop based on OODA (observe; orient; decide; act), is extending exponentially.
- The network able to manage such a complex process needs an architecture where the satellite is a key part of the backbone, because: (1) only its coverage is appropriate to support long extensions and far away operations; in most cases, in complement with dedicated planes like AWACS; and (2) it has increasing power to transfer huge quantities of information under safe conditions, to fixed and mobile assets.

All lessons learned from recent operations (Iraq, Afghanistan, Libya) have showed a significant shortage in bandwidth. US and NATO armed forces "complain" about the limitations of current capacities, due to the capacity limitations they suffered during previous operations (Fig. 34.1). In some cases, comsatcoms



Source: Defense Information Systems Agency (DISA)

**Fig. 34.1** Recent operations have fed the need for commercial satellite services

capacities have been required to support very sensitive operations, demonstrating that despite their specific characteristics, these commercial capacities could be indispensible to absorbing the demand peaks.

For those reasons, armies are now looking for spectral alternatives to meet their fast growing needs:

- Comsatcom capacities in Ku and C band tend to be saturated;
- Milsatcom capacities, especially in X band, are used in priority for core, fixed communications, and are not optimized for highly mobile terminals and high data rates.

Hence, armed forces are looking forward to having Ka band serve their increasing needs for bandwidth. New Ka band milsatcoms capacities will go along with new Ka band comsatcoms capacities.

In the next years, it can be assumed that the shift towards Ka band will come from the increasing needs related to UAVs, VSAT (very small aperture terminal) and COTM (communication on the move). Data rates over 100 Mbps for UAVs are not possible in Ku band, but only in Ka. Ka band terminals also have the advantage of being smaller and flat, which make them more adapted to military applications, VSAT and COTM in particular.

To get a sense of the needs of these UAVs, COTM and VSAT, it can be recalled that, according to some estimates:

- UAVs like Global Hawk or Predator need a 0.5–1.5 m antenna to receive from 50 to 150 Mbps;
- Tactical VSAT need a 1–2.5 m antenna to receive from 2 to 20 Mbps;
- COTM receive 0.5 Mbps with an antenna less than 0.5 m in diameter.

The development of Ka band for government and military and security applications seems the most promising way to feed the “bandwidth hunger.” New technological developments regarding the structure of satellites, such as the development of High Throughput Satellites (HTS) based on steerable beams (e.g., the Eutelsat KA SAT manufactured by Astrium, which is able to deliver 90 Gbps), as well as more powerful and versatile terminals, can ensure that providing more bandwidth and higher data rates will come from current developments in Ka.

### 34.2.1 Demand Generated by UAVs over Europe, the Middle East, Asia and South Asia (EMEA&SA)

Current estimates indicate that based on the 300 UAVs that were in service in 2010, by making use of all frequency bands, there could be around 800 in 2020 (of which US UAVs would represents 80 %). While there were no Ka-band UAVs in 2010, there could be 550 in 2020.

The average UAV traffic rate was 5 Mbps in 2010 and 10 Mbps in 2012; it could jump to more than 100 Mbps in 2020. According to these figures, the military Ka band bandwidth demand generated by UAVs in EMEA&SA could reach 1 Gbps in 2015, and more than 7 Gbps by 2020.

In the more specific US case, pulling out of Iraq and Afghanistan will mean a decline in the number of US units in orbit, but not a decline in bandwidth need: the estimated number of orbits (1 orbit = 4 UAVs) moved from 44 in 2010 to 58 in 2012. The estimates reach 65 from 2013 to 2015, with a decline after 2015, reaching 61 in 2016, and 44 in 2020, due to troop draw down. But bandwidth per UAV will go from 15 Mbps in 2010 to 60 Mbps in 2016 and 80 Mbps in 2020.

The US Department of Defense leads the development, ownership and operation of UAVs; official US estimates for High Altitude Long Endurance (HALE) and Medium Altitude Long Endurance (MALE) UAVs are 445 in 2013 and 645 in 2022 (US Annual Aviation Inventory). The traffic per UAV, in Mbps, could move from 5 in 2010 to 105 in 2020, with an accelerating rate of growth speed after 2015 (need could be 25 Mbps per UAV in 2015). Hence, the US Department of Defense Air Force Unmanned Aerial Systems Flight Plan (2009–2047) states that:

- For Predator and Reaper, Wideband Global Satcom (WGS) Ka band terminals should start fielding by the second quarter of 2011;
- Thirty percent of the Predator and Reaper airborne terminals should be capable of using WGS by the fourth quarter of 2013;
- Forty percent of the Predator and Reaper fleet should be operational with Ka band compatible terminals by the fourth quarter of 2016.

If US UAV traffic globally to milsatcom represents 14 Gbps in 2020, the Ka band equivalent in GHz could be 9 GHz, of which 6 GHz are for EMEA&SA.

Persistent, multi-role intelligence, surveillance and reconnaissance (ISR) will drive UAV growth: strategic UAVs like Predator, Reaper and Global Hawk will grow and have improved sensors and capture capabilities. Other missions, such as border control, counter piracy and counter terrorism (Sahel, Somalia, Yemen), could sustain UAV demand.

In the aftermath of Iraq and Afghanistan, boots on the ground could be avoided as much as possible, at least for a time. Under these conditions, special forces and units would require high levels of protection and information coming from the sky, namely satellites. The need for persistent surveillance (e.g., with full motion video at 30 frames per second) will drive an increased need for bandwidth.

The total bandwidth demand for US strategic UAVs served by milsatcoms and comsatcom could move from 3 Gbps in 2010 to 9 Gbps in 2012, 14 Gbps in 2014, 18 Gbps in 2016 and 19 Gbps in 2018. It could drop back to 18 Gbps in 2020, because UAV on-board processing and advancements in data compression techniques could lower the bandwidth needed per UAV. Then, US UAV comsatcom could reach 4 Gbps by 2020.

### 34.2.2 Demand Generated by COTM and VSAT over EMEA&SA

If we assume that UAVs will represent 25 % of comsatcom demand for EMAA&SA, COTM will represent 15 %. COTM application will emerge first. COTM and VSAT will represent 60 % of Military Ka band initially, changing to 45 % by 2020. Military Ka band bandwidth demand for COTM and VSAT could move from 0.5 GHz in 2014 to 1 GHz in 2015, to 4.5 GHz in 2018 and 6 GHz in 2020.

If we assume that EMEA&SA represents 80 % of global US Government & Military demand, and that share could decline to 65 % in 2020, then:

- Without transfers from other bands (Ku, C) to Ka, the total military Ka band demand in EMEA&SA (UAVs + COTM/VSAT) would move from 2 GHz in 2015 to 7 GHz in 2017, and 13 GHz in 2020;
- With transfers from other bands, the trend for total military Ka band demand in EMEA&SA (UAVs + COTM/VSAT) could be: 3 GHz in 2015; 8 GHz in 2017; 15 GHz in 2020 (with an assumption of 25 % cannibalization in 2020).

This forecast tends to confirm a limited transfer from existing X and EHF to military Ka, due to the very high resilience required for the core milsatcom applications that can only rely on X band.

The estimated demand for commercial satcom over EMEA&SA reached 5 Gbps in 2005 and 10 Gbps in 2010, and could, if a growth rate of 4 %/year between 2010 and 2020 takes place, reach 14 Gbps by 2020. If the growth rate is 6 %/year, it could reach 17 Gbps by 2020.

More than the trend, what needs to be confirmed is the pace. The new Ka band potential coming to operations will depend not only on availability of resources in space (in other words, satellites in orbit), but also on the availability of terminals and the way their procurement is coordinated with the added bandwidth coming from space. The challenge on earth is as great as the one in space!

## 34.3 A Changing Paradigm?

The widely changing landscape of military and security needs to be filled with telecommunications satellites may have been prepared, or at least accompanied, with new procurement approaches and concepts to make sure that milsatcoms and comsatcoms can work more closely, in a way as complementary as possible, to deliver performing services.

Still, if huge military programs are being deployed in the US or in Europe, commercial satellite operators are more and more active in taking part in the process, and are able to feed the military needs with commercial offers.

Hence, changes are simultaneously taking place at the governmental level and at the fleet management one.

### 34.3.1 The Military Establishment Satcoms Policy: Looking Beyond Proprietary Systems and Building on Commercial Offers

- The US policy:

Unsurprisingly, the change came first from the Pentagon, which, building on some lessons learned from recent operations, opened the way for a shift from commercial capacity leasing to commercial managed services, and even more recently, from managed services to commercial value-added services delivering end-to-end services.

The US Department of Defense, by far the main customer, has been the most active in changing the way it will lease commercial capacity and services in the future.

As the “US national security space policy” states:

> Strategic partnerships with commercial firms will continue to enable access to a more diverse, robust, and distributed set of space systems and provide easily releasable data. Strategic partnerships with commercial firms will be pursued in areas that both stabilize costs and improve the resilience of space architectures upon which we rely. Innovative approaches will be explored for their utility in meeting government performance requirements in a cost-effective and timely manner. *We will rely on proven commercial capabilities to the maximum extent practicable*, and we will modify commercial capabilities to meet government requirements when doing so is more cost-effective and timely for the government. *We will develop space systems only when there is no suitable, cost-effective commercial alternative or when national security needs dictate* (US National Security Space Strategy 2011).

Five key elements can be considered to describe the US policy development:

- Building on those principles, the US Department of Defense has reformed its clearance policy related to satcoms services in order to be more inclusive of the commercial capacities. The focus is on information assurance and security and Foreign Ownership, Control and Influence (FOCI). The Information Assurance, which includes a cybersecurity dimension, will become increasingly important, requiring one of three levels of security: “assured,” “secured” and “core protected.” The first two levels are required for UAVs satcoms.
- A general shift towards performance-based solutions with service level agreements. To this end, the Department of Defense needs are shifting from pure bandwidth leasing to more emphasis on services and integrated solutions.

This broader perspective will change some industrial relationships, as the pure capacity providers will become more dependent on solution integrators.

- An increased acceptance of "commercial on the shelves" (COTS) solutions. Instead of developing specific solutions, US armed forces are increasingly adopting market solutions for non core protected Ku and Ka bands; hence, the increasing use of commercial terminals. Again, this trend will incite for vertically integrated operators.
- Instead of having a collection of diversified providers, the new policy will look for large procurement vehicles with larger integrated solutions providers, in search of improved service and better value. From that perspective, to stand as a Pentagon prime provider, managed services and end-to-end services will become key.

Along with this policy, the Pentagon established a Request for Information (RFI) in 2011 as a project of the US Department of Defense to lease as of 2014 a mix of military Ka and Ku band capacity, preferably on the same satellite, from a commercial operator over 15 years.

- An evolving NATO policy: The NATO Strategic Concept, approved November 19, 2010, makes a reference to space policy when it states: "A number of significant technology related trends—including the development of laser weapon, electronic warfare and technologies that impede access to space—appear poised to have major global effects that will impact on NATO military planning and operations."

However, space policy is still a highly national asset, not only because only a few NATO nations can in fact contribute to the discussion, but because many NATO nations have realized the key importance of space capabilities only recently, in the course of recent operations. In that sense, the mere fact that NATO Strategic Allied Command Transformation (ACT) has recently created the NATO Bi-SC Space Working Group (SWG), gathering ACT and ACO (Allied Command Operations) representatives with ACT providing the leadership and administrative support, is of major importance.

The mission of this SWG will be to:

- Provide advice and recommendations for the development of direction and guidance for "space support to NATO operations";
- Recommend appropriate requirements on doctrine, organization, training, leadership and education, personnel, facilities and interoperability to improve the space support to NATO operations;
- Coordinate and support the NATO Defense Planning Process for space support to NATO operations;
- (Upon approval by the chairman), liaise with national and international space organizations as required;
- (Upon approval by the chairman), liaise with industry and academia as required.

This new interest towards space activities comes at the moment of the NATO agencies reform, following the NATO Lisbon Summit (November 2010). It was decided that former NC3A and NSA would merge to set up a new entity, the NATO Communication and Information Agency (NCIA), created on July 1, 2012. This entity will be in charge of organizing the procurement of commercial satellite capacities, as a complement to the national (member states) contributions organized on the basis of their own capacities.

This important reform should be understood within the context of the path NATO has followed regarding spacecoms needs. During the cold war, NATO ambitioned to own its specific capabilities, as was the case with the airborne C3I capacity (AWACS). A first NATO satellite was launched in 1970, and the last two NATO satellites were launched in 1991 and 1993. Their design, meant to last 10 years, was dedicated to NATO needs and the same as for UK Skynet IV. This policy of self-procurement was abandoned in early 2000, when NATO decided to make use of member states satellites, considering that the coverage and availability would be better assured if a greater number of assets was included in the process. Hence, since 2005, NATO has been making use of member states' capacities, dealing with core strategic communications only (troops welfare purposes being a nations duty), and services from the private sector (E2E services provided by Thales). To complement this resource, and to face the need for increased capacity, the NSP2K program, subject to a Memorandum of Understanding signed between UK, France and Italy, asserts that these nations can sell non-used capacities from their national satellites. Hence, France is selling non-used capacity from its Syracuse satellites to NATO. Since 2010, and after lessons learned from Afghanistan, it has become obvious that such a mechanism would be unable to face NATO's needs in the future, should far away and long-term operations again take place. If core needs are to be provided by NATO member states, NATO now seems ready to make extensive use of commercial capacities in the bands they currently use (X, UHF), as well as in new bands (Ku and Ka). This process will not necessarily be a "soft" one, because NATO will impose legitimate but significant constraints on the providers: a total availability, which means backup and restoration capacity (including teleport), fleet coverage flexibility and even "virtual capacity," against which NATO will only pay for what it uses; capacity will have to be granted, but only the share used will be subject to payment.

- A new European perspective? The European Defense Agency (EDA) European satellite Communication Procurement Cell (ESCPC):

On July 4 2012, the ESCPC was established among five members (UK, France, Italy, Poland, and Romania)[2] as a pilot case for "pooling and sharing," in order to allow the contributing member states to benefit from a common procurement scheme at the European level. This significant achievement came after the European Council (June 1, 2011) invited the Commission, after consultation with EDA and ESA, "to evaluate the need for improvements of the available space infrastructure to develop secure services based on the integration of global satellite communications, earth observation and positioning" and "Space Council Orientations (December 6, 2011) recognized that "Satcom represent a key capability in any crisis response and crisis management operation, and a highly crucial and scarce

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[2] At an initial stage of the process (2009), Netherlands had indicated its readiness to participate.

resource, especially when ground infrastructures are damaged or destroyed, and recommends (. . .) to work towards a secure and guaranteed access to commercial and governmental satellite communications for crisis response and crisis management actors." EDA Steering Board identified Satcom as a key domain where a "pooling and sharing" approach should be implemented; this is what the EU ministers have endorsed. The key purpose of the ESCPC is to overcome fragmented procurement of commercial Satcoms within the EU, pool orders in order to make significant savings, and improve the effectiveness of military expenditure. The cell activities can reach a business volume of at least € ten million per year. With the signature of the contract with Astrium services on September 28, 2012 (see http://www.eda.europa.eu/news/12-09-28/European_Defence_Agency_facilitates_access_to_commercial_SatCom_services_for_Member_States, the initial Operational Capability is expected to end in 2012.

### 34.3.2 A Dynamic Satcoms Fleet Modernization Including More Commercial Assets

Along with the need to provide more bandwidth, and the institutional moves to include, on a wider basis, commercial services provided by satcoms operators as a usual resource to feed military and governmental needs, two major trends can be identified:

- Governments are still heavily investing to develop proprietary systems in different frequencies, with a preference for Ka;
- Satcoms operators are extending their fleets as well, to provide more services and capacities to military and governmental requirements.

Unsurprisingly, the US Government made an aggressive move to military Ka band with the Wideband Global Satcom system (WGS). The plan is to develop a US Government-owned global constellation of milsatcom; four WGS satellites are already in operation (Block 1: WGS 1 in service over the Pacific since April 2008; WGS 2 in service over the Middle east since August 2009; and WGS 3 in operation over Europe and Africa since June 2010. Block 2: WGS 4 launched on January 19, 2012, to go into service over the Middle East mid 2012); plus five more have been ordered (WGS 7 and 8 ordered 2011; WGS 9 ordered 2012, with an option for a tenth satellite, WGS 10), embarking a mix of military Ka and X band.

Each satellite has cross-strapped X band and military Ka band payloads; two-way Ka band services; ten Ka band steerable spot beams; and can deliver 2.7 GHz of Ka band bandwidth per satellite. Three satellites could cover EMEAA&SA, providing an equivalent of 8 GHz of cumulated military Ka bandwidth.

With the WGS constellation, military Ka band will become available anywhere on the planet to the US air, maritime and ground fighters, C3I planes and UAVs. Military Ka band will be the next frequency of reference for US armed forces:

- Terminals will operate in military Ka band;
- Civil Ka band will not be compatible with WGS;

- UAVs could be equipped with radomes tuned only for military Ka frequencies.

Similarly, other governments also make investments in military Ka band. A large group of nations has decided to co-invest in WGS to access Ka and X bands from the system. Australia will use WGS 6; Canada, Denmark, Luxembourg, Netherlands, New Zealand will share WGS 9. As such, WGS capacity will be a major driver of interoperability among all nations included (USA, Australia, New Zealand, Denmark, Netherlands, Luxembourg, and Canada), as this large group of nations, on both sides of the Atlantic and extending to Asia-Oceania, will build upon that standard.

France and Italy will co-own Athena–Fidus in Ka band and EHF, which is to be launched in 2014, and it can be assumed that the new French milsatcoms, COMSAT NG, as a successor of the two Syracuse III satellites, will include similar specifications.[3]

Hisdesat (Spain commercial operator/provider as a dedicated subsidy of Hispasat for military needs) and Norway armed forces have invested in HisNorSat to launch a military Ka and X bands satellite at the end of 2014; 1.5 GHz of military Ka band are expected.

Confirming that the trend towards market satellite operators providing more commercial services to the military and security establishment is a lasting one, several commercial operators have also already made the investment.

Among many developments, one can take note of the following:

- From 2013, Inmarsat will launch the Global Xpress constellation composed of three satellites, providing a mix of commercial and military Ka band capacity; the power delivered could be up to 4.5 GHz of military Ka bandwidth over EMEA & SA.
- Yahsat launched Yahsat–1 A in 2011, and Yahsat 1–B in 2012; both are able to provide some military Ka bands capacity in the Middle East and Africa (France is leasing such a capacity for its Abu Dhabi permanent base). Yahsat 1 A is operating in C, Ku and Ka bands, while Yahsat 1B is operating in Ka band; each satellite has a capacity of 1 GHz of military Ka band.
- Avanti planned to launch Hylas 2 in 2012 at 31°E, with 24 fixed spots and one steerable beam in Ka band Government spectrum (spot beam able to access military Ka band >400 MHz).

These trends cannot ignore that quite a significant number of satellite operators are providing capacities and services to governments in a pure outsourcing/commercial pattern.

From that perspective, Astrium Services (ASV) is, by far, the service provider that has developed the widest array of satcoms for military and security purposes in a market-oriented pattern. With its Paradigm subsidiary, Astrium has built a

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[3] On September 12, 2012, the French Ministry of Defense procurement agency, DGA, announced that it had launched a study on the future capacities of military satellite communications, with a view to design the next COMSAT NG program aimed at replacing the Syracuse III system in 2019. It will be noticed that the DGA asks for due consideration of the "potential of cooperation with European partners," more specifically the UK and Italy.

commercial capacity under a long-term Private Finance Initiative (PFI) contract with the UK ministry of Defense, for the provision of military satellite communications services to 2022. Since 2003, Paradigm operates the five satellites of UK Skynet. In a very similar but different way, Astrium is in charge (MilSat Services Gmbh) of the German SatcomBw, which includes satellites, ground segment and maintenance. Since the second launch in 2010, two satellites are operated under a 10-year contract, in order to provide the German forces with an independent and secure network.

But, because of the ever-increasing demand for military and security needs, we could also find new economic models that are even better equipped to compete with more traditional patterns. One of them could aim at delivering a full range of services – from capacity to value added services – building on an extensive fleet, ready to cover and deliver in all the critical areas, fulfilling all the key requirements, readiness, flexibility, sustainability, cost-effectiveness, redundancy, which will make a difference. From this point of view, only few satellite operators, building upon their wide fleet and large geographical coverage, their ability to manage all critical frequencies and their experienced services management units, as well as on their air and terrestrial infrastructure, will be able to build a new relation with governments. Instead of providing pure technical resources, these units will provide a comprehensive set of complex services, end-to-end, in a long-term and sustainable bidding relationship, making the best use of a large and competitive fleet and coverage. At that moment, satellite operators will cease being considered as providers and become partners of the key military and security apparatuses.

This moment is not very far away, and worldwide companies, like the three "first" (Intelsat, SES and Eutelsat) are working to design the best balance between risk-taking, best fleet management, extended services and capacities, cost efficient solutions and appropriate balance between private and public customers.

The moment when public customers receive service that is as efficient and capable of performing as that received by private customers (which is currently based on a "special relationship" where satellite operators differentiate between public needs and commercial demand), will open the way to a very different "alliance" between commercial operators and public requirements.

## 34.4 Conclusion

Between 2008 and 2010, the revenue coming from government and military demand to market satellite operators for fixed satellite services rose from 700 million dollars to 1 billion dollars – a 20 % increase in three years. In 2010, the three "first" operators received more than 93 % of the total: Intelsat came first with 48 %, SES came second with 30 % and Eutelsat came third with 15 %. There is no need to point out that all these key players are preparing for the new "alliance" period of time, where private satcoms operators will provide an increasing contribution to governmental and military needs.

This very significant shift will be accelerated by the financial crunch and the fact that satellite operators are leading the overall investment flow manufacturers receive in their books.

The time where public–governmental needs were fulfilled with public money, and private-customers market needs were financed with private money, has passed. In the very near future, public needs could be financed by private resources, with private operators being partners for a significant period of time, enough to make the investment worthwhile. This change goes far beyond public–private mechanisms (like PFI) that were developed during the last years. It seems that governments are paying attention to the fact that the private sector can deliver, in a performing and efficient way, when it comes to satellite telecommunications. At the beginning of the 1990s, it took some time to understand that terrestrial telecoms could be managed by private operators at least as well as public firms had before. It may be that, in the field of satcoms, a similar change will take place in the next years. Even though military needs might be more demanding than people in the street's private mobile phones, specialized, performing and experienced satcoms operators will be able to face the challenge.

Governmental satcoms are changing; this decade, providers will certainly pay more attention to private satcoms operator capacities and services, provided they pay more attention to their military and security force clients. What is at stake is a new partnership, and a new alliance.

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# Positioning, Navigation, and Timing for Security and Defense

# 35

Jean-Christophe Martin and Frédéric Bastide

## Contents

## Abstract

Global Navigation Satellite Systems (GNSS) allow users to compute their position, velocity, and time anywhere in the world, anytime, and with a high accuracy. The best known, most popular GNSS, is the US Global Positioning System (GPS), although the Russian GLONASS system is regaining strength. In addition, other powerful nations in the world are developing their own systems: the European Union, China, Japan, and India.

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This chapter reflects only the personal view of the authors and does not commit in any case the European Commission

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These GNSS mainly offer two types of services: an open service, available to anyone, and an authorized service, available only to authorized users and which provides better performance. The authorized services already support defense military operations of the USA and Russia, while the open services have become instrumental in civil security operations of any state for police and civil protection for instance.

Open services from the current and future GNSS can be combined in order to deliver better performance to users. This is called the "interoperability" concept. On the contrary, the authorized services cannot be combined except if security and specific cooperation agreements are in place. In this case, the combined use of authorized services could also bring improved performance for defense applications.

This chapter addresses these aspects on the use of the GNSS for defense and security applications.

## 35.1 Introduction

Global Navigation Satellite Systems (GNSS) is the generic term for space-based systems that transmit signals that can be used to provide three services: Position, Navigation, and Timing (PNT). The best known and most popular of the GNSS is the US Global Positioning System (GPS), although the Russian GLONASS system is also well known but really less used and other systems are being developed, most notably Galileo by the European Union, Compass by China, IRNSS by India, and QZSS by Japan. This is a domain in constant expansion with probably about 100 GNSS satellites available in 2020, doubling the current figures of slightly more than 50, which include around 20 and 30 operational satellites from GLONASS and GPS, respectively, at the time of this writing (http://www.glonass-center.ru/en/GLONASS/, ftp://tycho.usno.navy.mil/pub/gps/gpstd.t) and 4 operational satellites for Galileo.

In an ever more connected world, society's reliance on high integrity and accurate PNT data is growing. The easy and costless availability of the GPS and of other GNSS has meant that their use as primary sources of data can be found in an increasing number of products and services which require position and time. The range of applications stretches from highly accurate surveying to in-car navigation to network synchronization to climate research.

Space applications and technologies are suited for dealing with an increasingly expanding concept of security. If, on the one hand, traditional customers are military users, on the other hand, a wider security and civilian community can benefit from space services in support of critical transport, internal security (e.g., civil protection, firemen), law enforcement (police, Professional Mobile Radio using TETRA or TETRAPOL standards), emergency services, strategic economic and commercial activities, custom, critical telecommunications, and critical energy.

**Fig. 35.1** Artist view of the ejection of the two first Galileo Satellites

## 35.2 Overview of Existing and Future GNSS

Global Navigation Satellite Systems (GNSS) are experiencing a new era. The US Global Positioning System (GPS) now serves over 500 million users in a bewildering breadth of applications. The Russian system GLONASS is enjoying a startling renaissance based on the recovery of the Russian economy (however, the order of magnitude of GLONASS users is currently less than one million worldwide).

In addition, the European Union is developing the Galileo system that promises to place 27 more satellites in Medium Earth Orbit (MEO) plus three spares in the 2018–2020 timeframe (Fig. 35.1). Also from Europe, three geostationary satellites and a ground segment compose EGNOS (European Geostationary Navigation Overlay Service), which augments the existing GPS constellation by providing integrity and improved accuracy. Since the end of 2011, EGNOS is operational for aviation. The USA has a similar operational augmentation system called WAAS (Wide-Area Augmentation System). In parallel China has started to develop its Compass system that promises a rich complementary constellation of satellites in MEO and Geostationary Earth Orbit (GEO). Furthermore, India and Japan are developing their own regional systems, respectively, IRNSS (Indian Regional Navigation Satellite System) and QZSS (Quasi-Zenith Satellite System), which will provide positioning and augmentation services.

### 35.2.1 Description of GNSS Systems

Detailed description of all GNSS has been published by the United Nations International Committee on GNSS (UN ICG) in 2010 through a report (www.oosa.unvienna.org/pdf/publications/icg_ebook.pdf) on the current and planned global and regional navigation satellite systems and satellite-based augmentations systems.

The UN ICG is an informal body of the UNOOSA (United Nations Office for Outer Space Affairs) with the purpose of promoting cooperation on civil satellite-based positioning, navigation, timing, and value-added services, as well as compatibility and interoperability among the GNSS systems, while increasing their use to support sustainable development, particularly in the developing countries. The participants are the GNSS providers (e.g., USA for GPS and the European Union for Galileo) as well as various user communities.

#### 35.2.1.1 The US Global Positioning System

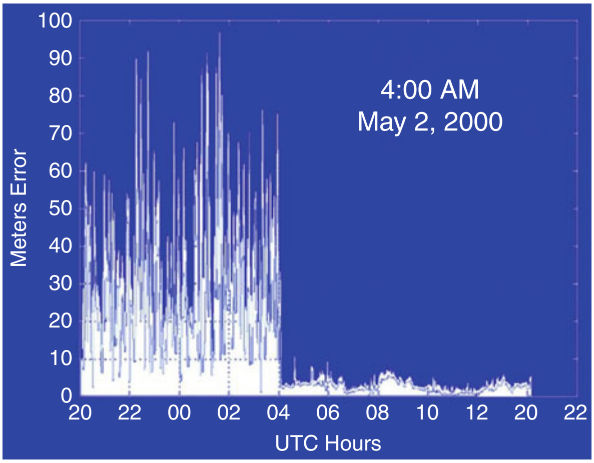
Originally developed by the Department of Defense (DoD) to meet military requirements, GPS was quickly adopted by the civilian world even before the system was operational. The foundations of the modern GPS were laid during the early 1960s by the US military. The Navy, Air Force, and Army each came up with their own designs and ideas. In 1973, a design took into account requirements from each of them and was approved by the US government. This was to become NAVSTAR. The first satellite for the new NAVSTAR GPS was launched in 1974, and from 1978 to 1985, another 11 were launched for testing purposes. The full nominal constellation of 24, that today allows navigation system to use worldwide GPS coverage, was completed in 1993. Currently, the GPS satellite constellation includes more than 30 operational satellites.

Initially GPS was only intended for military use, even for very strategic applications linked to the performances of their ICBM (Intercontinental Ballistic Missiles). But then in the “civil world,” tragedy struck. On 1 September 1983, Korean Airlines flight KAL007 from Anchorage to Seoul strayed off course into USSR airspace and was shot down by a soviet Su-15 fighter jet. All 269 passengers and crew were killed. Two weeks later, US President Reagan proposed GPS be made available for civilian use to avoid navigational error ever again leading to such a catastrophe. While by no means the only reason, the Korean Airlines disaster was certainly a major catalyst toward civilian access to GPS.

Having spent some $12 billion to develop the most used navigation system in the world, the US government included a function called Selective Availability (SA) into NAVSTAR GPS that could degrade its accuracy (by a factor of 10) for civilian users to ensure no enemy or terrorist group could use GPS to make accurate weapons. It worked by introducing deliberate errors into the data broadcast by each satellite. Military users could access the fully accurate system by using an encrypted signal that was broadcast simultaneously but not available to unauthorized users.

During the Gulf War, GPS became a strategic technology for the US military, which needed many more GPS receivers than it had. It solved the problem by using civilian GPS receivers, but to increase the accuracy of these devices, the SA function had to be temporarily disabled. Then in 2000, US President Clinton announced that SA would be disabled completely, as US government “threat assessments” concluded that removing SA would have minimal impact on national security. Though in the same speech he said the USA would still be able to “selectively deny” GPS signals on a regional basis when national security was threatened.

**Fig. 35.2** Improvement of the measurement quality after the Selective Availability has been turned off



This meant that the "local deny" could be done through other means such as the local jamming of a zone, this concept is known as "NAVWAR (Navigation Warfare)". In September 2007, the US government announced the decision to procure the next generation of GPS satellites (GPS III) without the SA feature. However, as of today, as the GPS-III satellite generation has not yet been launched, the USA still have the theoretic capability to re-activate the Selective Availability (www.gps.gov/systems/gps/modernization/sa/).

Position accuracy improvement for civil users in 2 May 2000 when SA was disabled (factor 5–10) (Fig. 35.2).

#### 35.2.1.2 GPS Modernization

The GPS modernization program is an on-going multibillion-dollar effort to upgrade the GPS space and control segments with new features to improve GPS performance. These features include new civilian and military signals. GPS modernization is in particular introducing modern technologies throughout the space and control segments that will enhance overall performance. For example, legacy computers and communication systems are being replaced with a network-centric architecture, allowing more frequent and precise satellite commands. A major focus of the GPS modernization program is the addition of new navigation signals to the satellite constellation. Most of the new signals will be of limited use until they are broadcast from 18 to 24 satellites. The military are using the PPS (Precise Positioning Service), which is an encrypted signal that can only be used by military or users authorized by military. The USA are also planning to develop a new PPS signal named M Code, which is also encrypted and dedicated to military users. Both the constellation (30 satellites) and the receivers will have to be changed. It will take roughly about 10 years, because most of the equipments cannot be changed immediately; this may be done around 2020/2025.

An audit made by the US Government Accountability Office (GAO) (United States Government Accountability Office 2010) in 2010 has stressed that there could be a risk to maintain the availability of the GPS constellation due to budget reasons and also to the difficulties faced by the US Air Force to develop and deliver on time new GPS satellites along with the required ground and user segments. This could have potential impacts on users if the constellation availability diminishes below its committed level of performance or below its current performance.

The USA has also developed over their territory, relying on geostationary satellites, a so-called Satellite-Based Augmentation System (SBAS) named WAAS (Wide-Area Augmentation System) which improves the performance of the GPS constellation. The geo-satellites provide corrections to the user and to the signal propagation errors in the atmosphere and integrity monitoring. It is extremely useful for civil aviation over US territory, principally for precision approach procedures down to 200 ft.

#### 35.2.1.3 The Russian GLONASS System

Flight tests of high altitude satellite navigation system, called GLONASS, were started in October 1982 with the launch of the Kosmos-1413. The GLONASS system was brought into operational testing in 1993 and the whole orbit group of 24 satellites was formed in 1995. By this time, the system provided continuous global navigation for all types of users with different levels of quality requirements for navigation support. However, reduction in funding for space industry in 1990s led to the degradation of the GLONASS constellation. Recently, the Russian President and the Russian government approved a number of policy documents, including the federal program "Global Navigation System" to provide adequate funding for the program. Russia has planned to spend 346.5 billion roubles (almost $12 billion) on its satellite navigation system during the period 2012–2020 (www.gpsworld.com/gnss-system/glonass/news/russia-expected-spend-12b-glonass-development-12619).

A major difference between GLONASS and both GPS and Galileo is the choice of the frequency bands and the concept of repartition of these frequencies. GLONASS uses one frequency for a pair of satellites. This leads to 15 different frequencies when using 30 satellites (so-called FDMA[1] techniques). The consequence is a large use of the spectrum, which is a rare resource. Whereas GPS and Galileo are using one frequency for all their satellites (so-called CDMA[2] technique), GLONASS is using different frequencies for its satellites and, by consequence, for its receivers. So, at the user level, a GLONASS receiver is more complex and more costly. As a consequence, the rough number of GLONASS-enabled receivers is less than one million, a small number compared to the GPS for which about 500 million receivers are manufactured a year. This difference also creates an issue of interoperability, meaning that combined GPS/GLONASS receivers were until recently expensive and complex. But thanks to improvements in semiconductor technologies over the past years,

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[1] Frequency Division Multiple Access.

[2] Code Division Multiple Access.

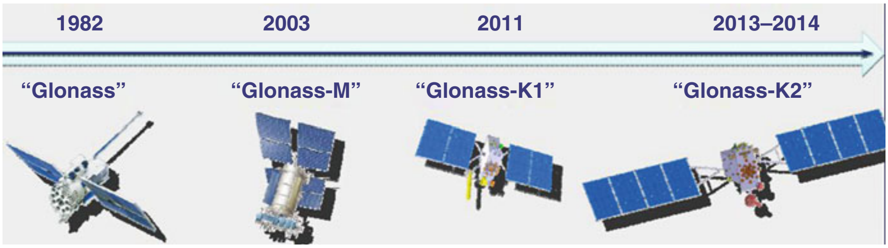

**Fig. 35.3** Evolution of the GLONASS satellites over the years

receiver manufacturers have managed to produce such receivers at a reasonable cost (Apple Iphone 4S and 5).

GLONASS is also undergoing a modernization process. This could in particular lead to the use of similar scheme (CDMA) than GPS and Galileo, which could improve consequently its interoperability with the other GNSS. But this evolution may be operational for the next generation, around 2020 12.25. The main issue is the duration of the satellite. The first generation of GLONASS satellite was designed with a 3-year lifetime, while the real operational life was of 4.5 years. In total, 81 satellites were launched. The second generation, known as GLONASS-M, was designed for 7-year lifetime. In August 2012, 28 satellites had been launched. The two most recent generations of satellites, GLONASS-K1 and GLONASS-K2, are designed for a 10-year lifetime (Fig. 35.3).

#### 35.2.1.4 The Chinese Beidou (Compass) System

The current plan is a fully operational constellation of 35 satellites by 2020. This comprises five geostationary orbit satellites, 27 MEOs, and 3 in inclined geostationary orbit (IGSO). On 14 April 2007, the first MEO satellite, named Compass-M1, was launched. On 15 April 2009, the first geostationary satellite, named Compass-G2, was launched. In November 2013, 14 operational satellites were in orbit: 5GEO+5IGSO+4ME.

According to the construction schedule, the Compass/BeiDou Navigation Satellite System is, as a first step, covering China and the nearby area, by around 2012. The full deployment of the System is planned to be completed between 2015 and 2020 and will offer global services. Chinese launchers are used for the deployment of the constellation (Fig. 35.4).

The Compass/BeiDou Navigation Satellite System will be able to provide two types of service at the global level: open service and authorized service. Through its open service, it provides free positioning, velocity, and timing services. Through its authorized service, it provides safer positioning, velocity, and timing services, as well as system integrity information, for authorized users. More particularly, the Compass/BeiDou Navigation Satellite System will be able to provide two kinds of authorized services, including a wide-area differential service (with a positioning accuracy of 1 m) and a short-message communication service in China and nearby areas.

**Fig. 35.4** Long March-3B launch vehicle

#### 35.2.1.5 The European Galileo and EGNOS Systems

The Galileo programme is Europe's initiative for a state-of-the-art global satellite navigation system, providing a highly accurate, guaranteed global positioning service. The program started in 1998 with the so-called GNSS2 initiative. The fully deployed system will consist of 30 satellites and the associated ground infrastructure. Galileo will be interoperable with the GPS system. Unlike GPS, Galileo is a civil system under civil control. However, it can be used for security and defense applications, because each Member State of the European Union is sovereign in deciding what its uses are.

Galileo will give to the European Union independence in satellite navigation, a technology used in sectors that have become very important for its economy (about 7 % of the EU GDP in 2009; http://ec.europa.eu/enterprise/policies/satnav/galileo/) and the well-being of its citizens. Whereas EGNOS is operational since 2011, Galileo is still in development. Two satellites have been launched on 21 of October 2011 (Fig. 35.5), two other on 12 of October 2012. The industrial contracts have been signed during the period 2010–2012. They may allow early services in 2015 and having 22 satellites in 2017, allowing operational positioning and timing services. The final constellation, named FOC (Full Operational Capability) with 27 satellites and three spare, is planned for the 2020 timeframe.

**Fig. 35.5** First Galileo rocket launch on 21 October 2011

Independent studies also show that Galileo will deliver around €90 billion to the EU economy over the first 20 years of operations, in the form of direct revenues for the space, receivers, and application industries and in the form of indirect revenues for society (more effective transport systems, more effective rescue operations, etc.). The main part of this revenue is coming from the user segment (the services linked to the receivers).

Guiding blinds in an unknown city, locate people lost at sea with a 3-m accuracy, guiding tractors by satellite for higher crop yields with much less fertilizer, reducing fuel and time consumption on the road and in the air, thanks to a better traffic management, making flights and landings safer: These applications are already being tested now. Thanks to its improved accuracy, through the combined use of GPS and Galileo, a huge range of innovative applications making everyday life easier and safer is foreseen.

Here is a high-level scheme of Galileo's structure (Fig. 35.6):

Prior to Galileo, Europe's first venture into satellite navigation was the development of EGNOS (European Geostationary Navigation Overlay Service), the European SBAS and the equivalent of WAAS in the United States. As WAAS does over US territory, EGNOS improves the performance of GPS over Europe and, since 2011, EGNOS makes GPS suitable in Europe for safety-critical applications

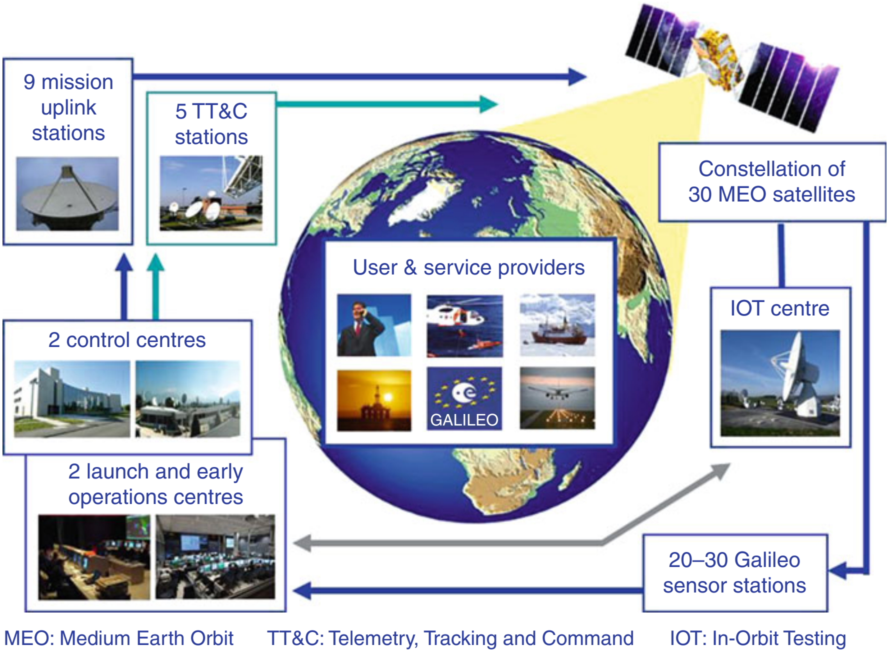

**Fig. 35.6** High-level description of Galileo infrastructure

such as flying aircraft or navigating ships through narrow channels. It should be noticed that EGNOS's design allows the augmentation in the future of GPS but also other GNSS constellations such as GLONASS or Galileo.

As a satellite navigation augmentation system, EGNOS includes a network of monitor stations across Europe. Beyond that, it constantly monitors the GPS signals. Thanks to this monitoring functionality, EGNOS is able to correct GPS orbit calculation and clock estimation errors as well as signal propagation delays through the ionosphere (an electrically charged layer of the atmosphere from around 20–2,000 km above the earth surface), providing a user positioning accuracy within 1–2 m most of the time, which a significant improvement compared to GPS alone, which may stay in the range of about 5 or more meters (depending mostly on ionospheric conditions). This accuracy improvement is relevant not only for civil aviation but also for some terrestrial "open-sky" for applications such as precision farming, that has widely adopted GPS+EGNOS in some EU regions.

EGNOS also provides verification of the system's integrity, which mainly relates to the provision of timely warnings when the GPS system or its data should not be used for navigation. It also provides a measure of trust that can be placed in the correctness of the information supplied by GPS. Integrity is a feature which meets the demands of safety-critical applications in sectors. They are mainly rail, aviation, and maritime, where lives might be endangered if the position calculated with the signals is incorrect.

EGNOS' infrastructure consists of three geostationary satellites over Europe and a network of ground stations. Since EGNOS is based on GPS, the receivers do not require major changes to GPS ones. Today, many GPS receivers available on the market are also EGNOS enabled.

At 23:04 on 22 of March 2014, the giant rocket Ariane 5 lifted off from the European Space Port of Kourou, sending to space it payload of satellites, amongst which the ASTRA 5B GEO-2 of carrying the EGNOS payload. This successful launch will ensure the replacement of an aging EGNOS satellite, and so provide augmented navigation services for another 15 years. ASTRA 5B has a launch mass of 5724 kilograms, a wingspan of 40m once its solar arrays are deployed in orbit, and a spacecraft power of 13kW at the end of its 15-year design lifetime. EGNOS is made up of transponders on board three geostationary satellites (Artemis, Inmarsat 3F2, Inmarsat 4F2), and an interconnected ground network of forty positioning stations and four control centres which cover most of the territory of the EU offering three high-performance navigation and positioning services.

EGNOS is owned by the European Commission and was launched in 2009 to be part of the Galileo global satellite navigation system. The European Space Agency designed EGNOS under a delegation agreement with the Commission. As from January 1st, 2014, EGNOS is operated by the European GNSS Agency (GSA) based in Prague.

Here is a high-level description of the EGNOS system (Fig. 35.7):

## 35.2.2 GNSS Services

GPS provides two types of services: a standard positioning service (SPS) and a precise positioning service (PPS). Authorized access to the PPS is restricted to the United States Armed Forces (USAF), federal agencies, and selected allied armed forces and governments. The SPS is available to all users worldwide on a continuous basis and without any direct user charge. The specific capabilities provided by the GPS open service are totally public. They are published in the GPS Standard Positioning Service Performance Standards (www.gps.gov/technical/ps/2008-SPS-performance-standard.pdf).

Likewise GPS, most space-based PNT systems will provide two types of services: an open service (OS) and an authorized service (AS). The UN ICG (see Sect. 1.1) has proposed the following definitions for those services:

- **Authorized Service**: service specifically designed to meet the needs of authorized users in support of governmental functions (e.g., PPS for military GPS and PRS – Public Regulated Service – for Galileo authorized users by the governments)
- **Open Service**: service (using one or more signals) provided to users free of direct user charges

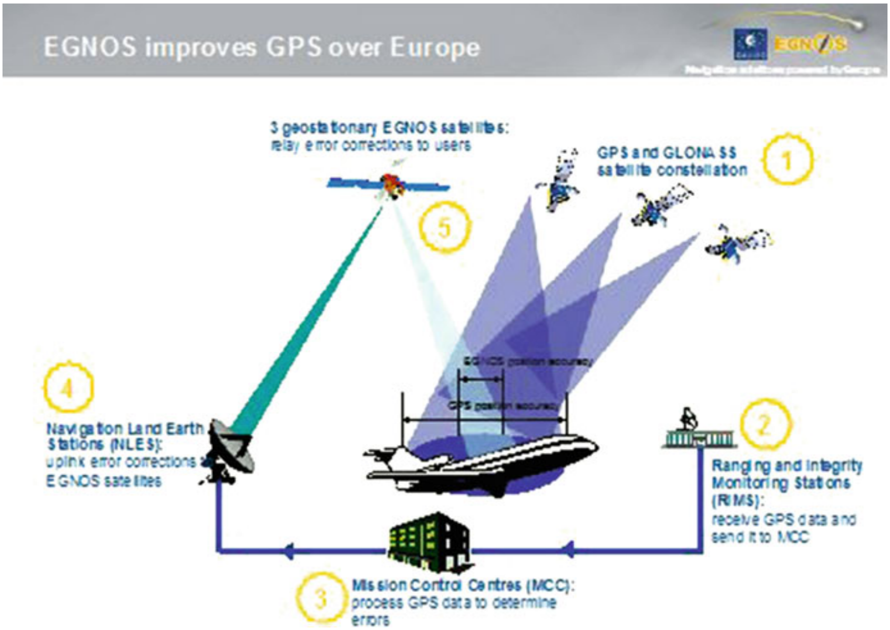

Fig. 35.7 High-level description of EGNOS infrastructure

In addition to these two services, other types of GNSS services exist such as the future Galileo commercial service. It will provide added-value data to users who accept to pay for it. It provides in particular the capability of authentication of the signal, which could be of great interest for legal applications, to be able to give a proof of a position or a time. This functionality exists also for the PRS but is limited to authorized users.

### 35.2.3 Concept of GNSS Interoperability

The UN ICG defines GNSS interoperability as the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system. In practical terms, it means that:

- Interoperability allows navigation with signals from different systems with minimal additional receiver cost or complexity.
- Multiple constellations broadcasting interoperable open signals will result in improved observed geometry, increasing end-user accuracy everywhere and improving service availability in environments where satellite visibility is often obscured such as forests, urban canyons.
- Geodetic reference frames realization and system time steerage standards should adhere to existing international standards to the maximum extent practical.

For a GNSS user its device will be able to process several GNSS constellations, not only GPS. These combined receivers will allow improved performance as compared to current GPS-only receivers.

The US-EU Agreement on GPS-Galileo Cooperation signed in 2004 laid down the principles for the cooperation activities between the USA and the European Union in the field of satellite navigation. In particular, this cooperation has led to the development of an interoperable and compatible signal design for the GPS and Galileo systems called the MBOC (Multiplexed Binary Offset Carrier) signal. The potential use of this signal by several GNSS is discussed between system providers bilaterally and multilaterally within the UN ICG.

A joint EU/US report (EU-US Cooperation on Satellite Navigation, Working Group C), also derived from the US-EU 2004 agreement, has demonstrated the benefits of GNSS interoperability by showing the advantages of combining future GPS and Galileo open services. The report demonstrates and quantifies the improvements that can be expected when using GPS and Galileo open services in combination under different environmental conditions. Particularly, in partially obscured environments, where buildings, trees, or terrain block portions of the sky, the combined use of GPS and Galileo often allows a position fix that would have been impossible otherwise with only one system. Furthermore the benefit of having two constellations of 30 satellites each, so 60 satellites, with secured access is widely recognized by the authorized users to be of a significant operational benefit.

### 35.2.4 Vulnerabilities of GNSS Services

Because of the increasing reliance of our societies to GNSS, a lot of studies (Volpe National Transportation Systems Center 2011) has been done to assess the possible failure modes and vulnerabilities of these types of systems and the potential mitigation techniques.

The vulnerabilities of GNSS can broadly be classified into four different categories:

1. System vulnerabilities (including signals and receivers)
2. Propagation vulnerabilities (atmospheric and multipath)
3. Accidental interference
4. Deliberate interference

A reduced satellites visibility can a bad geometry that could prevent the availability of a position fix. Moreover GNSS receivers can incorrectly process valid signals and can give incorrect results.

In addition, GNSS signals are very weak in power: typically less than 50 W transmitted from a distance of 23,000 km. When received at the surface of the earth, the signal power may be as low as $10^{-16}$ W, with a spectrum spread out effectively below the noise floor of the receivers. Accidental or deliberate interference with this signal can easily defeat the signal recovery or overload the receiver circuitry.

Furthermore, signals are vulnerable to disruptions in the atmospheric medium they pass through, and receivers can also unintentionally lock onto reflections of the signals, known as multipath, giving unexpectedly large errors. They are in particular also vulnerable to solar eruption and can be disrupted during this phenomenon.

These causes can have quite different effects on users, such as partial or complete loss of the positioning and timing service, poorer accuracy, very large jumps in position, velocity or time, and “hazardously misleading information” (HMI) that is to say, believable data that is dangerously wrong in safety-critical applications like civil aviation. The aforementioned SBAS systems (EGNOS, WAAS) are able to detect HMIs related to the GNSS and the ionospheric propagation. But other threats such as interference or local reflections may remain undetected.

### 35.2.5 Deliberate Threats to GNSS Services

Apart from the system-related vulnerabilities (over which the system providers have control), propagation channel errors (which are due to natural effects that can be modeled to some degree but that are by nature difficult to avoid) and accidental interference (which are difficult to anticipate), there are three distinct forms of deliberate man-made interference with GNSS signals: jamming, spoofing, and meaconing. These threats are increasingly worrying the GNSS stakeholders, because they could have safety and security consequences.

Jamming is the most likely threat that can impact the widespread use of the GPS. Jamming devices are radio frequency transmitters that intentionally block, jam, or interfere with GNSS receivers. Criminals who want to prevent GNSS tracking can produce jamming. They may be car thieves or road toll evaders, for example. In most countries, it is illegal to use GNSS jammers. It is the case in Europe and in the USA. However, in recent years, the number of websites offering “cell jammers” or similar devices designed to block communications and create a “quiet zone” in vehicles, schools, theaters, restaurants, and other places has increased substantially. The US FCC (Fedecal Communication) Enforcement Bureau has issued 20 enforcement actions against online retailers in 12 states for illegally marketing more than 200 uniquely described models of cell phone jammers, GPS jammers, Wi-Fi jammers, and similar signal jamming devices (http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-310226A1.pdf).

Meaconing (delaying and rebroadcasting of GNSS signals) and spoofing (transmission of a false GNSS signal) are more sophisticated and complex types of deliberate interference and therefore are for the time being less common. However, while a spoofer was a very bulky and expensive device some years ago, nowadays, spoofers can be portable and fit into a small box (http://www.insidegnss.com/node/2978). While jamming intends only to disrupt GNSS service, meaconing and spoofing try to maintain GNSS service but with a false computed position. The consequences of spoofing can be illustrated by the widespread use of unmanned vehicles guided by GPS, as is the case for UAVs (Unmanned Aerial Vehicles), as shown by an example recently carried out by the US Department of

**Fig. 35.8** Typical commercial jammers available on the market

Homeland Security (DHS) (http://homeland.house.gov/sites/homeland.house.gov/files/Testimony-Humphreys.pdf).

The crudest form of jammer simply transmits a noise signal across one or more of the GNSS frequencies, to raise the noise level or overload the receiver circuitry and cause loss of lock. Circuits and assembly instructions for GPS jammers are widely available on the internet, and commercial jammers can be bought for less than 20 euros. Commercial jammers are sophisticated and cheap: some are designed to fit into a pocket, some into car lighter sockets; most jammers are designed to block GPS, GLONASS, and Galileo. Powerful jammers are also commercially available, up to at least 100 W transmitted power.

Here are some examples of GNSS jammers that are sold on internet (Fig. 35.8):

Some more sophisticated can be used in defense, in a concept known as NAVWAR (Navigation Warfare). The jammer or the spoofer can be used by military forces in certain areas of conflict, for example, in order to deny GNSS services to non-allies. In this case, only authorized users (allies) are allowed to have access to GNSS services, giving them operational superiority on the field.

To overcome the above-described potential risks of interference, there are several countermeasures at different stages of the receiver, some of which are mentioned here:

- Noise jamming can be overcome to some degree by controlled reception pattern antennas (CRPAs) and noise filtering in well-designed receivers.
- The use of two antennas can overcome the threat of spoofing by comparing the differential measurements obtained.

- The front-end part of the receiver can incorporate jamming and spoofing detection. For example, an indicator called jamming-to-noise ratio (J/N) is available in some receivers.
- Inertial measurement units (IMU) can be hybridized with GNSS receivers. Inertial sensors (i.e., accelerometers, gyroscopes, and gyrometers) are not impacted by external radiofrequency emissions and are therefore able to provide a valid position even in the presence of jamming and spoofing, at least for a certain amount of time. This is probably the most robust countermeasure against the previous listed threats. When the GNSS receiver is jammed, the IMU "takes the lead" to deliver a position or a velocity to maintain its continuity.

## 35.3 GNSS Applications Relevant for Security and Defense

Space has a strong strategic value. It allows countries to gain independence, scientific and technological prestige, and the capacity to act as a global actor. In fact, the development of space technologies has been often linked to a vision of worldwide strategic posture. That was the case, starting from the 1950s, in the USA, Russia, and France, where launchers and space assets were historically conceived as key elements of nuclear dissuasion. But even if nuclear dissuasion is put aside, space is synonymous of a whole chain of strategic technologies and activities. These range from launching to the establishment of satellite telecommunications, from observations, meteorology and navigation. Space assets appear as a strategic set of infrastructures, meaning that they cannot be backed up by other types of ground networks and that their disruption would be critical to the whole society. Space assets should therefore be considered as "critical infrastructures," as their disruption would endanger both civilian and defense activities.

Space applications and technologies are best suited for dealing with an increasingly expanding concept of security. If, on the one hand, traditional customers are military users, on the other hand, a wider security and civilian community can benefit from space services which have been developed. This is particularly true for GNSS.

### 35.3.1 Space-Based PNT for Defense

GPS is the cornerstone of the US Defense of Department's (DoD) positioning, navigation, and timing services, and is integrated into nearly every aspect of the nation's military operations. GPS signals are used to ensure the accuracy of precision-guided munitions, guide troop movements, synchronize communications networks, enable battle-space situational awareness, and conduct search and rescue missions.

For instance, the Defense Advanced GPS Receiver (DAGR) is a handheld GPS receiver used by the US DoD and select foreign military services. It is a military-grade, dual-frequency receiver, and has the security hardware necessary

**Fig. 35.9** Defense Advanced GPS Receiver (DAGR)

to decode the encrypted P(Y)-code GPS signal. It is manufactured by Rockwell Collins and is produced since March 2004. Officials from the Space and Missile Systems Center's Global Positioning Systems Wing announced by the end of 2010 that Rockwell Collins planned to deliver the 400,000th DAGR (Fig. 35.9).

Today, the US GPS is used into many European armed and security forces equipments, especially armament systems, aircrafts, and vehicles. The development of Galileo PRS avoid enable European Defence users to rely on a second independent capability providing services of higher quality, reliability, continuity, and integrity. The Chinese, Russian, and Indian users of their respective systems' authorized services may also benefit from improved performance. Such authorized services will allow for better performance in the conduct of operations. The combined use of authorized services from different systems could also bring performance improvements even if such combination can only result from specific security agreements, unlike the combination of open services.

The Galileo PRS is relevant for national security for EU Members States, both for civil and military users, thanks to the civil nature of Galileo. The PRS could be used for the European Union Common Security & Defence Policy operations and for highly secured operations (Defense, Police, Customs, etc.). The Galileo Search and Rescue service (EU's contribution to the MEO COSPAS-SARSAT; http://cospas-sarsat.org/) also could be relevant for specific search and rescue operations.

Moreover, because accurate intelligence is critical to a mission's success, another important type of military applications using GNSS position and timing data is precise, secure, and portable military-grade geotagging (Geo Tactical Solutions, Inc.) of pictures. This functionality comes in support of geospatial photo/video capture, mapping, analysis, and reporting for military command and control. It includes a SAASM (Selective Availability Anti-spoofing Module (SAASM))

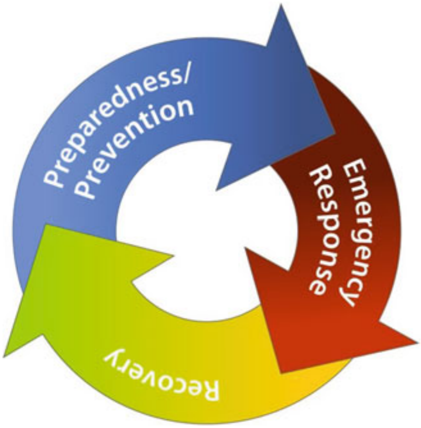

**Fig. 35.10** Disaster management cycle

compatibility which is dedicated to military users. It also integrated with an electronic compass, and supports GIS[3] integration.

### 35.3.2 Space-Based PNT for Civil Security Applications (Non-defense)

A critical component of any successful rescue operation is the knowledge of position accurate. Knowing the precise location of landmarks, streets, buildings, emergency service resources, and disaster relief sites reduces reaction time and saves lives in case of disaster, or other type of crisis situation. This information is critical to disaster relief teams and public safety personnel. GNSS data can contribute in every phase of the disaster management cycle (see the picture below) which is typically composed of three phases: (1) preparedness/prevention, (2) emergency response, and (3) recovery (Fig. 35.10).

For the preparedness/prevention phase, GNSS can support risk assessment tasks by allowing the precise monitoring of ground profiles (e.g., for landslides and earthquakes), sea level (e.g., for tsunamis), and infrastructure (e.g., for nuclear plant, bridges). GNSS could also support the broadcast of Early Warning Alert Message via their satellites downlinks in order to inform people to take particular measures in case a crisis/disaster is approaching. During the emergency response phase, GNSS can be useful for assessing the damage (e.g., support to the delivery of reference damage maps with geospatial information). It can also support the efficient management of rescue teams in the field (e.g., increase safety of the rescuers, coordination and logistic support to the operations, aid to aircraft/car

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[3] Geographic Information System.

navigation in difficult environment). Indeed GNSS data allows the real-time monitoring and tracking of teams and material, thus participating in the improvement of the situational awareness. As for the post-disaster/recovery phase, GNSS data can be used to support the restoration of the infrastructure, thanks to more efficient management of reconstruction crews and materials on the ground. Moreover, the analysis of GNSS data gathered before and during the disaster can be used to better model the causes of a disaster and better predict their future occurrence. Note that the combined use of GNSS with data from aerial- and/or space-based Earth observation systems, such as the European system corpernicus allows improved performance during disaster management operations.

For these types of applications, the open services provided by the existing GNSS are of great interest. The GPS has served for years now as a facilitating technology for public non-defense authorities as police or emergency bodies in addressing these needs. For instance, it has played a vital role in relief efforts for global disasters such as the tsunami that struck in the Indian Ocean region in 2004, Hurricanes Katrina and Rita that wreaked havoc in the Gulf of Mexico in 2005, the Pakistan-India earthquake in 2005 and the Haitain earth quake in 2012. Search and rescue teams regularly use GNSS, geographic information system (GIS), and remote sensing technology to create maps of the disaster areas for rescue and aid operations, as well as to assess damage. Another important area of disaster relief is in the management of wildfires. To contain and manage forest fires, aircraft combine GNSS with infrared scanners to identify fire boundaries and “hot spots.” Within minutes, fire maps are transmitted to a portable field computer at the fire-fighters’ camp. Armed with this information, fire-fighters have a greater chance of winning the battle against the blaze. Also, meteorologists responsible for storm tracking and flood prediction rely on GNSS. They can assess water vapor content by analyzing transmissions of GNSS data through the atmosphere.

As we have seen, GNSS data can give managers a quantum leap forward in efficient operation of their emergency response teams. The ability to effectively identify and view the location of police, fire, rescue, and individual vehicles or boats, and how their location relates to an entire network of transportation systems in a geographic area, has resulted in a whole new way of managing civil security. The modernization of GPS and GLONASS, and the development of new GNSS, will further improve the accuracy of satellite navigation data and therefore will facilitate disaster relief and public safety services. In short, GNSS translates to more lives saved and faster recovery for the victims.

Another good example of the use of GNSS for security non-defense applications is the combination of the so-called PMR (Professional Mobile Radio) with a GNSS receiver. PMR devices are typically used by the police for secure communications. Combining PMR with GNSS services provides telecommunications and satellite navigation positioning and timing. So, it is possible to imagine in the future the combination of PMR with secure and robust civil GNSS positioning and timing (e.g., authorized services such as Galileo PRS).

## 35.4 Conclusions

GNSS is starting to change our life as Internet has done. It is already a real fact for the citizen. It is also of paramount importance for security and defense users where accurate and reliable information on position, velocity, and timing is as crucial as secured telecommunication exchange.

The revolution is however still in front of us. In 2020, about 100 satellites will be in orbit around the Earth. They will give the users, civil as well as the ones dealing with security and defense, a large potential of new applications inducing societal and economic impacts.

In the field of security and defense, the operational advantage of using encrypted GNSS for authorized users, in particular in times of crisis, when open signals are jammed or spoofed, is huge. This is why, only authorized users will be able to use Galileo PRS worldwide, even when other signals will be disrupted. It is already the case for US military and its allies using GPS PPS worldwide. This confers a significant operational capability to the only few nations having such systems.

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# Eavesdropping

# 36

Pat Norris

## Contents

**Abstract**
The rationale for intercepting radio signals to and from satellites and of using satellites to monitor terrestrial radio signals is described in this chapter. A distinction is made between voice, data, and radar information and between military and civilian information. Issues of privacy are briefly discussed. Major breaches in the security of these systems during the Cold War are outlined to illustrate some of their weaknesses and the consequences of security failures.

## 36.1 Introduction

In this chapter the potential for radio signals to be intercepted by satellites and for radio signals to and from satellites themselves to be monitored is described (Norris 2010). The general name for this activity is signals intelligence (SIGINT),

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and it is broken down into two broad (and not always completely distinct) categories:

- Communications intelligence (COMINT): the interception of voice communications.
- Electronic intelligence (ELINT): the interception of other radio signals such as those of radars and navigation facilities and communications between machines.

The remainder of the chapter is broken into sections addressing the following topics in order:

- Voice communications
- Data communications
- Radars
- Monitoring of ocean vessels
- Research
- Invasion of privacy
- Security breaches in the Cold War

## 36.2 Eavesdropping Voice Communications

Military and security services in many countries seek information by intercepting conversations made via radio links. The conversations of interest include those between:

- Military units of another country engaged in military actions
- Military facilities such as missile launch sites and their headquarters (HQ)
- Known criminals and terrorists in their own country and/or abroad
- Unknown parties who are discussing relevant topics such as terrorism or major crimes

Satellites are involved in these intercepts in two different ways. The first technique is to eavesdrop from the ground on conversations that are routed through commercial satellites. In the 1970s, a large proportion of international telephone calls went via satellite, and this eavesdropping was therefore very fruitful. By the 1980s, however, most international telephone traffic had switched to undersea cables. This change from satellites to cable was not an attempt to avoid the eavesdroppers but was simply due to economics. Certain types of conversation still go by satellite, for example, where one of the parties is on a ship or an airplane, and eavesdropping of these calls is still viable.

Conversations via military satellites can also be intercepted but will usually be encrypted. Eavesdropping then requires the listening agency to know how to decrypt the signals.

The eavesdropping agency sets up a suitable radio receiver near enough to that of the phone company to be able to listen in to the radio signals up to and down from the satellite. For the agency performing the intercept, one attractive feature of intercepting conversations that go via satellite is that there is no physical contact and thus no way for the people talking to know that they are being intercepted.

The second general way to eavesdrop from space is to have special satellites that listen to ground-based radio communications. Commercial communications between microwave towers that proliferated during the 1960s and 1970s were one target. The eavesdropping satellites would pick up what is called "microwave spillage" – the signals transmitted between the microwave towers but in fact available for anyone with a well-placed antenna to receive.

In the 1980s and then more rapidly in the 1990s, long-distance communications grew rapidly as email, Internet, and other digital communications caught on. Instead of building more microwave towers, phone companies found it made economic sense to install fiber optic cables between the main cities, so the eavesdropping satellites found they had less and less to listen to.

The switch from analogue to digital signals gradually occurred also during this period. Digital signals can be processed in a computer, for example, to encrypt them. Eavesdropping agencies in western countries regulated the industry and made it illegal for the telephone or Internet companies to use the most sophisticated encryption techniques. The level of encryption that was permitted can be "cracked" by the agencies, although the agencies claim that it is costly to do so, requiring super-fast (i.e., expensive) computers. In recent years, stories in the technical press have suggested that there may be fast and cheap methods to read the encrypted messages, and if academic mathematicians are finding that out now, perhaps the eavesdropping agencies knew it all along.

In the late 1990s the explosion in the use of cell phones meant that more and more conversations were once again being sent by radio. There are approaching six billion cell phones in use around the world and the number keeps growing. All of the chatter, text messages, email, downlinks, etc. from the handsets go by radio to the relay masts that have sprung up by the million across the globe. The US and perhaps Russian satellites are in principle able to listen in to the billions of conversations and messages coming from or going to cell phones, but the scale of doing so is daunting because of the huge numbers of phones in use. The conversations are carried on digital signals and thus are encrypted. Before the eavesdroppers can decide if a conversation is worth listening to, they have to decrypt it. To avoid having to decrypt every one of the billions of conversations every day, the agencies try to narrow down the deluge of calls to those they reckon are worth devoting time and effort to. The number of the caller and the number of the receiver are not encrypted, so one tactic is for an eavesdropper to wait until a telephone number of interest is involved in a call before bothering to decrypt. Another tactic might be to focus on calls from or to a particular area.

Communications between military units and facilities are carried on special radio frequencies different from those used by the general public. One type of information that a listener can obtain using multiple receivers is the location of any radio transmission in the relevant frequency band – this tells him that some military activity is underway at that location. Many military forces use a technique called "spread spectrum" to eliminate this danger. The transmission is made undetectable by spreading it across the radio spectrum so that it is extremely weak at any given frequency. You have to know the algorithm used to spread the signal in order to detect it – and needless to say the military authorities keep that information to themselves. Another technique is to change the radio frequency from time to time – called “frequency hopping” – which makes it difficult for the eavesdropper to intercept the whole conversation. The sequence of frequencies used in the hopping exercise is known to the people holding the conversation but of course is a closely guarded secret.

Radio systems with the spread spectrum or frequency hopping features are expensive and sophisticated, so even the most advanced countries may use “ordinary” radio signals some of the time. One example was during the North Atlantic Treaty Organization (NATO) intervention in the Balkans in the 1990s. The NATO forces did not have enough of the latest military radio sets to give to all of their troops, so many of the troops started using their cell phones over the public networks available in the region. The military agencies that NATO was fighting had access to those public networks and could gain information of military significance from this unauthorized use of cell phones by the NATO troops. There are reports that the use of smartphones and 3G phones by NATO troops in Afghanistan in the 2010s is causing similar problems – the troops are reacting to the lack of smartphone features on the standard military handsets.

Several examples of the use of intercepted conversations by anti-terrorist agencies have been reported. In November 2002, the US National Security Agency (NSA) detected a phone call coming from a phone number on its watch list. The person of interest was Qaed Salim Sinan al-Harethi considered to be the al-Qaeda operative who planned the attack on the *USS Cole* in a Yemeni harbor in 2000 that killed 17 US sailors. It is likely that the call was made using an Inmarsat satellite phone, and NSA was probably picking up all Inmarsat signals in the region at a suitably located ground facility. The Global Positioning System (GPS) chip in Al-Harethi’s phone enabled the NSA operators to determine exactly where the phone was. The Central Intelligence Agency (CIA) operation in nearby Djibouti was alerted, and they deployed a Predator unmanned aircraft to the area intending to fire its Hellfire missile at al-Harethi. CIA standing orders require that before taking action that leads to fatalities, the voice of the target person must be recognized by at least two agents. The analyst had been listening to al-Harethi on tape for several years and could tell that he was not the speaker on the phone. Then the speaker engaged in a conversation with someone else in his vehicle – apparently asking directions from a man in the rear seat. The analyst recognized the second person as al-Harethi and this was confirmed by one of his colleagues listening to a playback of the short conversation between driver and passenger. Having had the identification confirmed, the analyst sent the radio signal that directed the Predator to fire its missile which destroyed the car and all of its occupants.

This was the first, but by no means the last, such CIA killing.

The United States is not alone in targeting enemies by listening to their satellite phone calls. Russia killed Chechen rebel leader Dzhokhar Dudayev in 1996 by using such a call to pinpoint his position.

## 36.3 Eavesdropping Data Communications

Information of interest to eavesdroppers may well be in the form of data rather than speech. In fact, voice and data are increasingly mixed together making the distinction largely academic. Telephony via the Internet is one form of this mixing (Skype is the most popular version of this) – Voice over Internet Protocol (VoIP) to give it its technical name. Lost within the flood of data flowing through the Internet, VoIP phone calls are hard to spot. The Internet breaks up the data into "packets" and sends them to their destination via any of thousands of switches. A packet for a phone call is indistinguishable from an email packet or a YouTube packet. Worst of all, some packets in a conversation might go via one switch, other packets via other switches – they get put back together again only when they reach the recipient of the call. Sir David Pepper, who was Director of Britain's eavesdropping agency, General Communications Headquarters (GCHQ), from 2003 to 2008, described the move to VoIP as "his biggest problem. It is a complete revolution; the biggest change in telecoms technology since the invention of the telephone."

At the start of the space age and before the digital age got underway, data of interest to eavesdroppers was usually military or diplomatic. For example, the United States and its allies monitored radio transmissions between Soviet missile test flights and the Soviet ground operators initially from stations in friendly countries that bordered the Soviet Union such as Turkey and Iran and on ships and islands in the Pacific Ocean where many of the long-range missile tests ended. As the space age progressed, ELINT satellites became a part of this listening network.

As explained by British intelligence expert Chapman Pincher "the signals emanate from devices fitted to various points on the missiles to inform engineers on the ground about velocity, altitude, aerodynamic details and engine performance, which they must know to improve range and accuracy" (Pincher 1984). Such telemetry data (as it is called) also measures temperatures, electrical currents, fuel usage, and the on/off status of each piece of equipment. The telemetry data is particularly valuable if a missile fails in some way, since otherwise the engineers will be left guessing as to the cause of the failure. The data is just like the information in an aircraft black box, a crucial source of information for air crash investigators after an aircraft accident. The challenge for the eavesdropper is to figure out what the telemetry data means. The US intelligence historian Jeffrey T. Richelson likens it to trying to understand the switches and dials on a car dashboard if all words and numbers have been deleted from them. By a process of informed guesswork, you would gradually work out which data refers to speed and what the units are, which to engine status, and so on. Satellites ensured that telemetry data from missile tests right across the Soviet Union and the Pacific Ocean could be intercepted (Richelson 2002).

On their side, the Soviets/Russians could collect this kind of information using ships, since the US long-distance missile tests head out over the ocean – and are announced in advance to warn civilian shipping. Hence, the Soviets never built satellites dedicated to this task.

The ability to monitor each other's missile telemetry data was so important that it became enshrined in the Strategic Arms Limitation Treaties (SALT) that brought Cold War nuclear escalation to an end. Article XV of SALT-II (1979) states that "neither Party shall engage in deliberate denial of telemetric information, such as through the use of telemetry encryption, whenever such denial impedes verification of compliance with the provisions of the Treaty." By monitoring the other side's missile tests, each Cold War superpower could check if the other was infringing the agreements on development of new missiles or enhancements of old ones.

Today we live in the digital age where data is a primary means of communication in military, commercial, and personal life. Intercepted emails are frequently a source of news headlines, illustrating how much of modern life is communicated in that way. Text messages and online purchases or money transfers also generate data that can be intercepted. The everyday business of any organization is likely to involve the movement of data – here are just a few examples to illustrate how pervasive data is in every form of modern life:

- Buy a lottery ticket – the transaction is transmitted to lottery HQ.
- Take cash from a cashpoint or use a credit card – your bank is notified to debit your account.
- Visit the doctor or a hospital – your details are updated on a medical computer system.
- Drive through a toll booth – your license plate is photographed and computer processed.
- Buy or sell shares – transactions are notified to brokers, banks, etc. in the form of data.

More generally, computers interact with each other around the world by exchanging data, all of which is a target for the intercept communities. They may wish to corrupt or modify the data or just monitor it. Cyber warfare is the term seen more and more frequently to describe the efforts of organizations around the world to intercept and disrupt the data in computer and communication systems.

The above remarks about data pervasiveness are just as applicable to the military as to civilians. The objective of ELINT satellites may be to monitor data communications of a military adversary or of a terrorist/criminal group or of a government or commercial organization. The levels of encryption and other security measures to be overcome will vary depending on the sophistication and wealth of the target, but the principles are similar to them all. For the United States and Russia (and increasingly China), ELINT satellites are just one of the tools used in this task.

For the military, a new form of data intercept that is increasingly important involves remotely controlled aircraft or Unmanned Air Systems (UAS) as the drones are called. The United States and its allies have deployed several thousand UASs in Iraq and Afghanistan. Some of these are launched by throwing them in the air like a model airplane then transmit images back to the ground within the line of sight, i.e., from a few km away at most. At the other extreme, UASs, the size of a small airliner, stay over the battlefield for up to 48 h at a time controlled remotely from the other side of the world. Imagery is sent back from such UASs via satellite to the control center where trained pilots and image analysts "fly" the UAS – instructing it to change course or swivel its camera or, in some instances, fire a missile.

Intercepting the imagery and command links of these UASs is a high priority for the other side. Given that the imagery travels by radio link over satellites back to the United States, you would expect the channels to be heavily encrypted. But the Wall Street Journal reported in 2009 that Iraqi militants had been intercepting unencrypted imagery from the US UASs. The paper quoted Lt. Gen. David Deptula, who oversees the US Air Force's unmanned aviation program, as saying "Those kinds of things are subject to listening and exploitation," he said, adding the military was trying to solve the problems by better encrypting the drones' feeds. If irregular forces in central Asia can intercept this data, it is likely that Russian and Chinese ELINT systems can too.

## 36.4 Eavesdropping Radars

The first satellite launched with the intention of observing the earth was an ELINT satellite – the tiny GRAB satellite launched by the United States in 1960 (see Fig. 36.1). GRAB provided hitherto inaccessible information about radar systems deep inside the Soviet Union, and it worked by receiving radio signals across a very wide range of frequencies and relaying them to a station on the ground. The satellite didn't process the signals in any way, just acted like a mirror in taking radio signals that it heard at its 1,000 km altitude and beaming them downwards to a friendly station. By having a suitably located station on the ground, signals from deep inside the Soviet Union could be monitored. GRAB helped analysts identify and analyze two Soviet radar systems, one associated with antiaircraft missiles and the other with missile early warning. The advantage of knowing the characteristics of an adversary's radar is not only that in future you know what it is when you detect it, but you can design electronic countermeasures to jam it or confuse it.

The success of GRAB encouraged the United States to use satellites extensively to analyze its adversaries' radars and other military signals. The tiny GRAB evolved into massive satellites, many of them in geostationary orbit, 36,000 km above the Earth, which is so distant from the Earth that the satellites require giant antennas to pick up the signals from far below.

Like the United States, the initial Soviet eavesdropping activities were to probe electromagnetic emissions from defense systems such as radars and to listen in on communications between military forces. The Soviets, and the Russians today, use satellites in orbits at about 1,000 km altitude, thus avoiding the need for the giant antennas that the US geostationary ELINT satellites require.

The head of the Ukrainian factory that manufactured the Soviet first generation Tselina satellites described the two main objectives of monitoring the radars of the United States and its allies as first "finding out their capabilities in a combat situation and obtaining data to take [spoofing or blocking] countermeasures" and secondly "to detect signs of changes in the activities and battle preparedness of foreign armed forces." The data collected by the current Tselina-2 series is sent

Credit: National Security Agency

**Fig. 36.1** The world's first ELINT surveillance satellite: the US GRAB

back to Earth via the Geizer data relay satellite which gets information to intelligence analysts much more rapidly than was the case with the previous generation's tape recorder whose contents were radioed to Earth once or twice a day.

Although China has none of the giant eavesdropping satellites in geostationary orbit that the United States deploys, it has used low orbiting satellites, many in the small satellite category (<½ ton), to monitor radar and data traffic in the East Asia region.

## 36.5 Eavesdropping to Monitor Ocean Vessels

Detecting radio signals from ships at sea is a specific category of SIGINT satellites.

Out in the ocean far from the radio-rich environment on land, ships are in principle easy to spot – they will be the only source of radio signals for miles around. Ships transmit radio signals to communicate with each other and with their base. Their radars also transmit very strong radio signals (radar is an acronym loosely derived from "radio detection and ranging") and then detect the much weaker echoes as the radio signals bounce off objects such as other ships, airplanes, missiles, or objects on shore. The beauty of this situation is that even if you can't decipher the radio signals you know a ship is there.

The American Navy had dominated the world's oceans since World War II, while the Soviet Union was largely surrounded by land and frozen water, and thus naval power was never a high priority for them. Rather than try to match the United States at sea, the Soviets focused on anti-ship missiles in order to keep the US fleets at bay. They were carried by a mix of submarines, destroyers, and patrol boats and would fire them at an enemy over the horizon and out of range of the Soviet ship's own radars. As part of this policy, the Soviets somehow needed to be able to locate the US ships. Initially this was performed using radar-carrying aircraft, but these were limited in their range and at risk of being shot down.

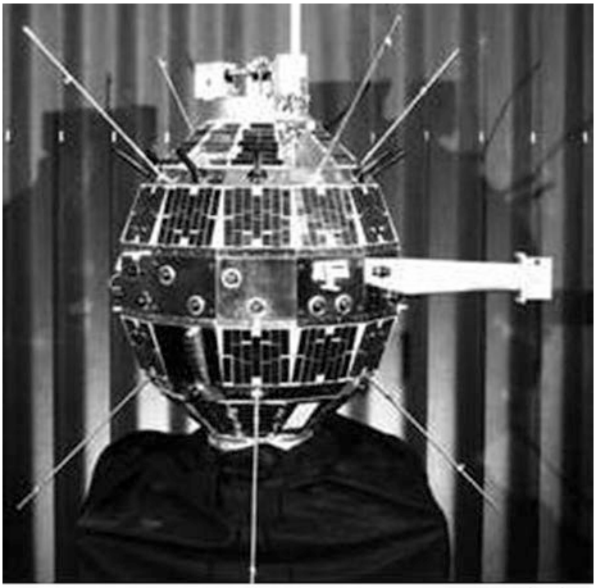

**Fig. 36.2** POPPY: the first in what became the NOSS series of US maritime ELINT satellites

Credit: NRO/NRL/NSA

As the space age gathered pace in the 1960s, the Soviets were quick to create a series of satellites to monitor the US naval movements. Starting in 1967 they launched satellites that carried radars to detect the US ships even when their radios and radars were switched off.

The United States too quickly grasped the potential of this scheme (see Fig. 36.2). Both countries have continued to place in orbit groups of 2, 3, or 4 satellites so that they can triangulate the signals from a ship using the different time and direction of the ship's radio signals as seen by each satellite in the group. In addition to detecting ships and working out their exact location by triangulation, these satellites allow the ships' radar signals and radio communications to be collected for later analysis.

The US authorities have compiled a database of ship movements based on data from a variety of sources including ELINT satellite information plus data from Navy and Coast Guard air and sea surveillance. Civilian as well as military ships are monitored reflecting the threat from terrorists and the United States' interest in the navies of countries such as China and Iran.

If the enemy ships are careful and observe radio and radar silence when the ELINT satellites pass overhead, it would be useful if the satellite had a radar of its own that could detect the ships below. A series of Soviet/Russian ELINT satellites have carried radars onboard for that purpose; one of the Soviet satellites crashed in Northern Canada in 1978 dispersing the radioactive material used to generate the satellite's electricity across the region – the Soviets had to pay Canada several million dollars for the cleanup, but this didn't stop them using the same radioactive technology on later satellites. There are occasional press and web reports that US satellites carry radars too. Other reports say that the US satellites can detect the faint radio emissions from a ship's engines and the magnetic effects of a ship's hull.

In the case of China, the importance of monitoring America's Pacific fleets and other regional navies is not hard to understand. Besides the long-standing military flash point of Taiwan, there are regions in the South China Sea where valuable oil and mineral resources are at stake and where ownership is disputed by countries in the region such as the Philippines or Vietnam.

Like the United States and Russia, China has a number of dual-use oceanographic satellites mainly dedicated to monitoring ocean conditions using radar altimeters and scatterometers to measure wave heights, winds, ocean currents, etc. and multispectral infrared sensors to monitor plankton blooms and other phenomena loosely described as "ocean color." Better knowledge of the oceans is important to commercial shipping, fishing, and undersea drilling, and it is also important for a navy, for example, to optimize the deployment of its submarine fleet and to more reliably detect the presence of the submarine fleets of other countries.

All of these ocean monitoring satellites are in orbits below 2,000 km altitude – the Russian radar variety sometimes fly as low as 250 km. The military versions are often identifiable by virtue of their dual or triple vehicle configuration.

## 36.6 Research

The technical challenges of identifying and capturing specific communications from space are daunting. The wide range of radio frequencies and the billions of transmitters filling the radio waves make finding communications of interest extremely difficult. As a consequence, many spacefaring countries are undertaking research into what can and can't be picked up by SIGINT satellites.

As an example, since 1995 France has been placing experimental ELINT payloads and satellites in orbit. The objective is to eventually have satellites that allow France to figure out the location of and, where possible, identify individual transmitters and radars. This information would help French forces avoid detection in any military conflict but initially the objective has been to understand how much information can be obtained in order to justify the funding of a future operational system. They have all been placed into orbits that are about 700 km high – thus not requiring the gigantic receiver dishes of the American eavesdropping satellites that hover 36,000 km above the Earth. It is not clear if the eventual goal is also to intercept individual communications or if it is limited to identifying and characterizing the different types of transmitters. Because of the high cost of the satellites, France is seeking partners in the venture from among other European Union countries, but so far with limited success.

## 36.7 Invasion of Privacy

The US NSA and its counterpart agencies in its English-speaking close allies, the UK, Canada, Australia, and New Zealand, have collaborated in intercepting and analyzing communications traffic around the world. Ground stations located in

Credit: National Security Agency

**Fig. 36.3** Headquarters of the National Security Agency 20 miles NE of Washington DC

those countries pick up communications from dozens of satellites and channel them to the headquarters of the NSA in Maryland, USA (see Fig. 36.3). This eavesdropping became public under the name ECHELON, although in fact ECHELON is only the name of a software program that sorts the information and was heavily criticized by the European Parliament in 2001 not only because of the invasion of privacy involved but also because of suspicion that the information was used to help American business. The European Parliament's criticism was tempered by the fact that "only a very small proportion of communications are transmitted by satellite." The Parliament noted that "the majority of communications [can] be intercepted only by tapping cables and intercepting radio signals." The continued extension of undersea cables means that fewer and fewer countries rely on satellites for international communications. The countries that lack a cable connection and therefore need satellites are mostly African or isolated small islands, for example, in the Pacific Ocean.

A subtle but apparently persistent problem is that NSA is forbidden from listening to US citizens without prior authorization. The problem is that to tell if one of the speakers is American, you have to listen to the conversation – James Bamford has described how this Catch-22 tied NSA in knots for several years, as they veered between intercepting almost nothing (thus being legally watertight) to intercepting nearly everything in the post 9/11 environment (arguably illegal) (Bamford 2008). According to documents released by whistle-blower/traitor Edward J Snowden in 2013, the Prism (US) and Tempora (UK) programs apparently circumvent this Catch-22 by having the UK perform the intercepts.

## 36.8 Security Breaches During the Cold War

Since the end of the Cold War in 1989, much has been made public about the Soviet successes in penetrating US eavesdropping activities. These stories provide some idea of the objectives of the participants and of the weaknesses of the systems involved and therefore offer lessons for today.

In 1948 the Soviet Union changed all its cryptographic equipment and codes, making it impossible for the United States to decipher them. The Soviets had placed spies inside at least one of the US intelligence agencies and had discovered the vulnerability of their communications. The spy or spies in question were never caught. An example of how this loss of access to Soviet communications left the United States in the dark came before long when North Korea invaded its southern neighbor in 1950. The invasion came as a surprise to the US intelligence community, which presumably would not have been the case if the United States had been reading Soviet diplomatic and military communications during the preceding year given that North Korea was strongly assisted by the Soviet Union.

Another Soviet breach of US security came when two NSA employees, William Martin and Vernon Mitchell, defected to the Soviet Union in 1960, strengthening the Soviet ability to confound US eavesdropping. The United States' inability to read Soviet ciphers continued for 30 years until 1979. During that period, America's most costly regional conflict, the Vietnam War, had been fought and lost without the ability to intercept many Soviet communications.

The situation was actually worse than this. The Soviets were relatively secure from US intercepts at least of their most important traffic. But in the other direction, the Soviets knew a lot about how the US systems worked. For 17 years from 1967 to 1984, a US Navy communications officer, John Walker, was feeding the Soviets detailed cryptographic code information. A few months after Walker began, America's Pueblo spy ship was captured largely intact by the North Koreans, allowing the cipher machines it contained to fall into Soviet hands – the crew had failed to destroy them before being captured. All crypto keys were changed throughout the US Navy once they knew that the Pueblo had been captured. But the Navy didn't realize that one of the people receiving the changed lists was John Walker. So for the next 17 years the Soviets had the three types of cipher machine aboard the Pueblo plus regular updates of the codes and cryptographic keys in use.

Walker's KGB case officer Oleg Kalugin said that the twin Soviet intelligence coups (the Pueblo and Walker) enabled the Soviets to keep track of US nuclear submarines and naval ships. He described it as "the greatest achievement of Soviet intelligence [during] the Cold War."

The United States and its allies suffered further embarrassments. Spies such as Geoffrey Prime in Britain and Christopher Boyce in California (the latter popularized in Robert Lindsey's 1979 bestseller *The Falcon and the Snowman* and the 1985 film of the same name) provided the Soviets with details of the US eavesdropping satellites. It seems likely that the Soviets then took measures to ensure that the information collected by those satellites was compromised. This could include transmitting deliberately false information to mislead the US listeners, as well as the simpler action of changing procedures and equipment to prevent the interception of signals and communications.

The United States eventually broke the Soviet codes in 1979. The breakthrough is said to have come as a result of small, steady, and persistent advances in understanding how the Soviet encryption machines worked. Once the full breakthrough was achieved, NSA was able to "hear secure encrypted voice communications better than they were hearing each other."

## 36.9 Conclusions

With the proliferation of computers and the use of the Internet, more and more information is communicated between people and machines. Furthermore, the explosion in the use of cell phones, tablets, and other mobile devices means that more and more communications are carried by radio signal – the term "wireless" has come back into use to describe this technology. We are familiar with this phenomenon in the civilian world, but it applies equally to the military community. One of the consequences of the use of wireless is that the communications can potentially be intercepted by unauthorized listeners – and the United States, Russia, and probably China have satellites to assist in that task. The Cold War demonstrated that one of the weakest links in a country's attempt to maintain security is their own nationals – the Soviet Union was able to penetrate US encryption and prevent the US reading Soviet communications in part thanks to information supplied by traitorous US and British officials. The recent activities of Bradley Manning (Wikileaks) and Edward J Snowden demonstrate that this weak link is still a threat to the security of communications.

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# Integrated Space Related Applications for Security and Defense

# 37

Alessandra Fiumara

## Contents

## Abstract

This chapter makes an overview of space integrated applications for security and defense. In the context of ever-increasing globalization, security and defense issues become inextricably linked. Global threats come up. The conceptual meaning of risk has changed from a physical enemy to be fought with weapons to an insecurity permanent feeling impacting the daily life of citizens. The scenario is characterized by new challenges: a boost in the number of crisis, their diversified nature (technological accidents, natural disasters, complex man-made crisis), their unpredictability, and their locations all over the world. Moreover, new domains such as energy, transportation, and mobility are concerned by security issues.

This evolution entails an integrated approach involving different actors from military and civilian contexts. Integration and interoperability are also considered for the development of adequate capabilities. Space systems have always been playing an essential role in the security and defense domain, at

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strategic, tactical, and operational level. When different technologies are integrated, a wider spectrum of applications can be generated and space technologies provide services otherwise unobtainable, such as the generation of added value for reliable information, the provision of autonomous surveillance of remote areas, the creation of cost-effective innovative solutions for new users, and the increase of crisis response efficiency. Thanks to their intrinsic capabilities to provide services across borders and nations, satellites are a good ground to experiment and push forwards concepts such as interoperability, sharing, and dual use.

Far from being exhaustive, the chapter gives an overview of the different applications domains and the current developments and trends. To deliver concrete examples, emphasis is paid to European context, projects, and programs.

## 37.1 Introduction

The flows of trade and investment, the development of technology, and the spread of democracy have brought prosperity and freedom to many people, while others have perceived globalization as a cause of frustration and injustice. In much of the developing world, poverty and diseases rise up to security concerns, and in many cases, economic failure is linked to political problems and violent conflict.

If on one hand the geographical European area is more stable than in the 1990s, security threats raise from instable neighbors, from transnational phenomena, and from sectors with new aspects of security such as energy, cyberspace, water, piracy, and natural disasters. Less conventional threats can arise from afar and can affect security at home. These dangers include attacks, terrorist strikes, drug trafficking, cyber assaults, or the unlawful disruption of critical supply lines. The exploitation of the environment, of its natural resources, and of the renewable energies also appears as new vulnerabilities both at single state and at worldwide level. Moreover, the number of civil crisis (environmental natural disasters, technological accidents, and complex man-made emergencies) is increasing.

The European and “Occidental” security actors have today important challenges: the contribution to the international stability, including the management of its brutal degradation, the management of crisis occurring far from home, and the protection of the citizens and critical infrastructures.

These challenges imply the involvement of a high diversity of actors. The situations are no more military “sensu stricto”; they are multidimensional, more complex, unpredictable, and with interlinked threats. Very often, crisis occur in fragile States, and Occidental countries intervene within a multinational framework that involves military and civil actors, international organizations, nongovernmental organizations (NGO), and private companies. The relationships between these actors are not yet organized or formalized but a coherent and comprehensive approach has to be sought to integrate diplomacy, commercial, development, and humanitarian actions together with police, justice, and defense. At national level, governments are redefining their national and international security strategies and crisis and security units are created at interministerial level.

The international implications of the phenomena go far beyond national borders; therefore, bilateral, multilateral, and regional patterns of cooperation have also been developed. This also occurs at European level. With the endorsement by the European Council in December 2003 of the European Security Strategy (ESS), European Union (EU) Member States committed to give the European Union the tools to contribute to its security and stability. The European Council, its General Secretariat, and the European Defence Agency all play a significant role in the delivery of Europe's security policy, and the European Commission plays an equally important role through its various policies. EU processes have been rationalized to take into account the commonalities between civil and military capabilities and operations, reflecting the political will for a more integrated approach and for an increase of the European crisis response.

## 37.2 Space Capacities Responding to the New Threats

The different elements that characterise the context lead to new operational requirements that have to be fulfilled by adequate capabilities.

- The unpredictability of crises leads to: the need to give priority to permanent surveillance, prevention, and anticipation
- The need for increasing responsiveness the localisation anywhere in the world leads to:
  - the need for remote wide areas mapping and operational support far from home
- The increasing integration of actors and the national budget constraints lead to:
  - The need of interoperability
  - The need of sharing information among partners
- Emerging risks lead to:
  - The need for cost-effective innovative solutions applied to new domains, such as energy and transportation, and generally to the security for the life and health of citizens and to critical infrastructures

In all these areas, space assets play a major role. Space applications and technologies are best suited for dealing with an increasing expanding concept of security and for providing smart solutions for the above defies. Faced to these issues, emerging countries start equipping themselves with space capacities for security and defense.

Traditional customers are military users and still remain for those applications related to the strict defense domain, such as the early warning satellites for missiles detection and tracking. But a wider security and civilian community starts benefiting from space services. Satellites do not perform tasks which cannot be performed otherwise. However, they can achieve similar goals with different characteristics and by providing some unique benefits, as illustrated in ▶ Chaps. 30, "Space Applications and Supporting Services for Security and Defense: An Introduction," ▶ 31, "Earth Observation for Defense," ▶ 32, "Earth Observation for Security and Dual Use," ▶ 33, "Telecommunications for Defense," and ▶ 34, "Telecommunications for Security and Dual Use" of Sect. 3 of the present handbook, respectively, for the Earth

Observation, Tele- communications, Positioning, Navigation, and Timing applications. They are resilient to natural disasters and to classical threats, they allow a quick reestablishment of the utilities, and they are nonintrusive. Space is a privileged place for acquisition and transfer of information. It allows autonomous and continuously updated evaluation of sensitive situations.

When different technologies and techniques are integrated, higher performances in products and services are obtained. The last decade has seen the development of increasingly diverse satellite applications, driven by evermore sophisticated user needs and by strong technological innovation across satellite, ground segments, and terminals. The growth of these "integrated applications" is favored by several factors. A combination of multiple different space assets and a combination of space and non-space assets offer:

- Value-added information for the reliable information in the surveillance and preparedness phases
- A nonintrusive capability to acquire and update information on a global scale, in all weather conditions, night and day, from a stable and secure environment, providing the capability to permanently monitor and control wide remote or dangerous areas (sensitive theaters, strategic infrastructures, fleets, and persons)
- Dual use capacity and intrinsic technical characteristics to provide services and a consequent borderless, ideal to experiment interoperability concepts
- Global coverage increased service responsiveness obtained by reducing the time the information is made available to people on the theater or decision makers

Integration can be performed at different level, and a consequent but today, the effort is still put "at a posteriori," on the ground segment, since each mission is conceived individually. The complexity of the nowadays crisis however calls for an increasing integration of the actors. Their operations could benefit in terms of efficiency from a more integrated approach occurring at an earliest stage of the definition of the systems, taking into account the operational requirements of a wide variety of users, including interoperability between different space and non-space systems. The integration is moving at an earlier phase of the value chain, from post processing at ground level of data deriving from different sources to conceptual integrated design of system of systems. Integration stimulates strong technological innovation across satellite, ground segments, and terminals but also implies issues to be deeply considered such as data policies, financial aspects, and governance.

### 37.2.1 Value-Added Information for Surveillance and Preparedness

The integration of space-based systems and Earth-based instrumentation can provide geo information added value products to support prevention and intervention. In this context, information coming from different sources are complemented and integrated in terms of space sampling, time interpolation, and thematic contents. Historical data, ground sensor data, and space observation data acquired at different frequencies (visible, infrared, microwave), measuring different contents, are used to evaluate sensitive situations.

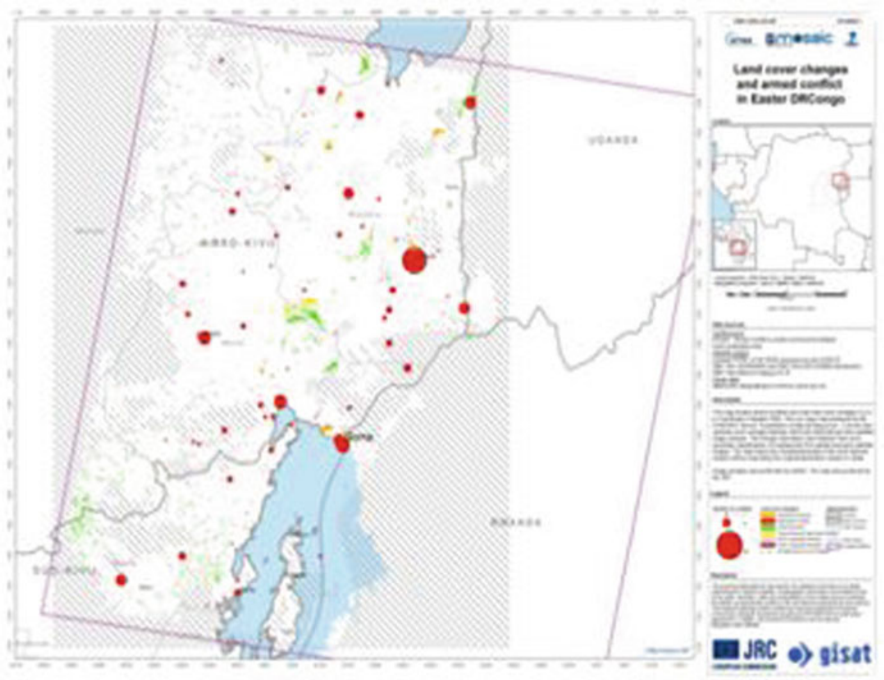

**Fig. 37.1** Land use change 2003–2008 and occurrence of conflicts in Eastern Congo (Raleigh et al. 2010)

The very first level of *integration of space and non-space* data is performed for the calibration and the validation of the processing algorithms used for the satellite data product generation (calibration and validation campaigns).

The GMES service element contains many examples of added value product as elements of the security services. The Natural Resources and Conflict Service provide an evaluation of crisis indicators aimed at improving current alert systems. These indicators specifically address the relations between security issues and possible conflict factors in regional crisis. The core product provides conflict-related geo-spatial information for countries at risk of armed conflict or with ongoing conflicts. It looks into the interlinkages between land degradation and land use changes. Land use or land cover changes are derived *from multitemporal analysis of Earth Observation data*. The information is then combined with other non-satellite data to analyze potential spatial relationships. Integration is also used for the generation of a multitemporal coherence map by Synthetic Aperture Radar acquisitions at different dates (see Fig. 37.1).

Each Earth observation mission is characterized by different parameters such as different frequency channels, different ground resolution, and orbit period, thus providing different and complementary source of information. The revisiting cycle characteristic offers the possibility to generate coherence maps. A significant example is the integration of *different satellite data* (radar and optical data) for

**Table 37.1** SIGRIS products

| Risk management phase | SIGRIS products |
|---|---|
| Knowledge and prevention (seismic hazard assessment) | Maps of the inter-seismic deformation at the fault scale |
| | Maps of the geodetic deformation at the regional scale |
| | Models of faults showing strain accumulation |
| | Maps of the Central Mediterranean geodynamics |
| | Ground velocity profiles across seismic zones |
| Crisis management | Maps of the coseismic ground displacement |
| | Models of the seismic source |
| | Maps of the earthquake surface effects |
| | Models of post-seismic relaxation |
| | Maps of strong earthquake damage |

thematic mapping. It is well known as classification of Synthetic Aperture Radar (SAR) images is a difficult task because of the poor radiometric resolution due to the presence of the speckle noise in the image. Nevertheless, microwave data brings complementary pieces of information, for instance, being sensitive to vegetation geometric properties, as opposed to optical data (visible and near infrared) whose primary information concerns the photosynthetic activity. Taking advantage from the good radiometric resolution of optical data through suitable segmentation algorithms, it becomes possible to incorporate the valuable information brought by radar into the vegetation classification task. As an example, it is worth recalling the main goal of SIGRIS, a project funded by the Italian Space Agency, aimed at developing a sophisticated disaster model, forecasting and early warning system to be used by the Italian Civil Protection Department in support of seismic risk management. Table 37.1 shows the products generated by the integration of the following *different Earth Observation satellite and non-space data:*

- High-resolution (<1 m) optical imagery from commercial satellites (EROS-B, QuickBird, GeoEye, WorldView), also as stereoscopic acquisitions
- Synthetic Aperture Radar (SAR) image data from the ERS, ENVISAT, ALOS, and COSMO-SkyMed satellites
- Continuous GPS data from many different sources

### 37.2.2 Remote and Dangerous Areas Surveillance

Space capabilities are unavoidable when risks and interventions occur in remote, wide, or dangerous areas. Out-of-area operations have produced new paradigms of action for the EU civilian and military forces: extended duration; widened tasks; multiple, geographically spread, and remote areas of intervention; and diversification of the type of operations. Because space sensors are nonintrusive and offer global surface coverage, they are unsurpassed in their ability to support

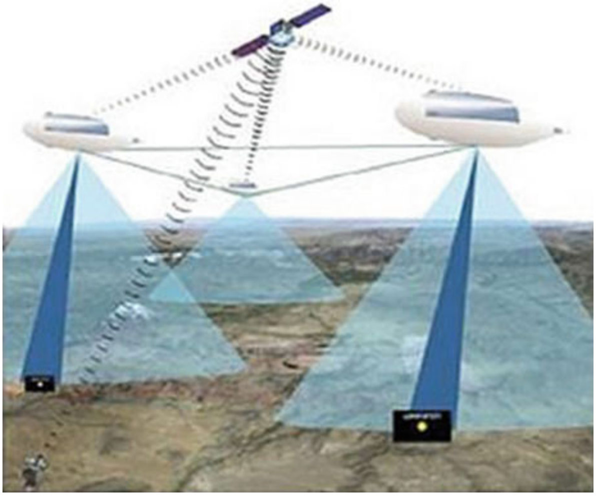

**Fig. 37.2** UAVs networking and collaborating with satellite while providing video surveillance services

strategic operational planning. They offer an entirely legal means of locating and identifying potential strike targets over a very wide area and they generate the technical data needed for operation to be carried out. Earth observation satellites are used since they provide permanent, autonomous, all weather, night and day data acquired in stable conditions, but an increasing role of Unmanned Aerial Vehicles is observed. They are increasingly used for civil applications although their largest use lies within military applications. The remote piloting of Unmanned Airborne Vehicles (UAV) and the use of onboard sensors and/or weapons make SATCOM vital for the command and control of these unmanned aircraft operations and to allow data transmission. They are used when manned missions are considered too dangerous (see Fig. 37.2).

Surveillance of dangerous but also wide and remote areas such as deep sea can benefit from the use of integrated space technologies. The Automatic Identification System (AIS) is a short-range coastal tracking system currently used on ships. It was developed to provide identification and position information to vessel and shore stations. Outside the range of 40 nautical miles from the coast, the currently deployed terrestrial AIS network benefits from space-based AIS which by integration can track the complete maritime journey of a ship. Satellite AIS may also be used for backup purposes. Although no full operational space-based AIS is in place at the moment, a number of satellites equipped with AIS receivers can provide data. A European-based SAT-AIS is an initiative in partnership with the European Maritime Safety Agency (EMSA) and ESA. The ESA program defines the design/investigation of a sustainable space-based system that will provide AIS data. Currently, the SafeSeaNet operated by European Maritime Safety Agency ensures the effective tracking of vessels and hazardous cargoes based on the data received by coastal stations. From the coastal stations, the AIS messages are transferred via national stations to three regional AIS servers that provide the data to the EMSA SafeSeaNet server. This SAT-AIS initiative shall add another server to this system that will deliver AIS data received via satellite to the SafeSeaNet server.

The MARitime Security Service (MARISS) is a GMES Service Element initiative that integrates near real-time satellite Earth Observation (EO) data with conventional vessel tracking data to deliver an understanding of the maritime situation to coast guards, navies, and border police forces in Europe. It is based on the *integration of multiple space systems (SATCOM, SatNav, and EO), terrestrial assets (radar), and AIS* for the provision of services in the domain of maritime security. Authorities are able to differentiate between vessels more easily and therefore obtain much improved maritime domain awareness and control. Thanks to the existence of COSMO-SkyMed constellation (with currently four fully operational satellites), it is possible to observe the same area more times per day and to cover the entire Mediterranean every 8 days.

### 37.2.3 Sharing and Interoperability

Sea is also an environment where most of all integrated and shared surveillance is possible and has benefits for the actors involved. Sea is a "no right" environment; the sovereignty gives room to cooperation more easily than in other contexts. Space capabilities, for their intrinsic technical characteristics (providing services overarching country borders), are best suited to be exploited by the various authorities, both within and across nations.

Sea is also an area where major synergies can be achieved through the military and civilian authorities exchanging information. The importance of integrating maritime surveillance for more efficient operations and reducing operating costs leads to different initiatives at EU level. An example is the BlueMassMed (BBM) pilot project, launched in December 2008. The BMM pilot project focuses on the Mediterranean and its Atlantic approach. An equivalent project is MARSUNO for Northern Sea. BMM is going to provide substantial input to the process leading toward the establishment of the Common Information Sharing Environment. It triggers the cooperation between 37 authorities out of six nations, removing legal barriers for cross sectorial and cross border data exchange. Optical and radar Earth observation satellite data are used as well as coastal radar and AIS. The common picture creates a "shared situational awareness" among all the nodes of the system. Satellite imagery is used in the wide area rapid mapping service as well as in the vessel tracking service. The deployment of telecommunication systems allows sharing the picture among 100 of interconnected nodes in an efficient, secure, rapid, and comprehensive way (Fig. 37.3).

In the same line is the concept of "Network-Enabled Capabilities." In this respect, SATCOM constitute the necessary communications' infrastructure for NEC capabilities at strategic level and also play an important role at tactical level. The basic idea is to exploit the potential of information technology to upgrade the current and future military equipment in order to improve the "shared situational awareness" at all levels, from the infantry unit to the headquarter. This will in turn

**Fig. 37.3** Demo phase at the BlueMassMed final conference, June 2012: "Sharing Mediterranean Sea picture among partners"

speed up the military decision making process and make the armed forces more efficient and effective in performing the whole spectrum of military operations, unaffected by distances, frontiers, or mediums.

Another example is the MUltinational Space-based Imaging System (MUSIS) which should replace the existing national Earth observation systems in a common framework. The joint intergovernmental effort for cooperation of France, Italy, Belgium, Germany, Greece, and Spain, recently joined by Sweden and Poland, envisages the interoperability of all ground segments of the space missions involved for a straightforward mutual access to the assets, while the partners continue to develop their own space components on national basis (defense and dual use assets).

The examples above demonstrate the will to increase cooperation among actors. Cooperation may be operational or technical, involving exchange of data or capabilities or involving developments and systems sharing. Over the past decade, European defense budgets have been declining steadily. The current financial crisis is exacerbating the situation and resulting in further deep cuts. In this current economic crisis, no nation can afford to procure all space-based facilities needed to meet all its requirements. Maintaining capabilities or acquiring new ones is of course the prime objective, but care must be taken through the cooperation process to take due account of issues relating to sovereignty, national security, data protection, and the rules governing the safeguarding of classified information. This occurs between countries, between different authorities of a same country, and even between each structure of a same authority (such as the large number of structures of the National Civil Protection). The starting point for an increased cooperation is, inter alia, the identification of common operational requirements, areas, and modalities with potential substantial improvement. Concepts such as "pooling and sharing" or "dual use" are currently promoted. The pooling and sharing approach goes through the acceptance of the need to share via incremental trust-building process among partners. Sharing information and intelligence multinationality is a sensitive matter (albeit often resolved quickly on operations), but the technical issues allowing sharing, such as standardized image formats, network architectures, storage capacity, analysis capacity, and coherence, can be addressed independently. While pooling is a question of technical interoperability, technology, and money, sharing is a matter of trust and political determination. It is an ongoing process, both within nations than across different nations, which aims at pushing the "need-to-know" concept toward the "responsibility-to-share" approach.

### 37.2.4 Innovative Solutions for Emergent Risks

New threats may affect the life of citizens and of critical assets. Critical assets comprise a wide variety of elements, either man-made structures (e.g., energy pipelines, industrial sites) or natural assets (e.g., freshwater points), whose disruption, destruction, or alteration may impact the security of the states and citizens. Security of citizens and of assets can profit from integration of space and non space assets. New services can be developed, addressing a new and wider category of users and customers. Until recently, many users communities were not addressed at all. The involvement of the final user and the service provider is a key element. Obstacles to the diffusion of space integrated commercial solutions still remain the lack of  solid crisness cases, the resistance to change, the lack of briefing and persuasion of the final user.

A two-step approach is generally adopted in these new domains involving new users and customers. A feasibility phase is followed by the demonstration of the full operational capacity. Studies and demo phases are supported by cost-benefit analysis which defines the economic impact of the envisaged solutions. At the Ministerial Conference in Den Haag in November 2008, ESA launched a new program called the objective of which is "the development of operational services for a wide range of users through the combination of different systems." The concept which undergoes the program is the utilization of at least two existing and different space services (such as satellite Communications, Earth Observation, satellite Navigation, human spaceflight technologies), this leading to a cross-fertilization across disciplines, to the development of a consistent integrated approach to applications initiatives, and to maximization of their efficient and cost-effective implementation. Several thematic areas have been identified, the overarching categories being safety, health, development, energy, and transport. Security is an issue coping with each of them.

**Fig. 37.4** Wind-energy developer Renewable Energy Systems Americas has signed an agreement to use Globalstar satellite modems to transmit data from remote wind-energy monitoring stations assessing potential sites

### 37.2.4.1 Some Examples

In the field of *transport security*, space-based solutions may increasingly help meeting mobility challenges such as management of ship or lorry fleet, road and rail traffic monitoring, the mobilization of emergency services, or the tracking of dangerous goods. Whereas space assets are already introduced in single services, their integration becomes essential when the safety critical services need to be continuously available, e.g., GNSS/satellite navigation for outdoor location services in combination with indoor technologies to expand the location services into tunnels and to provide continuity and availability of positioning; satellite communications used in combination with terrestrial networks and gap filler technologies to provide narrowband communication links with the transports while high data rate links (terrestrial and SATCOM) are established between a central information and management center and the local control centers of the rescue services/authorities; and Earth observation data used to provide general weather information and infrastructure status for risk and impact reduction.

*Energy security* is critical for the growth and prosperity of European economies. Space services already play an important part in the commercial sectors of the energy industry, but there is a significant potential for increase (see Fig. 37.4). An interesting and high-potential near-term application is the potential contribution of space assets to the management of future, complex *energy grids* with large components of renewable energy plants. The current trend to increase the share of renewable energy sources (solar, wind, etc.) means that the power output will become less centrally controllable and will increasingly depend on accurate forecasts of natural resources for production and of electrical load, decentralized control, synchronization (for reliability and stability of the grid), and rapid information and data exchange. A first application is to improve the effectiveness of pylon stability monitoring via satellite radars. The second is to support the integration of telecommunication network through integration of satellite services for backup and fast deployment of new nodes. Thirdly, it feeds satellite meteorological data into an enhanced wind forecast algorithm, thereby facilitating coordination of electricity supply and demand.

*Critical infrastructures* handling essential goods, such as water, food, confidential information, financial transactions, or resilience services, represent key enablers in a large variety of economic sectors. Infrastructures are particularly exposed to hazards when physically spread out, e.g., linear infrastructures such as pipelines.

Oil and gas pipelines count as critical infrastructural assets for which incidents may have major consequences in terms of economics, safety, and political order. In this respect, inspections are essential to guarantee the pipeline's integrity. Safe and effective operation of pipelines needs to be guaranteed at all time as a safety-related event can have major consequences in terms of economics, safety, and even political order. It is of great importance to perform inspections so that the integrity of the pipeline is guaranteed. As of today, pipeline operators inspect their infrastructure mostly manually, using vehicles and helicopters. Due to limited budgets, the inspection frequency is not optimal (once every 2 weeks to once every 5 years depending on the type of inspections). Current inspections can be improved and optimized by exploiting the added value of multiple space assets (Earth observation, satellite communication, and satellite navigation). Third party interferences such as excavation activities can be detected through change detection techniques over Sat EO SAR data. Erosion and landslide effect on elevation changes can be monitored through SAR Permanent Scatterer Interferometry. Data from in situ sensors installed along the pipeline infrastructure can be collected by a real-time transmission to a processing center using a mobile satellite communication link. Field operators can identify the exact location of threats using GNSS signals.

*Health*. People's mobility has significantly increased during the last decades. In case of medical incident occurring during the travels of citizens, the provision of an adequate and professional health-care support is not always immediately available and straightforward. Despite the constant increase of the number of telemedicine assistance services nowadays, the level of service provided on board transportation means (airplanes, ships, cars, etc.) for telemedicine purposes is still largely limited to the use of telephone as a communication tool between patient and physician. The integration of positioning and telecommunication space systems can bring added value by ensuring a real-time and face-to-face communication as well as transmission of physiological data.

Other integrated applications refer to prove the viability and sustainability of an integrated set of services supporting *land mines* activities. The services are based on the integration of Earth observation data, GNSS navigation, and SATCOM technologies with existing mine action tools and methodologies, databases, and procedures. Earth observation data, satellite communication, and satellite navigation are considered of assistance to produce socioeconomic impact maps, for decision makers to set mine action priorities; to identify low-risk areas that could be released without performing the costly and risky step of clearance, by combination of indicators of mine/ERW presence and indicators of mine absence; to characterize the environmental setting of a hazardous area (humidity, slope, surface roughness); to support the geo-referencing of data and the navigation needs for nontechnical surveys, standoff detection, demarcation of hazardous zones, close-in detection, and clearance; and to provide global communication capabilities to securely transfer collected data into, e.g., IMSMA (Information Management System for Mine Action), for easier access to updated consolidated information and improved traceability and quality management of mine action.

### 37.2.5 Increasing Responsiveness

Satellite telecommunications are vital, particularly for operations and major emergencies which consistently expose a shortfall in the availability of telecommunications capacity in their aftermath (e.g., the Katrina hurricane, the Haiti earthquake, and the Pakistan floods). This is especially important for first rescuers during the first hours and days after the disaster, which are the most critical for saving lives.

Satellite communications are widely recognized by civil protection agencies as providing a resilient, complementary solution that can increase their effectiveness not only for command and control but also for delivering information derived from Geographical Information Systems (GIS) and asset tracking systems, which are in turn dependent upon the use of satellite Earth observation and navigation services. Civil security and defense actors have expressed in various fora, such as can be found in Conclusions of the “Space and Security” Workshop, jointly co-organized by EC, EDA, and ESA on 16/09/09 in Brussels, the need for operational and sustainable space-based services that would be more responsive, integrated, and under control. The leading requirement is to have the right information, such as layers of information on transportation networks, logistics facilities (e.g., hospitals), critical assets and infrastructure (e.g., airports/airfields), helicopter landing areas, and population gathering areas, at the right moment in time, at the right place (see Fig. 37.5).

Despite a wide range of present telecommunication capabilities, there are still a number of limitations that delay the delivery of time-critical data to users. To reduce time delays, relay satellites are placed in geostationary orbit to relay information to and from non-geostationary satellites, spacecraft, other vehicles, and fixed Earth stations, which otherwise are not able to be in touch permanently with each other. For example, to increase the European present telecom infrastructure in terms of final quality of the service, the European Space Agency is developing the European Data Relay System (EDRS). With *this system of systems*, data will be transmitted from low Earth orbit satellites or UAVs to an EDRS payload and relayed to the ground, from where they will be made available to the user.

In the telecommunication domain, *space assets are integrated with the ground network* for many applications. For instance, rescue operations require the rapid deployment of networks to ensure data and voice communication between rescue

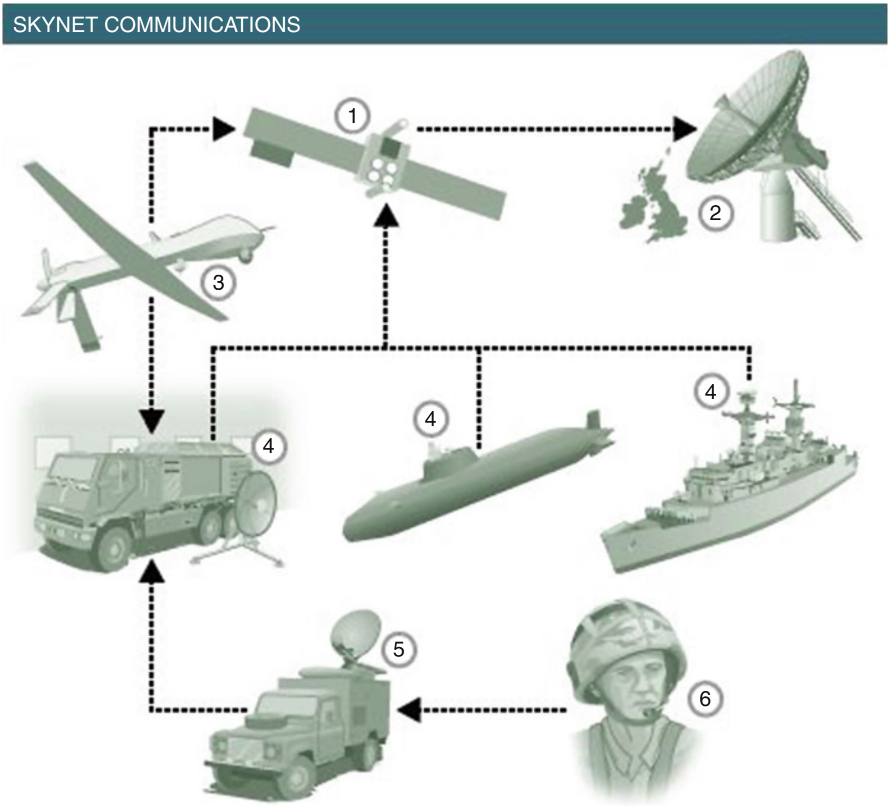

**Fig. 37.5** Skynet Communications: an example of SATCOM for military operations. *1*. Skynet 5 overhauls satellite communications for UK forces. *2*. The largely autonomous satellites talk to two UK ground stations. *3*. Skynet 5 supports high-bandwidth applications, such as UAV video. *4*. Antennas and terminals are upgraded to make best use of Skynet. *5*. New battlefield networks, such as Cormorant, feed into the system. *6*. System gives commander's access to more information faster

teams, generally belonging to different organizations, and the operational headquarters. Deployment of heavy communication infrastructure in such cases may result extremely time-consuming and does not guarantee interoperability between teams using different technologies and devices. Integrated services are used to establish radio coverage zones in areas that would otherwise have none and to achieve interoperability with other radio and telephone networks.

For example, ESA has investigated the possibility of an integrated infrastructure (system of systems) for crisis management, based on a holistic and user-driven approach, built upon existing and planned national and international programs (pursuant to the subsidiarity principle) and taking into account relevant non-space assets (ESA presentation at EDA Annual Conference 9/2/2010). The study analyzed an architecture designed to satisfy the needs of the civil security community, taking into account possible synergies and commonalities with defense-related requirements.

## 37.3 Conclusions and Future Trends

Space assets can play a fundamental role in security and defense applications. Although individual space applications (Earth observation, satellite navigation, and satellite telecommunications) alone can play a major role, it is the combination of different space and non-space technologies that brings unique benefits in terms of information content, surveillance autonomy, crisis responsiveness, information sharing, and cost-effective innovative solutions.

Integrated products and applications require so far a huge effort on the ground segment. The creation of the capacity for receiving imagery data in different formats provided by different satellite and fusing it into one usable and workable intelligence product include the development of new technologies for the data processing chain, the archiving facilities, information mining, and crowd sourcing. A consistent effort is necessary at a posteriori since space missions design and their implementation still follow national priorities in terms of requirements, time frame, and funding. The growing political maturity of the concepts exposed in this chapter is not yet reflected in the operational national plans for capacity developments.

For the production of integrated services, the connection with the final user is a fundamental link of the value chain of space. A consolidation of the user's requirements from the very beginning is also necessary for the translation of user needs into system and space component requirements, including integration of several space and non-space elements. This leads to a better understanding of how space systems and services should evolve to meet user requirements and also to the identification of new needs. A main issue is represented by the constant innovation being made in each of the different satellite systems and in the terrestrial arena. As a result, educating user communities about the capability of new solutions is an ongoing process. Not only education but also a revision of the current systems adopted by the users in order to introduce space in their current operations is a compulsory step toward the diffusion of space integrated solutions.

Since the growing complexity of the crisis situations, the challenge in the future is the optimization of the sharing of the space-generated products among the various users. The interoperability of the different technology systems used by the different institutions must be a strategic objective so that equipment does not place a barrier to cooperation between cooperating States for the sharing of information or the carrying out of joint operations.

The infrastructure should be designed to support flexible data sharing, integration, and exploitation by authorities and actors. Indeed, this latter act according to their duties, rights, and competences and the complexity of these functionalities is high due to the wide diversity of user communities, their high number, the related

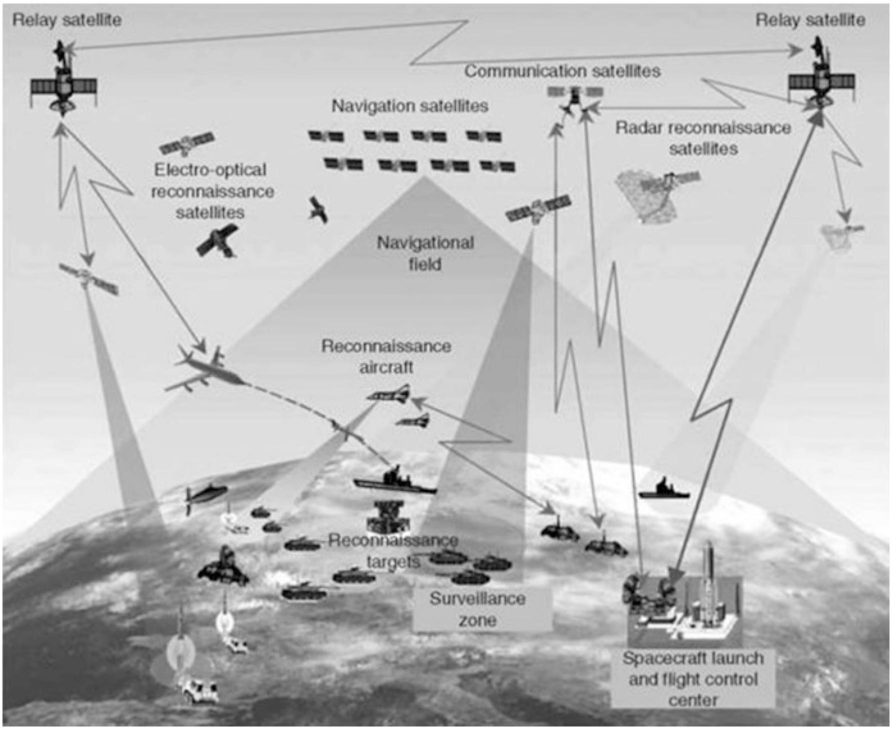

**Fig. 37.6** Integrated space, air, and ground-based reconnaissance and target designation system for military use

rules, and the heterogeneity of the current legal framework. Legal, financial, and governance issues are fundamental to succeed with an integrated approach and they often represent the main obstacle today.

A real integrated approach should result overall into a cost-effective and more efficient development of services and infrastructures (see Fig. 37.6). Although thrusts for cooperation appear among European partners for the definition of infrastructures and services that integrate, at an earlier stage of the definition of the architecture, the interfaces, and interoperability between different space and non-space systems as well as the operational requirements of the wide variety of users, not always the necessary convergence of requirements occurs and timescales sometimes conflict with national interests.

But it is a long ups and downs process which goes step by step and deeply depends on the concrete political will. GMES and Galileo programs are concrete examples of the results obtainable and the difficulties encountered. “If there is the will, there is a way.”

These considerations may be obvious. It is however difficult to foresee the real trends today. The consequences of the economic crisis at European level are also political and they are not clear at all. Will they lead to a more federal EU, meaning that cooperation and integration will be the way forwards, or will there be a tendency to go back to national vision and strategies?

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# Various Threats of Space Systems

# 38

Xavier Pasco

## Contents

**Abstract**

For roughly two decades, orbital systems, beyond their traditional strategic value, have gained a pivotal role in modern conventional security and defense activities. As a consequence, they have been considered as possible new targets in military confrontations, and the recent years have indeed demonstrated a renewed activity in the field of antisatellite researches and tests. This piece attempts to put these efforts in perspective and detail their different forms. It appears that besides the traditional kinetic destruction of satellites, leading to uncontrolled long-lived debris, other threats may have equally destructive consequences with more limited side effects. Directed energy weapons in orbit or even cyber attacks may become weapons of choice in the new space landscape. These likely perspectives must lead the international community to rethink the reality of threats related to space systems.

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## 38.1 Introduction

Space systems have gained an increasing importance in the everyday life of the modern societies: telecommunications by satellite, broadcasting of television programs, observation of the Earth's surface and oceans, observation of the atmosphere for weather forecasts, navigation, and worldwide broadcasting of universal time have so many applications that they contribute intimately to the day-to-day making of our contemporaneous world.

Besides, the needs for the defense of States and for the security and safety of their citizen feed widely on data resulting from the use of observation, electronic intelligence, or early warning satellites. These have contributed in an essential way to producing a strategic piece of information during these last 50 years, helping in the prevention of the bipolar crises. Chastely qualified as "national technical means," observation, electronic intelligence, or early warning satellites became one of the touchstones of the strategic dialogue of the 1970s and 1980s. In this context, keeping space safe and preventing any evolution leading to putting space systems in jeopardy became a key word. In particular, American presidencies of the Cold War had effectively resigned themselves to this established fact. For decades, according to recently published official US documents, it was clearly recognized that any preparation of an antisatellite interception would have been contrary to the spirit if not the letter of the SALT[1] protection of "national technical means" with the risky perspective "to stimulate satellite interception since we are more dependent on intelligence from space sources and would have more to lose."[2] In spite of two Soviet campaigns of antisatellite attempts during the 1970s which led to the US executive authorities to reexamine this position and realize a first antisatellite test in 1985, this particular form of militarization of the space was hardly pushed, the possible earnings remaining considered very thin with regard to the incurred strategic risks. The "stabilizing" function of these national technical means during the Cold War had been already well established and has been well informed since.

Considering this central aspect, the club of the space countries quickly agreed on the interest of keeping space free of weapons, in an explicit way or more implicitly. The text of the main legal body, the "treaty on principles governing the activities of States in the exploration and use of the outer space, including the Moon and the other celestial bodies," came into effect in 1967, has established the idea according to which the exploration and the use of the space are the privilege of the whole humanity. It has dedicated the freedom of research and circulation in space and has clearly indicated that the notion of State sovereignty cannot be extended in outer space or in the celestial bodies.

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[1] Strategic Armements Limitation Talks, treaty signed in 1972 by Richard Nixon and Leonid Brezhnev.

[2] Memorandum from the President's Assistant for National Security Affairs (Scowcroft) to President Ford, Washington, July 24, 1976. For a more complete vision of the position of the US authorities at that time, refer more largely to the archives recently published under the direction of McAllister (2009).

Establishing the founding principle of the "peaceful uses" of outer space, the text does outlaw the deployment of weapons of mass destruction in outer space as well as any military activity on the Moon and on the other celestial bodies.[3]

Nevertheless since approximately two decades, the international debate on the theme of the security of the spatial activities and more exactly on the militarization of the space returned to the front scene by becoming more radical. In the course of the transformations occurred during the 1990s, the initial preventions against a too extensive militarization of the Low Earth Orbit (LEO) have unmistakably weakened. Two main explanations can be called:

- The relative "downgrading" of the nuclear order as an international regulating principle and the consecutive "unbolting" of the debate on an increasing supposed vulnerability of the national spatial means: The United States in particular has mentioned the perception of an increased vulnerability considering the more and more central role played by satellites in the political, military, and economic life of most of the developed countries, with the United States in the first place.
- The emergence of new space actors, who may "threaten" to radically change the way space has been regulated under the auspices of a "club" of a few spacefaring countries, driving precisely these countries to anticipate this situation and bend over the elaboration of new international rules for the use of the space.

## 38.2 Change of Strategic Landscape: A Succession of Disturbing Events

More than in the 50 last years, this decade has known several events that have underlined the fundamental fragility of satellites. A series of destructions in orbit, deliberate or not, put space in full light, worrying the largest part of the diplomatic and military community. It came in a way to punctuate harder and harder debates in Geneva on the prevention of the arms race in space.

1. First of all, the shooting by China of a ballistic missile towards an old weather satellite on January 11, 2007, leading to its destruction and to the generation of a 1,000 long-lived fragments on a very busy orbit, surprised the whole world. This test was the first of its kind since the one undertaken in 1985 by the United States which proceeded to the interception of one of their satellite by using a missile embarked under an F-15 fighter plane.

   At the very moment of the 2007 interception, the Chinese representatives were supporting without reserve the international efforts in the United Nations intended to limit the creation of space debris and opposed against the United States within the conference on disarmament in Geneva on the theme of the militarization of the space with a very proactive posture about prohibiting antisatellite weapons.

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[3] By the end of 2011, 100 countries had already ratified the Treaty, among which any major space nation.

2. Although they denied having had such intentions, the United States did not delay "answering" their Chinese counterparts by proceeding themselves on February 21, 2008, to the destruction of one of their military satellites in perdition. According to the American authorities, the point was to destroy a satellite which reentry was considered dangerous. Nevertheless, the successful attempt demonstrated, at least incidentally, the efficiency of one of the components focusing for the antimissile defense, whereas that it also meant the American intention "to mark" clearly its strategic territory. To complete the "state communication" picture, the American authorities did not miss to let know that this interception occurred at a much lower orbit than the Chinese interception, showing that this had been managed on the side of the United States in a more "appropriate way" by generating very short-term fragments of life.[4]
3. Finally, less than a year later, on February 10, 2009, two satellites, one Russian (Cosmos 2251) and another one registered in the United States (a satellite of the Iridium constellation), collided and destroyed each other, generating some 1,800 fragments on equally very frequented orbits. This collision, the first one in the history of space activity, was going to finish, putting the question of space safety and security in the broad sense as one of the priority themes of the future space cooperation.

Besides these well-known events, other recent disruptions in space have dramatized the space scene further, whether due to presumed cyber attacks (suspected in 1998 in the case of the US-UK-German satellite ROSAT recently reentered in the atmosphere), to laser blinding or tagging (as suspected from Chinese origin towards an US NRO satellite in October 2006), or to interferences, whether purposeful as in the recent case of an Eutelsat satellite jammed from a source in the Middle East or accidental with the so-called zombiesat belonging to Intelsat and uncontrolled between April 2010 and January 2011 while emitting at full power and interfering during this period of time with a number of telecommunication satellites. As it will be explained below, these latest cases must also be considered as potential major sources of disturbances.

## 38.3 Early Armed Threats in Space

For a few years, the news has been dominated by controversies nourished by the supposed plans in a few countries of a possible deployment of weapons in the outer space. Such a subject is not new and has in fact been considered since the launch of the space activities. While no genuine "space arm race" has indeed been triggered during the Cold War, it is useful to remind nascent achievements in the 1960s, mainly carried out by the then USSR.

It must be noted that the "*weaponization*" of space has been considered very early in the history of space bipolar relationships. As early as February 1957,

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[4] Official US information has stated the figure of 175 detected debris (at the difference of 3037 for the Chinese event) with the last one reentered in the atmosphere by the end of October 2009.

eminent US military officers did not hesitate to present space as a new "theater of operations": "*In the long haul, our safety as a nation may depend upon our achieving 'space superiority.' Several decades from now, the important battles may not be sea battles or air battles, but space battles, and we should be spending a certain fraction of our national resources to ensure that we do not lag in obtaining space supremacy*."[5] A few weeks after Sputnik that same year, the Air Force Chief of Staff, General Thomas D. White, reiterated this general assessment, ensuring that "*whoever has the capability to control space will likewise possess the capability to exert control of the surface of earth*."[6]

If many projects aiming at militarizing space *stricto sensu* have emerged in the United States, none of them were given real credits by the successive presidencies in this country. The political authorities were more inclined to capitalize on the nascent nuclear ballistic force to ensure the strategic balance with the USSR. However, first initial developments made in relation with the ballistic threat can be cited that paved the way for ground-based space weapons. A first "missile defense" capability was proposed in 1958 with the two-stage Nike-Ajax nuclear armed antiballistic missile, later on followed by the more powerful Nike-Hercules and Nike-Zeus. First ABM interceptions occurred in 1962, opening the way to newer ABM missiles, namely, the Sprint and Spartan version leading to the "Sentinel" and "Safeguard" program in 1969 with the objective to defend a limited number of strategic missile silos. It must be noted that as early as May 1962, the then Secretary of Defense McNamara allowed the conversion of the Nike-Zeus model into an ASAT program (Program 505) which led to simulated interceptions and then to a successful hit in May 1963 against a cooperative target. Another existing ASAT capability based on the THOR missile was also operational and led to the shutdown of the Nike-Zeus capability. The THOR capability would also be terminated a few years later in the mid-1970s.

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[5] See excerpts of the famous 1957 speech by B. Schriever at http://www.af.mil/news/story.asp?id=123040817 (accessed August 2012).

[6] Quoted in Stares P (1985, p. 48). Military strategies would be also made public, for example, in a 338-page book, *The United States Air Force Report on the Ballistic Missiles* written by Colonel Kenneth Gantz (and forwarded by the well-known Generals White and Schriever). It was published by Doubleday and Comp in 1958.

Besides the most common proposals aiming at developing antisatellite weapons, the US Air Force was proposing as soon as 1956 two different strategies for the military investment of space. One of those consisted in using a manned ballistic rocket (*Manned Ballistic Rocket Research System project*), while the other one (*Manned Glide Rocket Research System*) proposed the use of a reusable glide body launched from a main carrying rocket. If this latest project may recall the early NASA studies made about the shuttle at the end of the 1960s, this last project was purely military by essence as it envisioned the possibility to bomb the Earth surface since the altitude of 64 kilometers! On its side, the Army, via the Army Ballistic Missile Agency (where Wernher Von Braun would ultimately help the United States to launch their first working satellite in January 1958), had the project of a super powerful rocket that would allow "colonizing" the Moon as well as other planets for military purposes. For a detailed expose of the military position at that time, see also Baker (1985, pp. 12–30)

The USSR gave itself the first role in developing threats actually *coming* from space orbital systems. A first series of "co-orbital" tests were indeed carried out starting from 1968 with a first alleged success in November that year and ended in 1971, obviously at a time when the new "*Detente*" was to be consolidated after the US-Soviet signature of Salt-1.[7] Realizing an alleged total of 5 successful interceptions during the first series of 7 tests, the technique used by the USSR was the "co-orbital" explosion carried out by a specifically designed orbital system within a kilometer-wide radius of the target. A second series of similar tests was undertaken between 1976 and 1982, based on the advocated need for the USSR to respond to future presumed ASAT capabilities expected from the US space shuttle then in construction.

The Soviet activity in the field was then perceived as highly intensive, and President Ford directed the start of an equivalent ASAT program that would ultimately take the form of an airborne missile launched from an F-15 *Eagle* airplane. After a few test launches performed in 1982 and 1985, a third launch ended up with the interception of a US satellite target directly hit by the so-called Miniature Homing Vehicle (MHV), the third stage of the ASM-135 Vought missile. Again, the program was officially phased out in 1988, in a context when the strategic and budgetary soundness of such projects was questioned.

In any case, this early history amply demonstrates that initial ASAT programs had been envisioned as being possibly part of the global arsenals from a military perspective if not from a political one. Only the key role played by spy satellites in the mutual nuclear deterrence prevented weapons in space from becoming operational during the Cold War. This did not prevent national R&D projects to develop, paving the way for possible future threats in space.

## 38.4 A Generic List of Possible (Intentional) Threats in Orbit: Assessing Offensive Realities of Today

In today's completely renewed strategic context, these early antisatellite efforts have regained some momentum. Early programs have clearly served as a basis for more sophisticated projects allowed by technical advances, while new research domains seem to have emerged. The analysis of over more than two decades of R&D efforts lead to the following list of existing R&D orientations, possibly leading to actual space weapons:

- *Kinetic energy weapons* (KEW) implying a physical effect on the target, either by direct impact (so-called "hit-to-kill" techniques) or nearby explosion creating killing debris (such as in the case of the co-orbital Soviet systems)
- *High-altitude nuclear weapons* (EMP) creating ionization and/or electromagnetic effects on objects in the affected zone

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[7] Signed in 1972 in Moscow, this test was incidentally pleading for the use of National Technical Means for treaty verification.

- *Directed energy weapons* (DEW) mainly using laser or microwave techniques depositing energy on the target

Obviously other kinds of threats on space systems exist such as electronic warfare weapons (EW) using jamming techniques rendering communications impossible, or cyber attacks. Exactly like in the case of ground-based interceptors, such threats do not necessitate the use of space platforms to be effective. For this reason, such threats have not been treated as a key issue in the context of this article, as they do not define per se a threatening "space system." However, they shall not be discarded as their reality is largely tangible today as it will be explained further below.

- *Kinetic energy weapons*, while simple in their principle (physical collision), do not use simple techniques. They imply the use of maneuvering satellites as well as the mastering of precise "*rendezvous*" techniques, the least to achieve in case of "*hit-to-kill*" weapons! This can be related to techniques implemented by a number of existing systems, going from experimental surveillance satellites (or so-called "inspector" satellites) used, for example, to picture other orbital systems (such as in the case of the US XSS 11 and 12 or the Chinese SJ-12 or SJ-06F systems), to the European *automated transfer vehicle* (ATV) used for service and precise docking with the International Space Station (ISS). All these systems have in common highly maneuvering capabilities as well as precise terminal guidance systems allowing effective orbital "*rendezvous*." Mastering such technologies would theoretically allow developing kinetic energy ASAT. Protecting any satellite against the kinetic effect at orbital speeds becomes virtually impossible with pellets more than a few centimeters in size. As a matter of fact, protecting any satellite against a kinetic threat is almost paradoxical in itself. Satellite architectures are indeed based on the use of as light materials as possible involving some level of fragility. This is the case for satellite buses or for on-board solar arrays. "Armored" space systems are then hardly feasible and in any case would increase cost at all levels, from development to launch. Only some level of physical protection against small-sized debris (in the millimeters scale) can reasonably be applied nowadays.

  However, if they can represent deadly threats, KE techniques remain highly costly in terms of energy (most notably when changes of orbits would be needed for performing an intercept) and, in a more sensitive manner, would create more debris that would add to the already rather congested orbital traffic. For sure, creating more debris would not account among the most preferred offensive strategies for most of the spacefaring countries whose space systems rely on an undisturbed and clean orbital space. Nations that do not intensively use space might possibly be less deterred from such actions.

- *High-altitude nuclear explosions* would make use of a nuclear bomb sent at an altitude of a few hundreds of kilometers with the objective to create highly intensive electromagnetic disturbances for Low Earth Orbiting (LEO) and even geostationary (GEO) objects. Cold War years were soon followed by the fear of an increasing nuclear proliferation that would make such a possibility more probable. Such an attack could indeed have an enormous effect on the whole activity in space, with, in the first place, the possibility for the attacker of annihilating a number of military systems precisely destined to warn against nuclear attacks, such as early warning systems, Earth observing, signal interception, or strategic communication satellites. In such a situation, most of the non-protected space systems would also be destroyed.

Major studies (HALEOS 2001) have shown that, compared with a terrestrial explosion, electromagnetic effects of a nuclear charge in space might be increased leading to potentially devastating impact beyond the only targeted orbits with short-term effects on the propagation of radio and radar waves, and longer-term effects involving the permanent excitation of Van Allen belts, with even the possibility of creating new magnetic belts resulting from the sudden expulsion of charged particles.

While ionizing effects would be specific to such explosions, other effects, such as electromagnetic effects, would be no different from those created by *directed energy weapons* (DEW) using high-power microwaves (see below). As a consequence, protecting any system against such threats would mean protecting it partially from a major consequence of a high-altitude nuclear detonation. In other terms, the main characteristic of such a nuclear threat would remain its "nondiscriminatory" effects on the whole orbital population. In any instance, such an attack would mean that a situation of war would preexist. This makes the use of nuclear attack clearly different from other intentional actions that might take place in more ambiguous scenarios or even in a covert manner.

- *Directed energy weapons* (DEW) are sometimes perceived as presenting a coming threat for space systems. Indeed, this threat is theoretically characterized by some level of intensity leading to likely modulated effects on the target. It can be considered that DEW may have basically three classes of effects ranging as follows:
  - Level 1: *A jamming effect*, i.e., time-limited disturbance of the satellite functioning that ceases when exposure to the weapon is over
  - Level 2: *A disruption effect*, i.e., permanent disturbance (without definitive destruction) requiring an external intervention or reset
  - Level 3: *An annihilation/destruction effect*, i.e., definitive disruption requiring an external replacement or repair at best[8]

DEWs may have different effects according to their domain of functioning: For example, an intense laser ray has a thermomechanical effect on any material and as such can neutralize or destroy sensors or even some structures. By contrast, a microwave weapon would not have any thermal effect but would produce instead a high-power electrical effect on electrical components, whether directly or indirectly. Low-level components such as receivers or some class of sensors would prove particularly vulnerable to such threats. As envisioned by largely publicized

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[8] This subjective scale can be paralleled to what has been almost theorized, or at least symbolized, in some US Air Force doctrinal documents using the infamous "5 Ds" to materialize the scale of gravity of any space attack: "***D**eception*, ***D**isruption, Denial*, ***D**egradation*, ***D**estruction*". See USAF (2004), Counterspace Operations, Air Force Doctrine Document, 2-2.1.

projects very early on (such as the US Space-Based Laser project), equipping space platforms with powerful lasers for ASAT kind of activities might be theoretically possible with the objective to overflow or even destroy targeted sensors. However, aiming at sensors might not be an easy task, with the additional possibility of the development of self-protection devices for the most sensitive satellites.

The literature has frequently referred to powerful lasers in orbit, mainly inherited from the early R&D experiments engaged during the Ronald Reagan years under the auspices of the United States, so-called Strategic Defense Initiative (SDI) often dubbed "*Starwars*."[9] Laser-based ASAT developed under such concepts would be much more powerful with the objective to bring about mechanical destructions on the structure itself of space systems, most notably on deployed solar panels. Obviously the development of such an armament would require much more energy generation that would make their development very problematic given the usual constraints applied to any space systems (size, weight, reliability). It is highly probable that these many technical constraints have largely put into question the development of such systems, even if it is probable that more or less secretive R&D has not ceased in this area. Following this logic, powerful microwave systems may represent a more threatening technology from an operational point of view than space-based lasers.

## 38.5 What Vulnerability, in Which Context? Very Different "Defensive" Situations

Of course, any offensive weapon will focus at the main vulnerabilities of spacecrafts. These vulnerabilities are usually related to support functions such as:

- Attitude control
- Tracking and telemetry
- Thermal management
- Power management

The dysfunctioning of any of these technical functions would generally mean a shutdown of the entire system in short or longer term. As a result, the attack modes may be very diverse, whether they involve the destruction of the solar arrays, the thermal increase of the satellite structure, or a cyber intrusion in automated management processes.

In addition, the vulnerability of any spacecraft can vary quite largely considering their very nature, the applied management processes, and even the very mission it has to fulfill. As an example, telecommunication satellites are controlled by multiple operators, private or public, which sell their services to many customers. In

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[9] In this respect, it must be reminded that, at its apex, one of the several versions of this project was envisioning the deployment of many space and ground-based laser systems, possibly relayed by orbiting mirrors in order to destroy reentry nuclear heads. This complex network of sensors and effectors was considered as an addition to some more conventional 4,000 intercepting "hit-to-kill" missiles or even satellites.

this particular case, many motivations can exist for attacking the space system, from a hostile action against a specific customer to a more "wide-range" terrorist-like attack. This means that the ways and means used for attacking the "satcom" function can be very different from an action to another, implying the need to protect many dimensions of a complex system.[10]

As for the navigation satellite, their systemic redundancy makes them less an easy target. In this case, jamming may be used but this time with local effects, as it has been sometimes the case during the recent conflicts using GPS-guided munitions. In the case of Earth observation satellites, in addition to their highly critical pointing and control systems, their sensing payload and their downlink communication systems appear as high-value potential breaches. This vulnerability is indeed increased by their relatively few numbers and by the accessibility of the Low Earth Orbit (LEO) they usually make use of. Last but not least of this non-exhaustive list, the weather satellites, while mainly on the geostationary orbit, may also be vulnerable due to the reliance on the good functioning of their sensors as well as on their communication downlink capacity. It is obviously reinforced for those satellites that orbit on LEOs.

## 38.6 The Notion of "Space Threats" and Its Relevance for the Security of Space Activities

As just shown above, the notion of "space threats" as strictly defined by space systems posing a threat in orbit might not reveal itself as the most urging issue to tackle. Indeed, most of the space systems that might be considered as potential offensive candidates seem to remain fairly confined to the prospective horizon. From a technical standpoint first, using space systems as offensive weapons is not a simple operation. It involves relying on very demanding systems (in terms of sensing, maneuverability, energy management, cost, etc.) that may not make them so easy to produce and use. From an operational point of view also, this complexity may not be what a military user is looking for, notwithstanding the fact that, in the case of using offensive KEWs, the consequences of any attack will make no discrimination in the end between the victim and the attacker. For this reason, and from the policy perspective, it seems reasonable to put into question the very relevance of "threats in space" as a central notion for building the core of the future of space security. For sure, such a view does not imply that the international community should not pay attention to these developments. On the contrary, the fact that such techniques might be used 1 day should trigger a widespread awareness that in this field, earliest actions against the development of such weapons will be the most efficient. But in parallel, the rather prospective nature of these kinds of threats must not lead space-leading countries to underestimate the importance of

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[10] Obviously, the uplink remains the targets of choice for any action against the satellite itself.

other sorts of threats that may be much more meaningful on the shorter term. A brief (non-exhaustive) list of such threats may be recalled:

- **Ground-Based ASAT Tests**

  The most recent ASAT tests performed in 2007 and 2008, respectively, by China and by the United States provide a good example of the practicability of and efficiency of ground-based ASAT missiles. As mentioned at the beginning of this article, the first one performed by China in January 2007 destroyed a decommissioned Chinese weather satellite on an 800 km circular orbit. A little bit more than 1 year later, the United States did hit a lower orbiting military satellite (246 km) with the stated goal to prevent an uncontrolled and dangerous reentry. In the first case, the interceptor used was a modified SC-19 missile, while the US military used the SM-3 sea-based intercepting missile developed for ABM purposes.

  Even if it must be recalled that the targets were mainly cooperative and their trajectory well is known from their "attackers," these two cases have however amply demonstrated how much mastering space interception from the ground has become accessible to the most prominent ballistic and space powers.

- **Alleged Risks of "Cyber Attacks"**

  Another type of risks, the "cyber attacks," has been alleged as becoming a major cause of concern for space systems. Cyber attacks can indeed take many forms and affect many elements of the entire space and control system. Tracking, telemetry, and control networks can be subject to such cyber threat with the impossibility to transmit reliable data for the control of the satellite platform. As a consequence, any satellite can virtually be taken over by a non-authorized user who can force a system shutdown or a wrong maneuver leading the system to put itself in a safe mode or in any other uncontrolled mode. In theory, such a takeover can be implemented via cyber intrusions in the command center or through key ground stations. Awareness about the possibility of such attacks has increased over the recent years. In 2001, a NASA audit report pointed out that "six computers servers associated with IT assets that control spacecraft and contain critical data had vulnerabilities that would allow a remote attacker to take control of or render them unavailable."[11] These conclusions have been largely commented and have motivated the adoption of unprecedented protection measures for the Agency space systems.

  A few recent cases have sometimes been cited that seem to sustain this assessment:

  – Some reports have claimed that the German X-ray satellite ROSAT (made famous recently due to its uncontrolled reentry during the night of October 22–23, 2011) had been targeted in September 1998 by a cyber attack leading it to wrongly orient towards the Sun, ultimately causing its shutdown. This "wrong

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[11] The report goes on blaming that "moreover, once inside the Agency-wide mission network, the attacker could use the compromised computers to exploit other weaknesses we identified, a situation that could severely degrade or cripple NASA's operations."

Source: NASA (2011).

maneuver" (the cause of a loss of the satellite sensors) is reportedly related to a cyber attack carried out against computers of the Goddard NASA Center as unveiled in 1999 by one of the specialists in charge of the center computer services. At this time, the attack perpetrated against the X-ray department of the center was attributed to a Russian origin. However, those facts have never been confirmed, just a "troubling" coincidence between the move of the satellite and an intrusion in the computer system having been officially mentioned by the inquiry.

- Another satellite, INSAT-4B-S, this time a telecommunication satellite belonging to India has been mentioned as having been affected by a cyber attack (*Stuxnet Worm*) that would have caused a severe loss of power, ultimately leading to reduction of the telecommunication capacity of the satellite by more than 50 %.[12]

Of course, another more generic risk is represented by a cyber intrusion in the information chain itself (data collection, processing, and dissemination) without affecting the satellite itself. This type of attack, even if indirect, may have consequences as serious as if the space segment itself was the target, for example, ending up with wrong data, unreliable imagery, and false alarms. While targeting only information, this type of intrusion can barely be deterred by strictly "space segment-oriented" defensive strategies and doctrines.

Cyber attacks will probably account for the most preferred offensive strategies when the objective will be to disrupt an entire "space system," especially when they are old generation, i.e., not protected against the latest software offensive devices. Here again, the capability to detect the origin of the attack and to attribute its responsibility will be the key for an effective deterrence strategy. At this level, there is no magic for space systems, and this type of vulnerability is essentially linked to a domain that remains partly external to the space sector itself.

- **The General Vulnerability of the Ground Segment**

More generally, the ground segment represents a key node for ensuring the functioning of any space system. Losing the ground segment necessarily means losing the space segment. In theory, the consequences on the long term might be less definitive than when a spacecraft is destroyed, as regaining control on the operation of the space system might be possible once the functions of the ground segment have been recovered. Hence, losing the control of the ground segment might be considered as a reversible situation and might not imply the same kind of strictly deterring positions as in the case of the space segment.

However, the border between both situations may sometimes be very thin, as taught by a case occurred to Russian satellites more than 10 years ago, in May 2001. As reported at that time, a fire destroyed almost completely a main control station leading to a total loss of communication with four military early warning satellites

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[12] Again, this case has not been fully acknowledged, yet some other hypothesis (supported by ISRO) points out the loss of one of the solar arrays of the spacecraft. No official position about the incident has been confirmed up to this day.

placed on an highly elliptical orbit Podvig (2002). Only one satellite has been recovered after a while, the three others having derived well beyond their nominal position. Those remained well out of reach by their dedicated ground segment. This "ground" damage has then become irreversible for the space segment itself. It may even include risks for other spacecraft, proving at this occasion that the safety management of satellites may be key in collective space security.

Here again, protecting the ground segment against attacks or hostile actions does not directly imply the protection of the space segment only. It may involve some level of "systemic" thinking, some redundancies (ground and space), as well as some parallel hardening techniques (e.g., against high-power microwave devices or even to prevent possible EMP effects). In addition, the adoption of degraded modes must also be considered for any key node on the ground. It is important to note that such measures must apply to both military and civilian satellite owners to be fully efficient.

- **The Case of Orbital Hazardous Events: The Example of "Zombiesats"**

From April 2010 to January 2011, Intelsat, the largest telecommunication satellite operator, has lost control over Galaxy 15, one of about sixty satellites composing its geostationary fleet. This spacecraft has derived over a large portion of the geostationary orbit without offering any possibility for being recovered during that 8 month long time. This event has had a double consequence:

- An increased collision risk affecting the whole community of the satcom users, civilian and military
- A powerful jamming of satellite telecommunications as Galaxy 15 has kept on emitting at full power during the whole period of time. One of the most documented consequences was the loss of WAAS (the US regional GPS *Wide Area Augmented System* for improved satellite navigation) in Alaska.

The control of this satellite (quickly nicknamed "zombiesat" in the large amount of literature devoted to this case) has finally been recovered in January 2011 by Intelsat. However, this case has amply shown what kind of disturbances such an event can create with the necessity for operators to avoid possible collisions and interferences.[13] It shows how much non-intentional actions can also present serious threats to space security that do not clearly relate to deliberate actions. There may be a specific vulnerability in face of such "zombiesats" on the geostationary orbit due to the vicinity of the satellites around some key orbital positions. This must be taken into account as a complexity factor of the collective space security, as this makes disturbances rather quick to produce, intentionally or not, both for civilian and for military systems. It must be noticed that operators have seized the importance of such potential developments and have chose to share their knowledge by setting up a common database allowing them fostering early and precise coordination when needed.[14]

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[13] For example, it has been reported that, at this occasion, SES, the second largest geostationary satellite operator, had to proceed with many very precise maneuvers around some of its strategic orbital positions.

[14] Via the creation in 2009 of the Space Data Association, based on the Isle of Man. Obviously, considering the wealth of information contained in those databases, such a private initiative cannot be without consequences on the general management of international relations in space.

- **The Jamming of Space Telecommunication from the Ground**

  Of course, last but not least, the simple jamming of space telecommunications by using ground-based devices must also be evoked in this list of “indirect” space threats. One of the most recent Iranian episodes (spring 2009) can be quoted as the Iranian government has decided to jam two satellites (*Hotbird 6/8W6*, *Eurobird 9A/2*) managed by Eutelsat, one of the two major European telecommunication operators. The goal was then to prevent the broadcast of information perceived as contrary to the Iranian regime interest. The cost to access such technologies is relatively low at the level of a government and these interferences remains sometimes hard to detect when they occur and in any case highly difficult to prevent. *A contrario*, the example quoted here, has shown that, for a time, operators themselves had been dissuaded to broadcast the controversial information (BBC and VoA notably).

All these examples show clearly that direct threats on space systems, as evoked in the first part of this paper, do not represent the sole source of possible security breaches. They may not even appear as the most probable cause of space insecurity, at least for the short to middle term. The difficulty remains both the attribution of responsibilities and, more difficult even, the establishing of the intentional nature of any catastrophic event. Any questioning about the setting up of international regulation, whatever their form, or of some sort of “space deterrence” must take this complexity into account.

## 38.7 Some Effects on Space Deterrence: Protecting Against What Threat and/or Vulnerability?

In light of these possible developments, thinking about future threats on space systems means thinking about the probable nature of those treats as well as the kind of possible enemy using them. At first glance, the most developed spacefaring nations have used their space assets in a strongly asymmetrical context in which only a few countries were able to use similar orbital systems, possibly in a hostile way. However, it is probably necessary to take into account other kind of threats that countries on the verge of becoming space powers might likely use in case of political or military showdown.

Generally, deterring any threat to develop against space assets will imply a large appreciation of this diverse nature of possible threats, whether intentional or non-intentional. This approach will probably go through a few preliminary protective postures and actions:

- **Establishing the capability to attribute an effect to a certain cause:** this capability, addressing either intentional or non-intentional threats, relies on very specific technical capacities whether they aim at monitoring LEO or GEO orbits. But, in parallel, according to the nature of the threat in orbit (KEW, DEW, Jamming, etc.) or from the ground (using the same kind of techniques in a different way), very different means will have to be implemented to protect the satellites. Some strategies may envision having on-board devices allowing detection (and characterization) of laser attacks for example. This may bring about a certain deterrent effect against an adversary who would rather have acted stealthily. Some other will possibly envision satellites more directly dedicated to detection and inspection. Of course, ultimately, these "defensive" systems may appear in reverse as potentially challenging this quest for permanent capacity to attribute any event to a certain cause. Indeed, by definition, such protective devices would make use of technologies that may allow discreet and more offensive actions. This is not the least of the paradoxes that such efforts would imply.

- **Creating a "red line" against any attack:** provided the cause of any event solidly established, the difficulty remains to establish a sort of "red line" beyond which military protective action would be legitimate. First, characterizing between the intentional or the non-intentional move will be key in determining the reaction of the "victim." There probably lays the most difficult issue to tackle when it comes to ensuring a comprehensive protective posture (including military) against any threat on space systems. It must be noted that even in the case of a recognized intentional action, the possible "graduate" nature of the hostile action (from deception to *destruction* to recall the "5 Ds" approach) may render difficult any decision about the nature of the counteraction itself. This aspect may be at the center of the current effort to establish "rules of the road." No doubt that it will also raise expectations about the resistance capacity of the next-generation space assets. This is the approach followed for the hardening of the electrical components, for example, with two (possibly contradictory) principles. Making well known that the considered system has been hardened while, at the same time, keeping any possible adversary in the impossibility to determine the methods and the techniques used, as well as the very level of this hardening.

## 38.8 Conclusions

In any event, the road towards limiting by principle threats on space systems in a significant manner will probably remain quite bumpy for a while.

At this stage, satellites have remained vested with a highly symbolic value that continues to put them at the center of the current strategic relationships. The recent events (Chinese ASAT in 2007 and in a way the US-made satellite destruction in 2008) have shown that affirming this kind of capability was also a part of "deterrence" postures or "state communication policies." It is well documented that satellites will become smaller and smaller, more and more able while less and less costly. The generalization of smaller high-performance spacecraft (whether military or civilian), possibly "launched on demand," announces the beginning of a new era for which a new equilibrium will have to be found. These progresses, sometimes promoted through concerted national efforts,[15] are also a part and parcel of the "equation" aiming at balancing the protective approach

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[15] Such as in the case of the US *Operationally Responsive Space* program, for example, even if this effort seems to remain in question nowadays.

with bolder technology-led solutions that are supposed to give an edge to the more advanced space countries. Answering this question and finding a workable balance will determine the fate of our collective security against the threats on space systems as well as it will orient the future nature of a possible "space deterrence."

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# The Issue of Space Debris

# 39

Fernand Alby

## Contents

**Abstract**

Since 1957, human space activities have placed a great deal of objects in orbit around Earth. Debris represents a growing risk for operational satellites, in case of collision, and on the ground when it reenters the atmosphere. This situation calls for action, namely, in the following four areas: obtaining accurate knowledge of the situation, protecting satellites and populations, reducing as far as possible the creation of new debris, and cleaning up in space by removing the largest objects. The prevention measures mainly consist in post-mission management for satellites and launchers. Measures have been developed, and have met with broad consensus. However, to ensure more systematic application,

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legal mechanisms are also being established, States being liable in the event of an incident. Protection actions are also needed, but offer only partial solutions: these actions involve setting up services for preventing the risk of collision and predicting atmospheric reentries. However, due to collisions between debris objects, these actions alone will not be enough to stabilize the debris population: cleanup actions will eventually be necessary.

## 39.1 Introduction

Since 1957, human space activities in orbit have produced a large amount of waste, known as space debris, which has become a real problem – to the extent that there is now an urgent need for regulation, while also developing the means to one day begin cleanup.

The purpose of this chapter is to describe the situation in space and the risks associated with this debris, and then to review the various actions to be implemented in the short and medium term.

## 39.2 The Situation in Orbit

### 39.2.1 Where Space Debris Comes From

More than 5,000 spacecraft have been launched since Sputnik, resulting in a large amount of waste being put into orbit. The different types of space debris include (Rathgeber et al. 2010):

- Operational satellites and abandoned satellites which remain in orbit around Earth.
- Upper stages of the launchers used to place these satellites in orbit.
- Operational debris, objects intentionally released during space missions: covers used to protect instruments during the launch phase, systems used to attach solar panels or antennas before deploying them in orbit, separation devices and straps, etc.
- Fragmentation debris: debris produced when objects in orbit collide with space debris or meteorites, and from the accidental or voluntary explosions of spacecraft.
- Propellant residue: solid propellant motors used to carry out transfers in orbit, especially between a transfer orbit and geostationary orbit, which release small alumina particles during thrust periods. This problem is especially critical at the end of the thrust period when combustion becomes unstable, at which point slag measuring several centimeters can be ejected into space.
- Debris from the ageing of materials in space. The space environment is very harsh, with major temperature differences between shade areas and areas exposed to the Sun, atomic oxygen and ultraviolet rays, etc. The ageing process causes large amounts of debris to be produced (separation of photoelectric cells, weathering of thermal protection covers, and peeling of paint, etc.).

There are other, more anecdotal sources of debris which have also had a significant impact on the population of objects in orbit:

- In 1961 and 1963, as part of the Midas 4 and Midas 6 experiments, the US Air Force planned to release several million copper needles (West Ford Needles) into orbit at an altitude of around 3,000 km. The goal was to create a ring of dipoles around Earth to act as a passive reflector for military communications. Only the second experiment was partly successful. The needles then formed clusters, 65 of which could still be seen from the ground in 1998.
- In the 1980s, the Soviet Union used Radar Ocean Reconnaissance Satellites (RORSAT) equipped with nuclear reactors. At the end of their mission, the cores of these reactors were re-orbited at altitudes between 900 and 1,000 km to allow their radioactivity to decrease before they fell back into the atmosphere. Leaks in the cooling circuit were found on 16 of these satellites, which resulted in drops of liquid sodium potassium (measuring between 1 mm and several centimeters) being released into orbit.

### 39.2.2 Debris Inventory

Knowledge of the debris population is obtained using radar or optical observation means, on the ground or in orbit, and by studying the effect of debris on surfaces that have spent time in space.

The debris is generally broken down into the following categories:

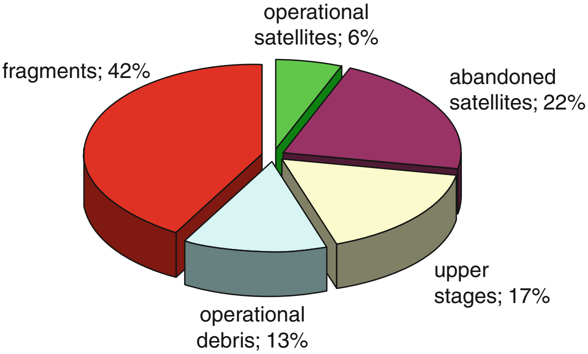
- "Large" objects, measuring more than 10 cm in low orbit and 1 m in geostationary orbit: these objects are listed individually, or catalogued, by space surveillance systems (see paragraph 3.1). Around 15,000 are routinely cataloged by the US surveillance network. However, their total number is estimated at 20,000, not all of them being catalogued.
- Objects measuring between 1 and 10 cm: based on statistical observations, the total is estimated at several hundred thousand.
- Objects measuring between 1 mm and 1 cm, which are counted in tens of millions.

Figure 39.1 shows the breakdown of catalogued objects by category (source: public catalogue of the US Space Surveillance Network). It should be noted that active satellites make up only 6 % of the population of catalogued objects in space.

Figure 39.2 (Source: NASA Orbital Quarterly News, volume 16, issue 1 January 2012) shows the progression over time of the number of objects catalogued by the space surveillance network in the United States. The total number of objects is the sum of the four components shown in the graph: fragmentation debris, spacecraft, mission-related debris, and rocket bodies. Two events in particular added large amounts of waste: the voluntary destruction of the Fengyun 1C satellite in January 2007, and the collision between the active Iridium 33 satellite and the abandoned Cosmos 2251 satellite in February 2009.

Figure 39.3 (Source: NASA Orbital Quarterly News, volume 16, issue 2, April 2012) shows the progression in the total mass of artificial objects in orbit around

Fig. 39.1 Breakdown of catalogued objects



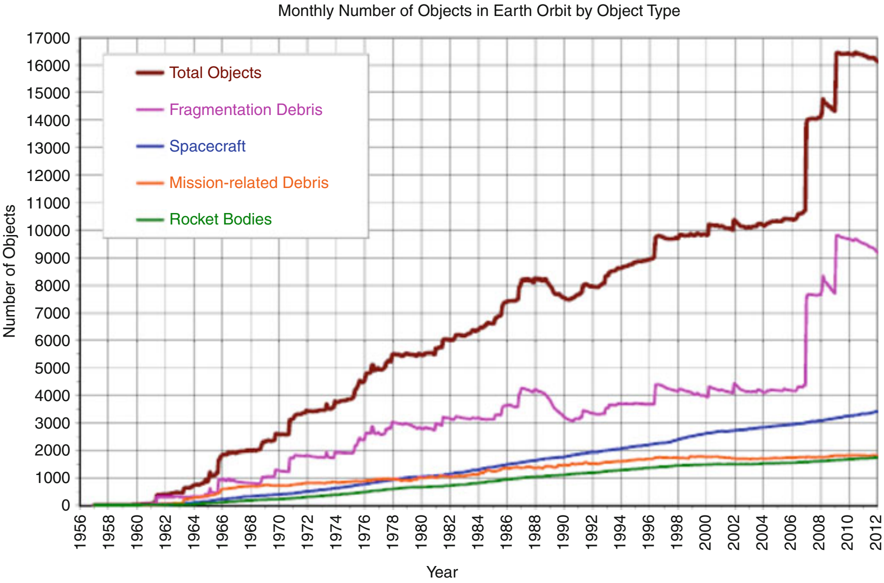


**Fig. 39.2** Progression in the number of catalogued objects as a function of time

Earth, and in each of the four categories mentioned above. The progression is almost linear, climbing steadily since the 1980s. The two events mentioned above impacted the number of objects, but not the total mass.

### 39.2.3 Lifetime

The lifetime of objects in orbit depends on their altitude, due to the effect of atmospheric drag.

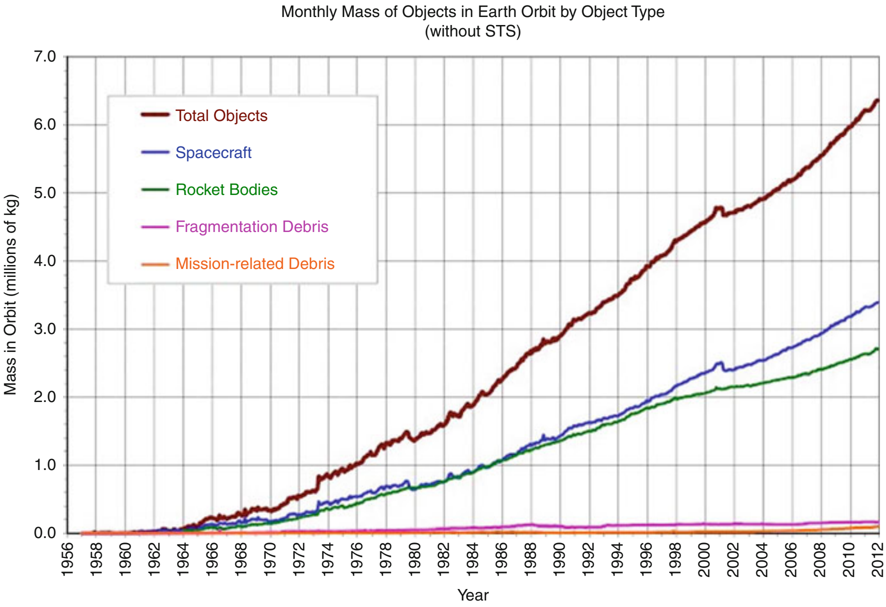


**Fig. 39.3** Progression in the mass of objects in orbit

Atmospheric density decreases more or less exponentially in function of the altitude. Traces of atmosphere are still present in low orbits, and these molecules slow the passage of orbiting objects. Reducing their speed causes them to lose altitude, in which case they meet even greater resistance, since the lower the altitude, the higher the atmospheric density will be. Ultimately, as the cycle continues, the object will be captured by the atmosphere and fall into the dense layers. This phenomenon is significant in low orbit (at altitudes below 1,000 km) and nonexistent in geostationary orbit. In the case of the International Space Station (ISS) located at an altitude between 350 and 400 km, the lifetime would be between 6 months and a year without maneuvers. Altitude-boosting maneuvers are made regularly to offset this disturbance. At a higher altitude, around 800 km, the lifetime of a satellite is around 200 years and beyond; lifetime increases quickly the higher the altitude.

However large differences in orbital lifetime estimation may be observed due to the influence of solar activity. The Sun's ultra-violet radiation causes excitation of the different molecules in the atmosphere resulting in the temperature being increased and in overall dilatation of the atmosphere. Important variations of the solar activity are observed during the 11-year cycle of the Sun. For instance, at 400 km altitude, according to the NASA MSISE-90 model of the upper atmosphere, the density during high-activity periods may reach 100 times the density value during low-solar-activity periods. This explains why a large number of satellite decays are observed during periods around the maximum. In addition, shorter term variations exist and lead to large dispersions when predicting reentries.

## 39.3 Risks Associated with on the Ground and in Orbit

### 39.3.1 Risks on the Ground

When the spacecraft reenters the atmosphere, encountering the dense layers of the atmosphere at a very high speed, it is subjected to strong aerothermodynamic forces. Appendages, such as antennas and solar panels, are torn off at an altitude of around 90 km, and at around 75 km the spacecraft disintegrates. The debris is exposed to a very high heat flux: most of the materials are vaporized, but some components can survive these conditions, e.g., materials such as titanium, steel, ceramics, or components which are shielded by others (masking effect). It is generally estimated that 20–40 % of the mass in orbit reaches the ground in the form of debris. This debris is distributed along the track mainly as a function of its surface-mass (S/m) ratio. The impact zone on the ground is typically 1,000–1,500 km long (in the direction of the track) and 50–80 km wide. The random fall-back of these pieces is a risk on the ground if they fall onto inhabited areas. Although debris is regularly found on the ground, thus far, the random reentry of debris has never caused any injury or damage.

When the object that is going to fall presents a major risk due to its mass or the materials it is made of, the usual procedure is to conduct a controlled reentry. This involves one or several deceleration maneuvers in order to guide the object's fall to a chosen impact zone on the ground, as was done for the MIR station in March 2001 and the European ATV, for example.

### 39.3.2 Risks in Orbit

Objects in orbit travel at a very high speed (8 km/s for an object in low circular orbit). At speeds such as this, the kinetic energy of even a small piece of debris is very high: at 10 km/s, a 1 mm aluminum sphere has the same kinetic energy as a rifle bullet. So it is understandable that satellite operators worry about the risks of collisions between their precious satellites and the debris they regularly encounter. Collisions are not a figment of our imagination: their effects can be seen on spacecraft and any surfaces that have spent time in space and returned to Earth. For example, a large number of impacts, luckily small ones, have been found on space shuttles, on the solar panels of the Hubble telescope, and on the LDEF (Long Duration Exposure Facility) spacecraft. They have also been spotted on the International Space Station during extravehicular activities. Unfortunately, collisions between large objects (catalogued objects) also occur, and have major consequences in terms of producing new debris. The most recent example is the 10 February 2009 collision between the Iridium 33 satellite and an old Russian satellite (Cosmos 2251) abandoned in space. The consequence was of course the destruction of both objects, and the creation of a great deal of debris: around 1,400 new objects measuring over 10 cm have been catalogued, and the smaller pieces of debris are far more numerous.

When a collision occurs, it is generally considered that:

- Debris larger than 1 mm can cause perforations: the effect on a satellite depends on the location of the impact and can result in equipment failure.
- Debris larger than 2 cm can result in loss of the satellite (lethal collisions) due to the force of the impact, its dissipation in the structure and projection of particles inside the satellite at very high speed.
- Debris larger than 10 cm not only results in loss of the satellite, but also produces a great deal of debris (catastrophic collisions).

## 39.4 Actions to Be Implemented

Now that we have a clear picture of the situation and the associated risks, we will discuss the implications and identify the actions to be implemented. There are four types of solutions:

- First, having the best possible knowledge of the debris population, how it is distributed and its characteristics. This involves space surveillance activities for the largest objects and modeling activities for smaller objects (statistical models indicating the particle flux).
- Once the situation has been ascertained, the next step is protection: protection against small debris thanks to shielding and adapted architecture, protection against large objects by avoiding collisions in orbit or during launches, and protection on the ground by monitoring atmospheric reentries.
- In addition to these actions, we must also stop creating new debris which will exacerbate the problem in the medium term. Thus, we must apply these prevention measures to satellites and launcher stages and most importantly, manage their disposal when they are no longer in use.
- Finally, in the longer term, we will surely have to do clean up in space, i.e., retrieve and remove the largest objects abandoned in orbit before the prevention measures went into effect.

In the following paragraphs, these four types of actions are described in greater detail.

### 39.4.1 Knowing the Situation

The goal of space surveillance is to inventory the objects above a certain size which are in orbit around Earth. This inventory (catalogue) provides information on the origin of the objects (name, launching country) and their trajectory (orbit parameters) so that the object can be looked up later. To obtain this information, different types of sensors have to be used: first, detection tools with a wide field of vision allowing objects above a certain size to be seen as they pass by, and their orbit to be roughly calculated so they can be found again later, and second, tracking tools with a narrow field of vision which can follow a given object in order to take trajectography measurements and better define its trajectory. These detection and tracking tools basically consist in radars for objects in low orbit and telescopes for objects in higher orbits. They may be located on the ground or in orbit.

The main source of information is the Space Surveillance Network (SSN) set up by the United States, which provides the most complete information. Russia has a similar system for which very little information is available. There is also the ISON telescope network, which provides a detailed catalogue of the objects in geostationary orbit. Finally, France has a limited-capacity network: the Graves system.

The core of the SSN is the JSpOC (Joint Space Operations Center) located at the Vandenberg Air Force Base. The JSpOC is responsible for programming the sensors and collecting and then analyzing the data in order to compile and manage the catalogue. The SSN can follow objects measuring around 10 cm in low orbit (and potentially objects measuring around 5 cm at low altitude and in inclined orbits) and objects measuring around 1 cm in geostationary orbit.

To create and manage the catalogue, the SSN uses two different orbitography models: (1) general perturbations (GP), an analytical model based on a simplified representation of forces, and (2) special perturbations (SP), a model based on numerical integration with a more accurate representation of forces. Only the less precise information produced using the GP model is available on the Space Track website. This information is set out in TLE (Two-Line Element) form: the object's SSN and COSPAR number, and the mean orbit parameters on two lines (see details and format on the Space Track website). TLEs provide only a rough idea of the orbit: the degree of uncertainty can be up to several kilometers on creation of the TLE, and gets worse over time. This information is not accurate enough to reliably predict risks of collision.

The population of smaller debris, below the size threshold, is no longer defined deterministically, but statistically: this information is obtained from flux models such as ORDEM (NASA) or Master (ESA).

For a given date and orbit, these models provide the flux on the different surfaces of a spacecraft, according to the size or mass of the debris in question. The flux is the number of impacts per surface unit ($m^2$) and per time unit (year). The models also indicate the direction and speed of the impacts.

As these small particles cannot be observed from the ground, knowledge of them comes only from information provided by debris detectors (very rare), or (primarily) from examining surfaces which have spent time in space after their return to Earth: LDEF (Long Duration Exposure Facility), Eureca, Space Shuttle, Hubble solar panels, etc. These observations are only possible in very low orbits, which allow the models to be correctly "readjusted" for the corresponding altitudes. For other altitudes, the models are "extrapolated" without there being any means of verifying their accuracy: given the absence of measurements, the degree of uncertainty is surely very high.

**Table 39.1** Annual probability of collision with objects >10 cm and with catalogued objects

| | Objects > 10 cm | Catalogued objects |
|---|---|---|
| ENVISAT | 0.015 | 0.0073 |
| ERS2 | 0.0039 | 0.0021 |

## 39.4.2 Protection

### 39.4.2.1 In Orbit

With the number of objects in space steadily increasing, predicting the risk of collision in orbit has become one of the primary tasks of the control centers which monitor and manage satellites. The annual risk of losing a satellite in a collision is no longer negligible, as shown in Table 39.1 for two satellites in low orbit (Klinkrad 2006):

It must be kept in mind that a collision would result not only in the destruction of both objects but also create large quantities of debris. For example, the collision between the Iridium 33 and Cosmos 2251 satellites created two clouds of debris: the 2012 SSN catalogue listed 492 pieces of debris from the Iridium 33 satellite and 1,361 pieces of debris from Cosmos 2251.

To manage this risk, operators use the available space surveillance data. These data allow them to foresee dangerously close passes several days in advance, to calculate the risk, and to conduct an avoidance maneuver, slightly altering the satellite's trajectory in order to ensure a safety distance from the hazardous object.

The surveillance process is fairly time consuming due to the inaccuracy of the available data: it generally involves a first-level of automatic surveillance which detects potential risks, which must then be more closely analyzed by orbitography experts. If the risk appears serious, trajectography measurements are requested from available radar means (usually military means): these measurements provide better knowledge of the hazardous object's trajectory, assisting the operators in taking the decision as to whether or not an avoidance maneuver must be implemented. The entire prediction process spans several days (typically 3). It should be pointed out that the avoidance maneuver changes the monitored satellite's trajectory, which generally means that its mission must be interrupted. In the case of an observation satellite, this can be a major constraint. A maneuver will then be needed to return the satellite to the nominal orbit before resuming its mission. All of this requires significant means: experts, controllers, radars, calculation means and TM/TC stations, etc., and uses propellants, reducing the satellite's lifetime by as much. To reduce the impact of these maneuvers, a planned maneuver (such as a position maintenance maneuver) can sometimes be anticipated, i.e., a maneuver that would have been necessary in any event can be implemented ahead of schedule, which limits the use of propellants.

To allow the risk of collision to be predicted more reliably, since 2011, the JspOC has dispatched collision alerts in the form of Conjunction Summary Messages (CSM) to operators: these messages are drafted using precise information and contain the characteristics of the close pass and associated dispersions (covariance). With this information, the operators are able to calculate the probability of collision.

This process is illustrated by the following figures from risk-of-collision surveillance for 18 satellites carried out at CNES (French Space Agency) in 2010: the automatic process identified 353 risks with a probability of collision higher than $10^{-4}$. In addition, 92 alerts were received from JSpOC. After analyzing these cases, 21 requests for radar measurements or support to JSpOC were issued (probability of collision higher than $10^{-3}$), and in the end, 13 avoidance maneuvers were carried out.

Risk-of-collision surveillance is not limited to close passes with “large” catalogued objects whose trajectories are known. Because they are so numerous, smaller objects represent a greater risk for satellites. Moreover, they are not catalogued, which means they cannot be avoided. Shielding has been developed to protect them, but due to the increased mass this implies, this solution is reserved for several special spacecraft, such as the International Space Station. Satellites are usually not shielded, but their walls provide a certain degree of protection.

#### 39.4.2.2 During the Launch Phase

During the launch phase and the first orbits, the launcher’s last stage and the satellites placed in orbit cross orbits used by other operators: this is especially true of a geostationary transfer orbit with a perigee in a low orbit and an apogee at an altitude of around 36,000 km. These newly injected objects will not be listed on the catalogues for some hours (typically 48 h), which means that other space users have no way of monitoring the risk of collision between these new objects and their satellites. This is especially important for manned spacecraft (such as the ISS) whose control center cannot monitor the risk from these objects.

The launch operator alone has information on the planned trajectory, and can therefore predict the risks of collision. This prediction must take into account all objects placed in orbit (launcher stages, satellites, structural components) for a period of approximately 48 h. In the event of risk, postponing the launch time by several seconds ensures a safety distance between objects. After this 48-h period, it is considered that the new objects are catalogued, and that each operator can carry out their own surveillance.

The main difficulty in predicting risk of collision during a launch lies in considering the dispersions affecting the orbit parameters of various objects at injection: propagating these dispersions over 48 h results in significant amounts of error around each body, and could close the launch slot completely if all catalogued objects were considered in the analysis. This is why predicting the risk of collision during the launch is generally limited to manned spacecraft and certain satellites of particular interest.

#### 39.4.2.3 On the Ground

As indicated in paragraph 2–1, when a spacecraft disintegrates on reentry, the resulting fragments represent a risk on the ground. Controlled reentries allow the fall-back area to be defined, thereby avoiding risk for populations. However, most reentries are uncontrolled, with no control over the fall-back area. For example, in 2011, of the 499 listed reentries, 25 were controlled and 474 were uncontrolled. The latter category included 63 satellites and launcher stages, i.e., slightly more than one uncontrolled reentry of a large object per week.

The debris fall-back area spans several hundred kilometers along the orbit path and measures a few tens of kilometers in width (typical values: length 1,000–1,500 km, width 50–80 km).

In the case of a natural (random) reentry, it is impossible to predict the exact location of the fall-back area, due to the lack of accurate information on several factors:

- The atmospheric density $\rho$ and its variability below an altitude of 200 km
- The object's attitude (i.e. its orientation with respect to the velocity vector) which defines the drag surface S: the object can be rotating, or stabilized, or have a variable orientation, inducing a possible lift effect
- The aerodynamic coefficient $C_D$
- The mass m

This makes it impossible to accurately estimate the main perturbation (atmospheric drag), which is proportional to $\rho C_D S/m$.

In terms of how precisely fall-back time can be predicted, the generally accepted uncertainty margin is 10 % of the remaining time to fall-back. For example, 10 days before fall-back, the uncertainty margin is ±1 day (i.e., anywhere within the limits of the inclination), and 10 h before, the uncertainty margin is ±1 h.

This 10 % margin has been confirmed by the atmospheric reentry exercises organized each year by the Inter-Agency Space Debris Coordination Committee (IADC), in which the orbits returned by each of the agencies are pooled, and the fall-back predictions are compared.

Thus, to summarize, if the uncertainty in the fall-back time is taken to be 10 % of the remaining time to fall-back, this gives the following dispersions on the position of the exact impact area:

- 48 h prior ±4.8 h or approximately ±3 orbits
- 24 h prior ±2.4 h or approximately ±1.6 orbits
- 12 h prior ±1.2 h or approximately ±32,000 km

This uncertainty value of 10 % could be reduced to around 5 % if better knowledge of the trajectory were available thanks to more measurements more evenly distributed along the entire orbit. In the best-case scenario, several hours before reentry, the uncertainty is around 30 or 40 min, corresponding to uncertainty on the impact point of slightly less than one revolution. It should be noted, however, that the debris *cannot* fall outside this 50- to 80-km-wide strip located beneath the orbit path.

Within several hours to several days after reentry, the Space Track website indicates the position of the observed passage point at 80 km, with an accuracy value of ±1 min (±500 km). Thus, after the fact, we can delineate an area of approximately 2,000 × 100 km which is liable to have been affected by the fragments. This additional information may be useful should it be necessary to determine liability.

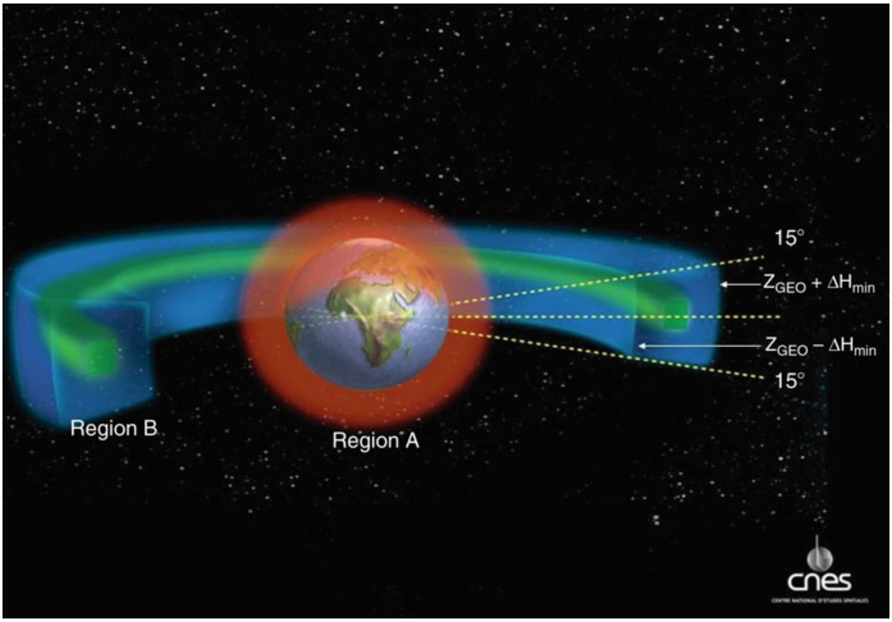


**Fig. 39.4** Protected regions in space (Region *A* – Low Earth Orbit, Region *B* – Geostationary Orbit)

### 39.4.3 Stopping Production of Debris

The problem of space debris is mainly an issue in low orbit and geostationary orbit:

- Region A: Low Earth Orbit (LEO) is where the highest concentration of space objects is found (density curve), especially at altitudes of 700–900 km. This is the area in which two major events occurred, resulting in the creation of large quantities of debris: (1) voluntary destruction of the Fengyun 1C satellite in January 2007 and (2) the collision between the Iridium 33 satellite and Cosmos 2251 in February 2009.
- Region B: geostationary orbit is a very specific area (circular and equatorial orbit, with a period equal to the period of the Earth's rotation). In order to share this unique resource between operators, the longitudes and frequencies need to be managed. Moreover, due to the distance from Earth, the effect of atmospheric drag is null, and debris created in this area will stay there and drift, crossing paths with positions occupied by operational satellites.

#### 39.4.3.1 Principle of Prevention Measures

The main space agencies represented within the IADC have identified two regions in space to be protected (see Fig. 39.4):

- The Low Earth Orbit (LEO)-protected region is the volume that extends from the Earth's surface up to a spherical shell of 2,000 km altitude above the equator.

**Table 39.2** De-orbiting maneuver and quantity of propellant required according to altitude

| Altitude (km) | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1,000 |
|---|---|---|---|---|---|---|---|---|
| ΔV (m/s) | 89 | 117 | 145 | 172 | 198 | 223 | 248 | 272 |
| Propellant mass | 62 | 81 | 99 | 117 | 134 | 151 | 167 | 182 |

- The geosynchronous (GEO)-protected region is a segment of the spherical shell defined by the following: the altitude extent is bounded by the geostationary altitude ±200 km (35,786 ± 200 km above the equator) and the latitude extent is bounded by ±15 deg (centered on the equator).

The prevention measures implemented by satellite or launcher operators can be broken down into three categories:

- No longer intentionally releasing objects in space (mission-related objects): e.g., covers which protect optical systems during launch, various other covers, springs and straps, etc., which used to be released after injection into orbit. This category also includes the alumina particles ejected by solid propellant motors, used for transfers into geostationary orbit, for example. In particular, these motors can release slag measuring several centimeters at the end of combustion: ejected at a low speed, this debris stays close to the orbit being used. Pyrotechnical cutting systems are also a potential source of debris when they are activated: using “clean” systems, which trap the debris produced, should reduce the creation of this type of debris.
- Reducing the risks of explosion in orbit: this means avoiding the accidental or voluntary explosion of spacecraft during their in-orbit lifetime. This period covers not only the operational mission phase, but also their post-mission life in orbit after the withdrawal from service phase. More than 220 fragmentations in space have been listed thus far, representing the primary source of debris. Many of these fragmentations had to do with the propulsion system or batteries. After mission termination, the object is “passivated” and then abandoned in space. To passivate means to make the object inert in order to eliminate the risk of subsequent explosion due to an internal cause (such as accidental mixing of propellants or battery overcharge) or external cause (such as a debris or meteorite impact against a pressurized tank). The passivation process consists in emptying all propellants remaining on board, lowering the pressure in all tanks (e.g., pressurization gas), and discharging and isolating the batteries to prevent accidental recharging.
- Managing the end-of-life orbit: the goal is not to leave objects in space for “too long,” due to the risks of collision and debris production. For satellites in low orbit, the best solution is to conduct a controlled reentry, which immediately frees up the orbit and minimizes the risks on the ground, by having the debris fall into an ocean. In practice, this operation requires a large amount of propellants, which increases rapidly with altitude. Table 39.2 indicates the amplitude of the maneuver and the amount of propellant required to go from a circular orbit at a given altitude to a reentry orbit with perigee 0 in the case of a 2-t satellite and a specific pulse of 290 s:

When controlled reentry is not possible, the accepted practice is, insofar as possible, to limit the time objects spend in orbit. The current maximum recommended period is 25 years. At the end of the operational mission, operators must maintain the ability to maneuver, in order to move the object into a lower-altitude orbit so that the wear from atmospheric drag will cause it to fall out of orbit within 25 years. Another solution consists in transferring objects above the protected region, i.e., to an altitude of over 2,000 km. Reentry into the atmosphere is no longer an option for satellites in geostationary orbit, due to the quantity of propellants this would require. Thus, this solution consists in freeing up the useful orbit by transferring objects to a "graveyard" orbit 200 km above the protected region. Once they have been transferred, the objects must then be passivated.

#### 39.4.3.2 International Cooperation

End-of-life operations are complex and represent a considerable workload for operators. Some of the main difficulties involved are:

- The difficulty of accurately estimating the quantity of propellants remaining in the tanks on board: given the uncertainty associated with the different estimation methods, greater margins are taken to ensure that the end-of-life operations can be carried out, which reduces the mission duration accordingly.
- The need to maintain control of the satellite, especially during passivation: risk of degrading the orbit attained or losing the attitude when the tanks are emptied.
- The difficulty of deciding to stop the mission of a satellite which is still operating correctly: the operator may tend to prolong the mission a bit, at the risk of not being able to carry out the end-of-life operations.
- The fact that these operations need to be taken into account right from the satellite or launcher design phase (necessary systems), which leaves open the question of spacecraft already in orbit.

Implementing these measures represents additional costs for operators: reducing operational life, cost of operations, additional systems to be included in spacecraft designs, deoptimizing launcher trajectories, etc.

Operators are of course willing to implement the prevention measures . . . on the condition that their competitors be subject to the same requirements. Thus, the challenge is to reach a general consensus so that all actors are applying the same rules. There have been discussions on this subject at various levels:

- The United Nations provides the natural framework for discussions between States. The Scientific and Technical Subcommittee (STSC) of the Committee on Peaceful Uses of Outer Space (COPUOS) has addressed the issue of space debris. Work in this area was completed in June 2007, with the publication of the UN-COPUOS Space Debris Mitigation Guidelines (reference A/AC.105/C.1/L.284) which sets out seven high-level guidelines to apply in space. This document was then ratified by the United Nations General Assembly on 10 June 2008 (A/RES/62/217). In 2010, the STSC recalled the importance of ensuring the safe and sustainable future use of outer space and decided to establish a dedicated working group. The working group will prepare a report on the long-term sustainability of outer space activities containing a consolidated set of current practices and operating procedures, technical standards and policies associated with the long-term sustainability of outer space activities. On the basis of all the information collected, the working group will produce guidelines, which could be applied on a voluntary basis by States, either individually or collectively; international organizations; national nongovernmental organizations, and private sector entities to reduce the risks to space activities for all participants and to ensure that all countries have equitable access to outer space (United Nations 2011). The report should be submitted to the COPUOS in 2014.

- More technical discussions are undertaken by space agencies within the framework of the IADC (Inter-Agency Space Debris Coordination Committee), made up of the following 12 agencies: ASI (Agenzia Spaziale Italiana), CNES (Centre National d'Etudes Spatiales), CNSA (China National Space Administration), CSA (Canadian Space Agency), DLR (German Aerospace Center), ESA (European Space Agency), ISRO (Indian Space Research Organisation), JAXA (Japan Aerospace Exploration Agency), NASA (National Aeronautics and Space Administration), NSAU (National Space Agency of Ukraine), ROSCOSMOS (Russian Federal Space Agency) and UKSpace (UK Space Agency). In 2003, IADC published the IADC Space Debris Mitigation Guidelines, a document which describes the prevention measures in detail. This document defines the protected regions in space, e.g., and explains that 25 years is the recommended maximum period for objects to stay in low orbit after the end of their operational life.
- Finally, for the practical application of these recommendations by manufacturers and operators, norms and standards will have to be developed for use in drawing up contracts. ISO completed an important task in drafting Standard 24113 (Space Systems-Space Debris Mitigation) published in 2010, which contains all of the rules relating to space debris. This document is based on a series of implementing standards describing how to apply them and proposing verification solutions and methods. A third level of documents, the technical notes, completes the body of work with substantiating information.

Other initiatives are also ongoing such as the International Code of Conduct for Outer Space Activities proposed by the European Union. The project was launched in 2008 as a means to achieve enhanced safety and security in outer space through the development and implementation of transparency and confidence-building measures. The proposed Code would be applicable to all outer space activities conducted by States or nongovernmental entities, and would lay down the basic rules to be observed by space faring nations in both civil and defense space activities. Discussions open to the participation of all UN Member States, will begin in 2012 with a view to adopt the Code in 2013.

#### 39.4.3.3 Application Mechanisms

The IADC recommendations were first adopted in the regulatory documents of space agencies, e.g., NASA, JAXA, and CNES standards, and the European Code of Conduct for Space Debris Mitigation (ASI, BNSC, CNES, DLR, and ESA). These documents applied to these agencies' projects, but not to the activities of private manufacturers and operators. Thus, the private sector was free of any obligation. However, the measures were generally applied by "responsible" operators.

This regulatory gap was mentioned in resolution 62/217 of the General Assembly of the United Nations dated 1 February 2008 (document A/RES/62/217), which approves the COPUOS Space Debris Mitigation Guidelines and states the need for a legal framework for States which are liable for the activity of their nationals: "…and invites Member States to implement these guidelines through relevant national mechanisms."

This need had already been stated in 1967 in the Space Treaty (Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies). Article VI stipulates that "the activities of non governmental entities in outer space, including the Moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty."

Thus, the States are liable in the event of damage caused on the ground or in space as a result of their nationals' activity. In response to this situation, States are gradually creating legal instruments allowing them to monitor the space activities for which they may be held liable. The United States, e.g., has set up a licensing system managed by three organizations: the FAA (Federal Aviation Administration) for launch operations, the NOAA (National Oceanic and Atmospheric Administration) for Earth observation satellites, and the FCC (Federal Communications Commission) for radiocommunications satellites. The United Kingdom has also set up a similar licensing system. In France, the Parliament passed the Space Operations Act (*Loi sur les Opérations Spatiales*) in June 2008, which came into effect on 10 December 2010. Other countries are taking similar initiatives and setting up equivalent systems.

The goal of these legal instruments is to set up a national authorization and monitoring system for space activities carried out under the State's jurisdiction, or for which the State is internationally liable under the United Nations Treaty. These instruments apply to satellite and launch operators, and their purpose is to ensure personal safety and public health and to protect property and the environment on Earth, in the atmosphere and in orbit. In this regard, requirements relating to the safety (risks on the ground) and prevention of space debris play a key role.

Although quite different in form, these various texts are basically equivalent in their content, and particularly with regard to debris prevention, they comply with the IADC Mitigation Guidelines and ISO standard 24113.

Nevertheless, the situation is far from perfect: the satellites and launchers in operation today were designed before these regulatory texts were published. Thus, it is not always possible to apply some of these rules, such as passivating used helium tanks to pressurize propellant tanks. For this reason, the texts generally provide for a transitional period during which operators must show that they have made their best efforts considering the existing design. Down the road, another problem may arise if all countries, without exception, do not implement equivalent

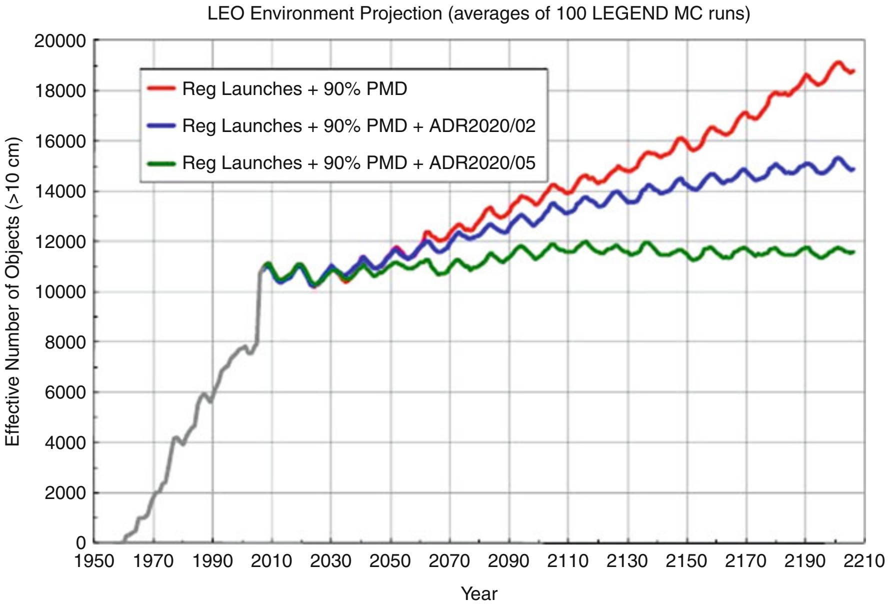


**Fig. 39.5** Simulated LEO population growth as a function of time

systems. To evade the requirements, operators could decide to base themselves in countries without regulations or with much less stringent regulations. This would create a situation of unfair competition, much like that existing in maritime law with flags of convenience.

### 39.4.4 Removing Old Debris

Prevention measures will be effective in significantly reducing or eliminating the creation of new debris, but this will not solve the problem of "old" debris already in orbit. Various studies are being carried out to estimate long-term debris population growth. The models developed by various agencies are based on variety of assumptions on the number of future launches, mission types, satellite size and lifetime, how thoroughly prevention measures are applied, the number of accidental explosions, etc. All of these models show the situation continuing to worsen.

Indeed, collisions between objects will produce new debris, which will in turn create new collisions, and so on. This chain reaction or cascading effect (also known as the Kessler syndrome, after Don Kessler, the NASA writer who revealed this phenomenon in 1978) will mainly occur in the region between 700 and 1,000 km of altitude, where debris is densest.

Figure 39.5 (Liou 2001) shows the progression over time in the number of catalogued objects, for three assumptions:

- No active debris removal
- Active debris removal starts in 2020 and two objects are removed each year (ADR 2020/02)
- Active debris removal starts in 2020 and five objects are removed each year (ADR 2020/05)

These three simulations are based on the assumptions that (1) the number of launches will continue at the same rate as over the past 8 years and (2) post-mission disposal (PMD) measures will be effectively applied with a 90 % success rate.

If the assumptions for long-term growth prove to be true (i.e., inexorable population growth even with full application of the prevention measures), cleanup in space will be necessary: abandoned objects will have to be removed. The largest objects, which are potential sources of more debris in the event of collisions, will have to be removed first. The studies available at present show that 5–10 large objects per year would have to be removed to stabilize the debris population.

Various solutions, some more exotic than others, have been proposed by many different authors, but certain technical difficulties still need to be resolved:

- Approaching and capturing a noncooperative spacecraft, which is likely to feature a complex rotation movement: the capturing solutions involve systems of nets, harpoons, claws or robotic arms, etc.
- Attaching a de-orbiting system: solid propellant kit, electrodynamic cable, inflatable surface, sail, etc.

No-contact solutions have also been proposed: e.g., a laser (on the ground or on board) to reduce objects' speed, electrostatic attraction between the chaser and the target, "blowing" the target via an electric propulsion system installed on the chaser, etc.

The technical feasibility of these solutions has yet to be demonstrated. Once more in-depth studies have been carried out, one or several designs will have to be selected, and missions demonstrating the critical technologies will have to be carried out before the first operational mission can be planned.

In any case, the cleanup spacecraft will have to be able to move between orbits in order to reach different debris, which will be fairly complex.

Aside from these technical challenges, other difficulties of political, legal, and economical nature will also have to be considered:

- Political difficulties: active debris removal operations could be used as a cover for military activities. This confirms the need for international agreement and transparency between the various actors. Also, certain countries may feel singled out or reproached when it comes to cleaning up the objects they have abandoned in space.
- Legal difficulties: there is currently no international consensus on the definition of the term "debris": according to the United Nations Treaties, objects in space forever remain the property of their launching State, so prior authorization is needed before touching an object belonging to another State.
- Economic difficulties: these cleanup missions will probably be fairly costly. Who will pay for them, and in what form? States will probably also ask themselves why they should remove their objects from space when other States do not do the same, or worse, fail even to apply the prevention measures.

## 39.5 Conclusion

The space debris issue is a growing concern for all space-faring nations: the increasing population of objects orbiting the Earth represents a collision risk to operational satellite and also a risk on the ground in case of fragments surviving the reentry.

Ongoing actions aim at knowing the situation (observations, modeling) better and at protecting satellites through shielding and collision avoidance. In parallel, important actions are necessary to reduce the production of new debris through the implementation of mitigation measures such as the disposal of satellites and upper stages at the end of their operational life.

However, the problem being global, the solutions shall be agreed by all. An international consensus is therefore necessary:

- In the short term, the same rules shall be applied by all space actors. Mitigation measures have already been defined and approved at the international level. National regulation systems shall be now implemented by each country to ensure their immediate application by all operators.
- In the middle term the space community has to confirm the future instability of the space environment, even if the mitigation measures are fully applied, and to confirm the need to remove from orbit several objects per year.
- In the longer term active debris removal missions will require an increased international cooperation due to complex technical, economical, legal, and political issues.

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# Space Situational Awareness and Recognized Picture

# 40

Louis Leveque

## Contents

**Abstract**

Space surveillance is an old story that is linked with the "Cold War" period and the first Sputnik launch in 1954. For 20 years, this activity was performed in the USA and USSR with little European involvement.

Since the collapse of the Soviet Union, there has been a renewal of interest in space surveillance capability for two different communities.

The defense community interest is mainly linked with the proliferation of space-capable states that implies a new risk of space militarization.

The commercial community interest is mainly linked with the degradation of space environment including space debris, radio electric interference, and space weather consequences.

The two communities try to find a cooperative way to establish a common space surveillance reference.

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DOI 10.1007/978-1-4614-2029-3_46,

## 40.1 Introduction

“Recognized Space Picture” is a generic term that may designate different functions concerning a certain knowledge of man-made space objects.

Players, in the defense world such as Space Forces or Strategic Forces, usually speak of “Recognized Space Picture (RSP)” to designate their requirements for a surveillance function mandatory to perform space operations such as defensive/offensive counterspace or missile defense.

The RSP is the equivalent for the space domain of the “Recognized Air Picture (RAP)” that is commonly used in NATO air control centers (Fig. 40.1).

In the civilian world, space operators and space agencies are using the term of “Space Situational Awareness (SSA)” for the surveillance information they need to operate and control their satellite fleets from launch to end of life operations.

The SSA is the equivalent for the space domain of the information provided to the air traffic control centers (Fig. 40.2).

In this chapter, we try to understand these different meanings taking into account, of course, the historical point of view but also the technological and operational evolutions that may lead to a future situation concerning space surveillance for defense or commercial applications.

## 40.2 A Historical Summary: Space Surveillance and Nuclear Deterrence

From Sputnik-1 flight (Fig. 40.3), defense community has been interested by space surveillance.

The world was living the “Cold War” with regular tests of nuclear and thermonuclear bombs; the German V-2 technology was developed by both sides to be able to carry these new weapons directly to the adversary territory without possible alert.

We must also remember that the Sputnik-1 launcher, the R-7 (Fig. 40.4), was developed to carry, on a suborbital or ballistic flight, the only available nuclear bomb in Russia that was much heavier than the current thermonuclear reentry vehicles (RV) (Fig. 40.5).

Due to this technical constraint, this launcher was also able to put in orbit a smaller payload such as the Sputnik-1.

In order to detect potential launch of ballistic missiles from USSR, it was mandatory for the USA to be able to discriminate between orbiting objects and ballistic ones. So, it was decided to elaborate and maintain a “Space Object Catalogue” inside an organization called Space Track (Charles 1969).

This catalogue was elaborated using different optical ground stations operated by the armed forces of the USA and Canada. From the beginning, Canada was indeed associated to this network, due to the unique northern geographical location of this country. In fact, this location is really adequate to survey both satellite and ballistic missile launches above the North Pole.

**Fig. 40.1** Recognized Space Picture

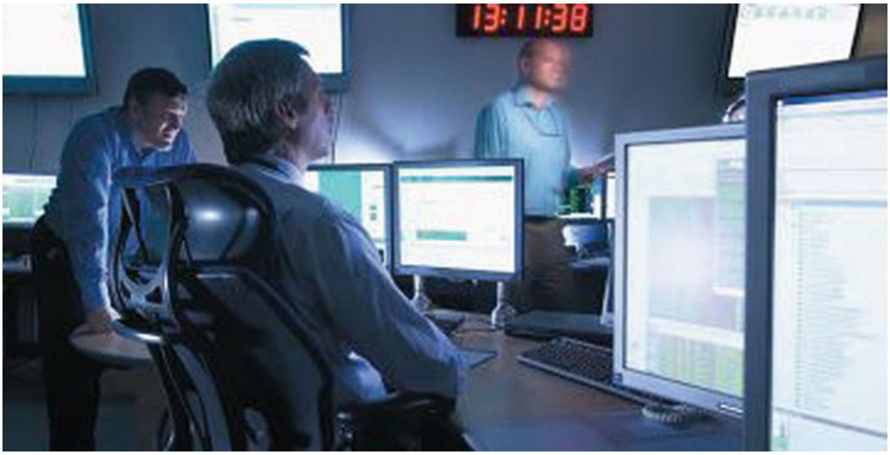

**Fig. 40.2** Space Situational Awareness

The Space Track network was composed of 15 stations using Baker-Nunn cameras (Fig. 40.6) scattered all over the world. The links between the stations were those of the fifties, and of course the computers for orbit determination were a little less powerful than the current PC.

## 40.3 From Space Dominance to Space Deterrence: The Recognized Space Picture

This first optical network was adapted to space surveillance but not adequate to detect ballistic missile launches. As a consequence, on both sides of the

**Fig. 40.3** Sputnik-1, 1954

North Pole, a radar network called Ballistic Missile Early Warning System (BMEWS) (Fig. 40.7) was deployed in the USA.

Of course, Sputnik-1 did not stay alone around the Earth and was soon followed by other satellites launched by the two leading nations of this cold war. As a consequence, the original optical network had to be reinforced with space fences (Fig. 40.8) able to detect new space objects, the tracking being performed with accurate optical stations.

As long as the satellite number was increasing, it was necessary to join the two networks, in order to reduce the false alarms caused in the BMEWS. On another hand, this first interoperability was also beneficial for the space surveillance network that could use the information provided by the BMEWS to improve its "Space Object Catalogue" accuracy (Sheehan 2009).

This situation lasted for 20 years until the first deployment of destabilizing missile defense systems in both leading countries of the "Cold War" and the establishment of treaties limiting the offensive and defensive ballistic weapons in the USA and USSR. These treaties were established because each country was able to verify the respect of the rules due to their respective "Space Dominant" position in the world.

**Fig. 40.4** R-7

**Fig. 40.5** Nuclear RV

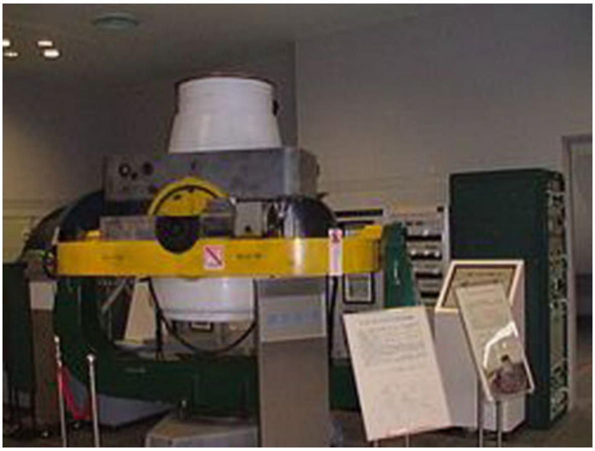

**Fig. 40.6** Baker-Nunn camera

**Fig. 40.7** Ballistic Missile Early Warning System (BMEWS)

During the same period (Laird 1984), this situation between the USA and USSR was also destabilized by the development of the French nuclear forces with the first ballistic missiles launched from silos (S-2 Albion) (Fig. 40.9) and nuclear-powered submarines (Le Redoutable) (Fig. 40.10).

France was adding a third player, of course, with limited offensive means, but in addition to this game-changing capability, this country also introduced its first space surveillance asset called Stradivarius that was settled in CELAR in Brittany (Fig. 40.11).

This capability was not acceptable by the NATO "Space Dominant" nation that wanted to keep its ability to operate in space without interference. We must remember that this capability was mandatory to monitor the USSR with respect to the treaties and, as a consequence, the survival of the USA in the Mutual Assured Destruction (MAD) concept.

**Fig. 40.8** Space fence

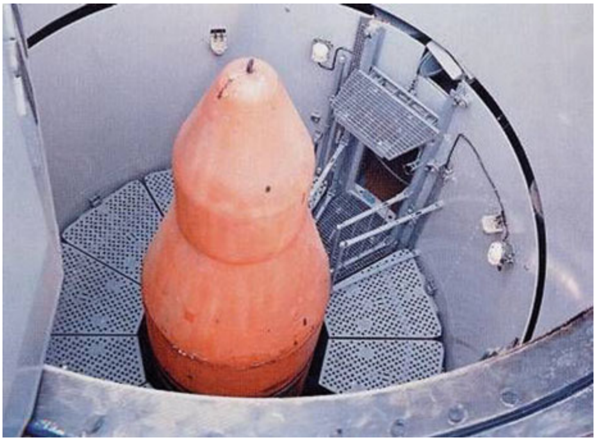

**Fig. 40.9** S-2

France and the USA thus find a cooperative agreement concerning the nuclear forces, but France was obliged to dismantle its space surveillance asset recognizing the “Space Dominant” role of the USA in NATO.

**Fig. 40.10** Le Redoutable

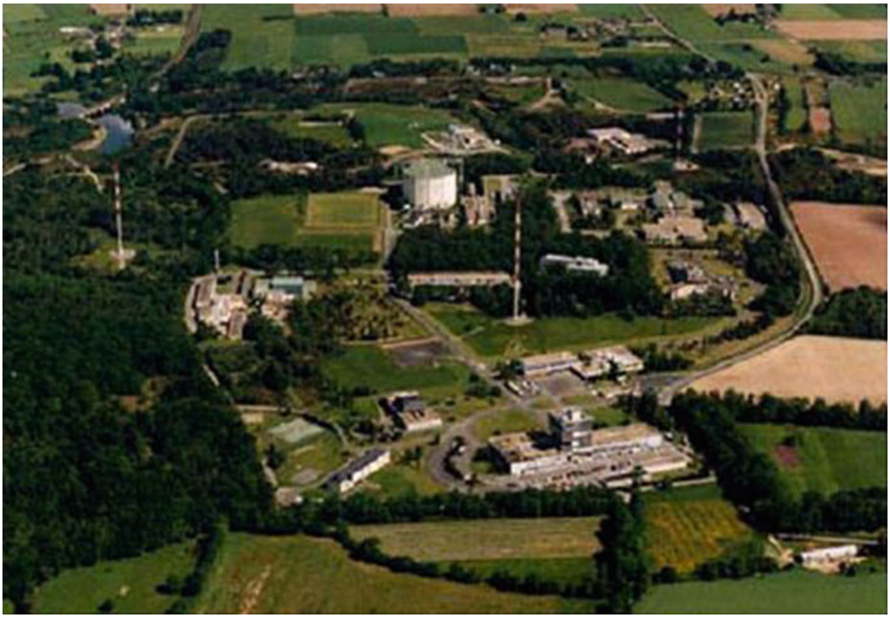

**Fig. 40.11** CELAR

**Fig. 40.12** Ariane-1

In exchange, Europe was allowed to develop its space access capability around the Ariane program (Fig. 40.12) that was possible thanks to the technical developments of the French industry responsible of the ballistic missile deployment.

The development of a commercial success in Europe in space access capability around Ariane family was performed during the following 30 years (Sinit 2009). During the same period, Europe was able to demonstrate its space capability in communication and observation satellites that are sold worldwide in competition with the ones in the USA.

This commercial evolution was the first European reaction concerning the US "Space Dominance" position.

For the space surveillance capability, Europe did respect the USA dominance until the end of the Cold War and the generalization of satellite use, not only for strategic purpose, but also at the operational level as force enhancement assets.

**Fig. 40.13** Overflying map of GRAVES

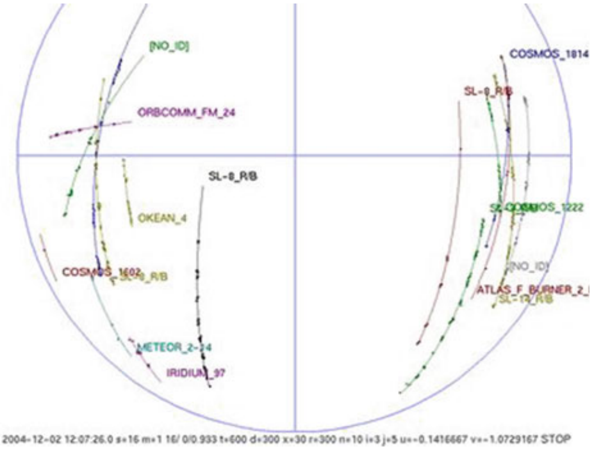

**Fig. 40.14** Helios

As a consequence, a European space surveillance capability was delayed until the end of the twentieth century with the development of the GRAVES (Fig. 40.13) demonstrator in France and TIRA in Germany. This French asset is able to detect all satellite overflying France in low Earth orbit and thus is used elaborately as a space catalogue independent of the shared US “Space Object Catalogue.” The German asset is more oriented towards the characterization of the space objects.

This capability to detect space objects included or not in the US “Space Object Catalogue” was used to find an agreement with the “Space Dominant” nation that deleted from its shared catalogue specific defense assets such as the military Earth Observation spacecraft Helios (Fig. 40.14).

This situation and the growing vulnerability of space assets to intentional or unintentional interference have triggered a doctrinal change in the USA that is now speaking of “Space Deterrence” instead of “Space Dominance” (Morgan).

This new doctrine is based on a risk sharing with allied countries and commercial entities for defense space assets. As a consequence, we may testify of this new doctrine through the development of new solutions such as the deployment of military payloads on board of commercial satellites or the transformation of the Joint Space Operations Center in a combined operation center including specific US allied nations.

The operations in this center are supported by the elaboration of a “Recognized Space Picture” that is the equivalent, for the space domain, of the Recognized Air Picture or RAP regularly elaborated in NATO air operations centers.

## 40.4 From Satellite Provider to Satellite Operator: The Space Situational Awareness

With the increase of satellites in orbit as well as the number of debris (see ▶ Chap. 38, “Various Threats of Space Systems” of Sect. 3 in this handbook), the alerts publicly issued by JSpOC have demonstrated to be inaccurate and with limited use to prevent collisions, as demonstrated by the Iridium33/Cosmo2251 collision of February 2009. Furthermore, the conjunction summary messages (CSMs) from JSpOC, which are based on projections of radar tracks, fall short of position data for radio interference maintained by the world’s major satellite operators by about two orders of magnitude, according to Richard DalBello, vice president, legal and government affairs, of Intelsat General. “We discovered that the majority of conjunctions, or close approaches, were missed by the Joint Space Operations Centre, and the majority of conjunction summary messages that went out advising us of close approaches were wrong,” DalBello said during a February 23, 2012, Washington conference on Space Situational Awareness organized by the Techamerica Space Enterprise Council and the George C. Marshall Institute. “So the bottom line is that the current products that are in use are not adequate for safety of flight, and indeed more recently we’ve been cautioned by the JSpOC are not actionable, and that they’re actually more or less advisory.”

This illustrates the real difference between “Recognized Space Picture (RSP)” as defined by the defense community and the “Space Situational Awareness (SSA)” required by satellite operators.

As a consequence, satellite operators have decided to regroup themselves in a Space Data Association (Space Data Association). The SDA is a nonprofit organization that brings together satellite operators who value controlled, reliable, and efficient data sharing critical to the safety and integrity of the space environment and the radio frequency spectrum.

The SDA was founded in 2009 by Inmarsat, Intelsat, and SES – three of the leading global satellite communications companies. By collecting and analyzing its authoritative radio frequencies, close approach, ephemeris, and points-of-contact data, the SDA’s Space Data Center performs “Space Situational Awareness” and threat mitigation analyses with previously unachievable accuracy and expedience. By mid-2011, the SDA membership spans both geostationary (GEO) (Fig. 40.15) and low Earth orbit regimes and now provides conjunction analysis processing for more than 60 % of all operational satellites in GEO.

The Space Data Association, which collects position information from 15 operators on 237 geostationary satellites and other 110 ones in low Earth orbit

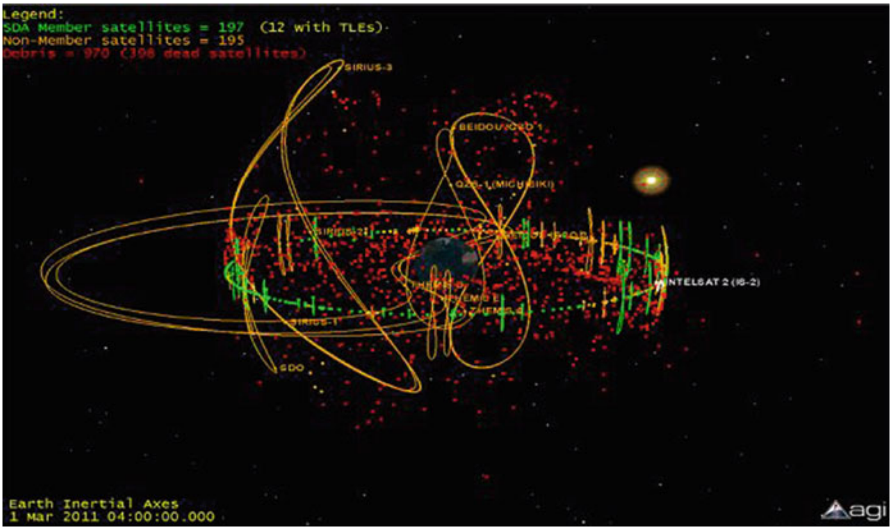

**Fig. 40.15** Example of GEO space situation

provided by seven operators, ran tests in 2011 comparing its data with the Conjunction Summary Messages (CSMs) provided by the US Joint Space Operations Centre (JSpOC), an element of the US Strategic Command.

To illustrate the associated challenges, it is worth to recall all the phases of a geostationary spacecraft where such a “space traffic” management is needed.

Up to 1998, telecommunications satellites were delivered to their geostationary orbit and validated by the space agencies (CNES, DLR, etc.); nowadays, this function is performed by satellite providers such as Astrium (Fig. 40.16).

The delivery phase starts at the moment when the satellite separates from the launcher. This is when the LEOP (Launch and Early Orbit Phase) teams take control of the spacecraft. For 10 days, between 30 and 40 specialists work shifts around the clock, to ensure the satellite is correctly delivered to geostationary orbit. They then monitor and control the satellite for a period of 1 month up to its final commissioning, the final step before “handing over the keys” to the customer.

At the very moment of launch, all members of the teams have their eyes glued to their screens, waiting for the first “squeak” from the satellite. Making contact is the initial step in the process. The control center must be hooked up to a network of ground stations located around the world for this purpose, so as to be able to acquire the satellite, irrespective of its position round the globe, during the initial phases of the mission.

When the first signal is picked up, the control center can then monitor initialization operations for the satellite subsystems (attitude control, power, propulsion, etc.).

Once the satellite is in cruise mode, the control center can initiate orbit circularization from the injection orbit (geostationary transfer orbit) to the final one. This involves positioning the satellite in the geostationary orbit at an altitude of

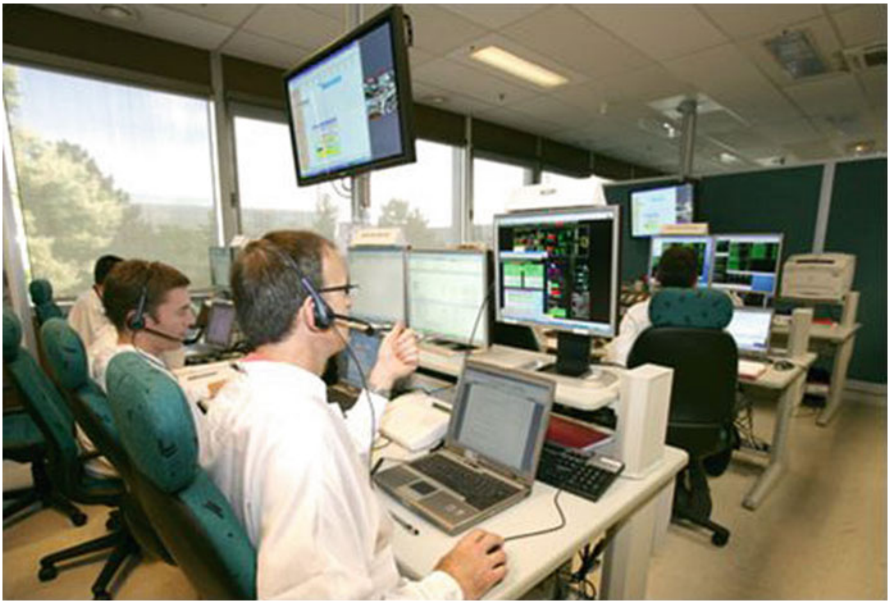

**Fig. 40.16** Control room

36,000 km in the equatorial plane, with three or four apogee motor firings, calculated and optimized by the orbit specialists in the Flight Dynamics teams.

Once the geostationary orbit has been acquired after around 6–8 days, deployment of the solar panels and antenna reflectors can begin. This phase takes between 1 and 2 days. The last step is finally the Earth acquisition, where the satellite is pointed at the Earth so as to be able to receive and transmit operational signals. This concludes the orbit acquisition process lasting about 10 days post launch.

All that remains is for the satellite to acquire its operational longitude and for the LEOP teams to validate its satisfactory operation.

The in-orbit test (IOT) phase can then start and is conducted in two parts. The first part is to verify satisfactory operation of the platform (platform IOT) and is conducted by the LEOP team. These tests are executed while the satellite drifts towards the longitude of its operational slot on the geostationary orbit. The second part is payload testing (payload IOT) and is usually directed from the customer's premises with on-site support from the industrial provider engineers. The LEOP center remains on standby, ready to take over the control of the satellite at any time if an abnormal situation develops. About 20 days are usually required to complete all in-orbit tests and make final, official delivery of the satellite to the customer (Bonaventure and Gicquel 2011).

In order to perform these operations, satellite operators need to elaborate a "Space Situational Awareness" function taking into account the exact location and status of their controlled asset.

This could be sufficient if the controlled satellite was alone in space, but it is far from the current reality because space is crowded not only with operational satellites but also with the vast quantity of debris accumulated since Sputnik-1 (see the issues of space debris in ▶ Chap. 38, "Various Threats of Space Systems" of Sect. 3).

## 40.5 Operational and Technical Tendencies: A Private-Public Partnership

From the defense point of view, we have seen sensitive operational changes in the doctrine of the USA. As an example, Patrick Frakes of Integrity Applications Incorporated, who served as director of space policy in the Office of the Secretary of Defense, said, during a Feb. 23, 2012, Washington conference on Space Situational Awareness organized by the Techamerica Space Enterprise Council and the George C. Marshall Institute: "*U.S. space policy has sent conflicting signals to U.S. government operators, particularly under the administration of President George W. Bush, when the secretary of defence was responsible both for providing space situational awareness (SSA) to the military, intelligence organizations and civil and commercial spacecraft operators, and for protecting "sensitive" SSA info.*" That changed when President Barack Obama took office and ordered a series of space policy studies through the National Security Council. That led to a refocusing of SSA on preserving the space environment and the responsible use of space. "*There's a how and a way in the policy statement, as opposed to what went before*."

On another hand, we can see a new maturity in the civilian world with the SDA charter that:

- Seeks and facilitates improvements in the safety and integrity of satellite operations through wider and improved coordination between satellite operators
- Seeks and facilitates improved management of the shared resources of the space environment and the radio frequency spectrum

This is a basis of a new cooperation potential for the two worlds.

If we consider now the technical tendencies, we can see a revolution from the Baker-Nunn cameras of the fifties and capabilities of the optical sensors of the twenty-first century.

In order to illustrate this revolution, we shall use the technical data elaborated by private companies in Russia.

The first revolution is the generalization of the Internet that allows a global connection of unattended sensors scattered all over the world.

This opportunity opens the way of a network of unattended optical and radio frequency stations either dedicated to specific satellite operators or scattered all over the world to support the conjunction analysis performed by a global entity such as SDA.

This capability has been recognized by different countries, and to illustrate this, we shall use a Russian industrial presentation in order to emphasize the fact that space surveillance is no longer limited to defense and institutional community but

НАЗНАЧЕНИЕ:

- ☐ Автономное обнаружение в широком угловом секторе низкоорбитальных и высокоэллиптических объектов
- ☐ Получение измерений для расчета целеуказаний оптическому комплексу сопровождения и точного измерения угловых координат

ХАРАКТЕРИСТИКИ

| | |
|---|---|
| Число телескопов | 1-5 |
| Апертура телескопа | 12-15 см |
| Поле зрения телескопа | до 15° x 15° |
| Обнаружительная способность | |
| для низкоорбитальных КО | до $10^m$ |
| для высокоэллиптических КО | до $12^m$ |
| Размер CCD матрицы | 4008x2672 |

**Fig. 40.17** Detection of space objects

that it is now supported by commercial and industrial community with capacities available in the whole world.

Second, we have seen the generalization of high-performance domes, optical telescopes, mechanical support, and CCD cameras for detection of space assets on all orbits compatible with Recognized Space Picture (RSP) requirements (Fig. 40.17).

This capability linked with accurate star catalogue and accurate time delivery through Global Navigation Space Systems (GNSS) opens the way to accurate tracking devices compatible with Space Situational Awareness (SSA) requirements (Fig. 40.18).

Finally, it is also possible to link to this network, radio frequency interference systems compatible with SDA requirements (Fig. 40.19).

Of course, if we consider the current economical situation, such a system may not be deployed by the defense world only, and we should consider a private-public partnership involving the space industry, the satellite operators, and the institutional organizations.

This should be possible only if space surveillance data exchange may be organized taking into account not only institutional data policy rules but also commercial requirements.

**НАЗНАЧЕНИЕ:**

- ☐ Обнаружение космических объектов по целеуказанию
- ☐ сопровождение и высокоточное измерение их угловых координат и фотометрических характеристик

**ХАРАКТЕРИСТИКИ**

| | |
|---|---|
| Апертура телескопа | 40 см |
| Поле зрения телескопа | до 3° x 3° |
| Максимальная звездная величина для низкоорбитальных КО | до $12^m$ |
| Максимальная звездная величина для высокоэллиптических КО | до $14^m$ |
| Максимальная угловая скорость поворота | до 3 |

**Fig. 40.18** Tracking of space objects

**НАЗНАЧЕНИЕ:**

Обнаружение излучений космических аппаратов и измерение их радиотехнических параметров

**ХАРАКТЕРИСТИКИ:**

Режимы работы:
обзорный и сопровождения
Диапазон: до 2.5 Ггц
Зона действия:
-по углу места 0-90 градусов,
-по азимуту 0-360 градусов

**Fig. 40.19** Radio interference monitoring

## 40.6 Conclusions

In this short paper, I try to analyze the evolution of space surveillance in terms of users' communities and technical capabilities.

It appears that the defense community has a specific requirement linked with its mission. This requirement is not constant versus time. As an example, it was initially to discriminate between orbiting objects (Sputnik) and ballistic vehicles. With the introduction of missile defense mission within NATO, the emerging requirement could be to discriminate between space debris and potential reentry vehicle. And we may imagine, in the future, a requirement linked with counterspace mission control.

The commercial community has a different requirement linked with the proliferation of man-made space debris, interference in the radio electric spectrum, and consequences of space weather events.

In order to illustrate this difference, we can take the example of "space submarines," that is to say, space objects that the defense community tries to hide among the space debris. The commercial community is not interested by a "space submarines" catalogue due to the fact that they do not need to avoid collision with nonexisting objects as in the maritime world. It is the responsibility of the defense community to avoid these potential collisions.

On another hand, the commercial community is very interested by old launcher stage debris if this object may collide with an operational commercial satellite. This specific debris that has no defense interest may be the higher priority for tasking and scheduling space surveillance sensors in the commercial community.

This short description indicates that even if the sensors may be the same for the defense and commercial world, their planning and tasking is different for the two systems due to the fact that the priority is not the same for the two communities. Moreover, the data obtained through the space surveillance sensors management has not the same confidentiality for the two worlds. A "space submarine" is highly classified for the defense community but has no interest for the commercial community.

This opens the way to a global analysis concerning the communality of Recognized Space Picture (RSP) and Space Situational Awareness (SSA).

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# Part IV

# Space Security Programs Worldwide

# Space Security Programs Worldwide: An Introduction

# 41

Christina Giannopapa

## Contents

**Abstract**

The following chapter provides an introduction to Part 4 of the Handbook concerning articles by specialist in the field of space security programs worldwide. It covers expert view on the launch and satellite programs of the spacefaring nations and those that have recently emerged. Additionally it covers space situational awareness and space weapons concepts.

## 41.1 Introduction

Space activities in the past were only the privilege of the governments of few faring nations. Over the past years there has been an increase in space activities, and the number of nation interested in space has increased. Space programs are designed around two main political arguments: access to independent information to support government interests and access to critical technologies and capabilities.

The governments' space programs have traditionally been designed to respond to programmatic objectives-related launchers and satellites, and nowadays also include applications. The launchers and satellite programs, civilian or military

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oriented, are often developed to reflect security objectives. The dual nature of space technologies and applications makes it difficult to strictly define space security programs in isolation.

In the twentieth century launcher programs were closely related to classified military projects demonstrating intercontinental ballistic missile capabilities (ICBM). Over the years they have seen a gradual level out to commercial launches separated from the military activities. Many countries still consider their launch program as a priority being the starting point for an independent access to space. Today besides the United States and Russia, capabilities to put satellites in orbit have also the European Space Agency, Japan, China, India, Iran, and Israel. Brazil is also close to acquire this capability. Most of these countries or agencies are offering services also on a commercial basis providing through their launch vehicles access to put satellites to space to many more countries around the world.

On 4 October 1957 the Soviet Union's space program put in space the first artificial satellite Sputnik 1. Initial satellite programs were fulfilling science and military objectives. Today, there are more than 50 countries in all continents that have a satellite in orbit. Almost 1,000 operational satellites are now in orbit with diverse Earth observation, telecommunications, navigation, and positioning missions. In parallel to the growing importance of these down-to-earth applications, science and space exploration remain key missions of space agencies, invigorating international scientific cooperation. The United States leads with more than 350 satellites in orbit, followed by Russia. The new landscape of space-faring nations is the result of two trends: the ambition of many countries around the world to develop independent national space programs and the globalization of the aerospace and defense industry.

This chapter of the handbook introduces different launch and satellite programs of space-faring nations like the United States, Russia, Europe, Japan, China, and India as well as emerging countries like Brazil. The chapter also includes papers on concepts and international implications of space weapons and space situational awareness concepts worldwide.

## 41.2 Space Security Programs of States

The United States launch program includes a number of launch options and over the years has increased its commercial side. The United States launch vehicles can place payloads in orbit from a few hundred kilograms to heavy payloads. In addition to orbital vehicles, they have a number of suborbital space launch systems, including vehicles under development for carrying people for tourism or research purposes. Despite of the success of the United States launch program, currently there is no orbital human space flight vehicle.

Russia can be considered today as having the most complete launch program in the world. Russia currently operates four types of launch vehicles, the Rockot, Soyuz, Zenit, and Proton. The launch vehicles are operated from two main launch sites, Baikonur and Plesetsk, while the third one in Vostochny is currently under construction. Russia today together with China is the only one in the world with capability for human space flights in low Earth orbit, and Russia is the sole provider of human transportation to the International Space Station. Russia over the past two decades has been offering its launching capacities for international and commercial uses. Russian launchers are among the leaders in the global launch market due to their high quality, cost efficiency, and compliance with the customer requirements.

The European launch program is developed and implemented though the European Space Agency. It is based on the joint cooperation of the Agency’s 20 member states, their national space agencies, industry, and Arianespace which is the company responsible for the operations and exploitation of Europe’s launch capabilities. Arianespace for over 30 years has become the global point of reference for commercial missions. The European family of launchers includes the Ariane 5, Vega, and Soyuz that secure Europe’s independent access to space and are launched through the Guiana Space Centre. The adapted European version of the most used and most reliable launcher in the world, the Soyuz, provides the potential for Europe with additional modifications should it decide to the possibility for human space flight. The evolution of the launchers program will be one of the subjects of discussion at the next ESA Ministerial Conference in 2014.

The Japanese launch program has progressed mainly for space science and space utilization. Its unique characteristic is that it has been promoted only for peaceful purposes. The key technologies of launchers are maintained and evolved by the government and Japan Aerospace Exploration Agency (JAXA) in cooperation with academia and industries. Japan has two types of launch vehicles. These are the liquid propulsion ones H-IIA and H-IIB launched from the Tanegashima Space Center and solid rocket Epsilon launched from the Uchinoura Space Center.

China has been sticking to the self-reliance and independent innovation path in its launch program. After 40 years of experience, China has developed a number of launch vehicles. The Long Mach is its primary expendable launch system family. There are three launch sites in China: Jiuquan, Taiyuan, and Xichang; currently there is fourth one under construction, the Wenchang Launch Center. China is continuously strengthening the construction of space transportation systems, further perfecting the completeness of LM launch vehicles, enhancing the ability of access to space, and developing a new generation of launch vehicles and upper stages. China puts the development of space industry as an important part of the country’s overall development strategy.

The Indian launch program started with the vision to utilize the potential of space technology and its applications for national development in the 1960s. India has made significant progress in launch vehicle technology. Today India’s efforts in launchers are undertaken by the Indian Space Research Organisations (ISRO). Over the years India has been developing the Satellite Launch Vehicle which retired in 1984: the Augmented Satellite Launch Vehicle; the Polar Satellite Launch Vehicle; and the Geosynchronous Launch Vehicle, and is making efforts for Reusable Launch Vehicles. ISRO has established launch complex at the Satish Dhawan Space Centre.

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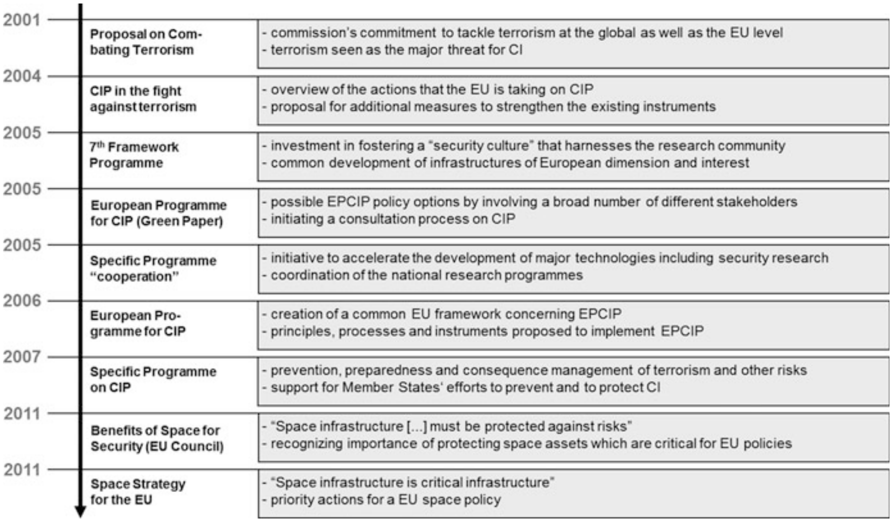
| 1997 | Protecting America's Infrastructures | - first report of Clinton's new Commission on CIP recognized nation's dependency on national CI<br>- recognized the extensive use and future dependence on GPS, which was identified as CI |
| 1998 | Clinton Administration's Policy on CIP | - with his 63rd Presidential Decision Directive, Clinton raised CIP to a national issue and goal<br>- aimed at an evaluation of vulnerability of GPS and GPS-based transportation infrastructure |
| 2002 | Homeland Security Act | - marked the starting point of a new US risk management and included the CI information act<br>- considered satellites as CI, especially as main requirements for telecommunication systems |
| 2002 | National Strategy for Homeland Security | - aimed at providing a framework for organizing the nation to contribute to a safer homeland<br>- strategy underlined the role of satellite-based services in field of homeland security in general |
| 2003 | Physical Protection of CI and Key Assets | - strategy allocated the responsibilities to provide best sector-specific CI and key asset protection<br>- failure to explicitly recognize space as sector of CI and to clarify space CIP responsibilities |
| 2003 | National Strategy to Secure Cyberspace | - strategy's objectives were prevention of CI from cyber-attacks and reduction of cyber vulnerability<br>- identified the DHS as lead agency for protection of information and communication satellites |
| 2003 | CI Identification, Prioritization, and Protection | - Bush's Presidential Directive established policy for departments and agencies to identify CI<br>- failure to identify specific space CIP agencies due to the cross-cutting character of space CI |
| 2006/09 | National Infrastructure Protection Plan | - DHS documents aimed at active cooperation between the many partners involved in CIP<br>- for the first time, this US CIP milestone recognized cross-cutting character of space applications |
| 2010 | National Security Strategy | - new administration brought changes for CIP, reflected by Obama's "National Security Strategy"<br>- space obviously mattered: strategy constantly mentioned space in line with cyberspace |

**Fig. 41.1**

Brazil has started its first steps into the space arena in the early 1960s. Since then it has made significant progress and is close to acquire launch capabilities. Its launch program has evolved from sounding rockets to the development of the launch vehicles VLS (Veiculo Lancador de Satelites) and VLM (Veiculo Lancador de Microssatelites). The first flight for VLS is expected in 2015. Brazil's space port is Alcantara Launch Centre. Another important part of the Brazilian space launch program is its cooperation with Ukraine for building and launching Cyclone 4 from its space port.

The satellite programs of the United States military and intelligence organizations provide services in telecommunications, surveillance, missile early warning, meteorology, positioning/timing, radio interception, nuclear detonation, and data relay. The United States has a unique capability of deploying military satellites of all types and on a global basis. Its military space program overshadows the military space programs of all other countries combined and that of civilian agency. This is expected to continue in the years to come.

Satellite programs in Europe can be divided to institutional, national, and multinational. The institutional satellite programs are developed by European supranational actors which are the European Space Agency with a number of satellite missions, EUMETSAT with meteorological missions and the European Union with the Galileo system for navigation and positioning, and the Copernicus (former GMES) system for environment and security. The three main European institutional actors are getting more involved in satellite programs for security purposes by utilizing the dual use approach and taking advantage of broad



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| 2001 | Proposal on Combating Terrorism | - commission's commitment to tackle terrorism at the global as well as the EU level<br>- terrorism seen as the major threat for CI |
| 2004 | CIP in the fight against terrorism | - overview of the actions that the EU is taking on CIP<br>- proposal for additional measures to strengthen the existing instruments |
| 2005 | 7th Framework Programme | - investment in fostering a "security culture" that harnesses the research community<br>- common development of infrastructures of European dimension and interest |
| 2005 | European Programme for CIP (Green Paper) | - possible EPCIP policy options by involving a broad number of different stakeholders<br>- initiating a consultation process on CIP |
| 2005 | Specific Programme "cooperation" | - initiative to accelerate the development of major technologies including security research<br>- coordination of the national research programmes |
| 2006 | European Programme for CIP | - creation of a common EU framework concerning EPCIP<br>- principles, processes and instruments proposed to implement EPCIP |
| 2007 | Specific Programme on CIP | - prevention, preparedness and consequence management of terrorism and other risks<br>- support for Member States' efforts to prevent and to protect CI |
| 2011 | Benefits of Space for Security (EU Council) | - "Space infrastructure [...] must be protected against risks"<br>- recognizing importance of protecting space assets which are critical for EU policies |
| 2011 | Space Strategy for the EU | - "Space infrastructure is critical infrastructure"<br>- priority actions for a EU space policy |

**Fig. 41.2**

definition of security and its application to a number of policies like transport and environment. At the national level, a number of European countries have been developing their satellite programs caring different types of sensors though their own national programs. More than 30 European remote sensing satellites are currently operating or are planned for launch by individual countries or jointly with others. Some of these are dedicated military satellites, others are dual use, and others are civilian or commercial satellites capable of providing data for security purpose upon request. Multilateral cooperation between European countries provides the possibility to develop high quality systems in a cost-effective way by pulling together needs and resources. This applies equally to the civilian as well as in defense and security domain. The Multinational Space-based Imagery System (MUSIS) is such an example. It is the initiative of France, Germany, Greece, Italy, Poland, Spain, and Sweden in the joining, aiming to produce surveillance, reconnaissance, and observation capabilities, as required in the time horizon of 2015–2030.

Chinese satellite programs cover Earth observation, communication and broadcasting, navigation and positioning, and scientific and technological test satellites. Until the end of 2011, China had successfully developed and launched 144 satellites.

The increasing number of space activities and satellites in orbit increases concerns on how to protect space assets. Space situational awareness (SSA) is a key enabler for detecting and protecting against threats faced by space assets. SSA is a complex topic that is not always used in the same way. However, it can generally be defined as information about the space environment and activities in space that can be used to operate safely and efficiently; avoid physical and electromagnetic interference; detect, characterize, and protect against threats; and understand the evolution of the space environment. Currently SSA is one of the most important topics in space security. The United States operates the largest SSA program in the world and Russia the second largest. Individual countries in Europe have partial capabilities and ESA since 2009 has started to implement an SSA optional program with financial participation by 14 Member States.

Overall, in space security, investments have fluctuated following the United States Department of Defense procurement strategy and this expected to continue for the largest part. A priority in the agenda of governments is protecting the space assets. Space security investments will also be driven by countries like Russia and new entrants in the field like Japan and Ukraine. Global spending is expected to reduce to $2.3 billion (€1.70 billion) level by 2017 and should recover by the end of the decade to $3 billion (€2.20 billion) driven by procurements of next generation systems (Euroconsult 2013).

## 41.3 Conclusions

Space programs aiming at the development and utilization of space technologies and applications constitute an essential part of capabilities in the security domain related to both civil and defense. The dual nature of space technologies and applications makes it difficult to strictly define space security programs in isolation. As the number of countries involved in space activities is increasing, there is an increasing need for ensuring both space for security and security in space.

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# United States Space Launch Programs

# 42

Jeff Foust

## Contents

### Abstract

The United States has an extensive array of launch options. This chapter addresses US space launch programs from two perspectives. The first is via policy: the various means, from executive branch policy documents to legislation, that the US government shapes the goals and direction of both government and commercial launch services. The second is via technology: an examination

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of the major orbital and suborbital launch vehicles in service today or under development by both government agencies and private companies and how well these vehicles meet the goals laid out in national policy.

## 42.1 Introduction

Space launch is an essential element of overall space security, and as one of the world's leading spacefaring countries, the United States has an extensive array of launch options. US vehicles in service today can place payloads in orbit ranging from a few hundred kilograms to more than 22,000 kg, with vehicles under development that will be capable of much heavier payloads. In addition to orbital launch vehicles, there are a number of suborbital space launch systems, including vehicles under development designed to carry people for tourism or research purposes.

However, US space launch programs have a number of problems as well. There is currently no orbital human spaceflight vehicles in service, with the retirement of the Space Shuttle in 2011, although several new vehicles are in development. High launch costs have eroded the American share of the global commercial launch market to nearly zero and have created budgetary pressures for government programs as well. New vehicles and markets, though, may address these concerns by lowering launch costs and increasing demand for launch services.

This chapter addresses US space launch programs from two perspectives. The first is via policy: the various means, from executive branch policy documents to legislation, that the US government shapes the goals and direction of both government and commercial launch services. The second is via technology: an examination of the major orbital and suborbital launch vehicles in service today or under development by both government agencies and private companies and how well these vehicles meet the goals laid out in national policy.

## 42.2 Space Transportation Policy

In the United States, space transportation policy is defined through several mechanisms. Each presidential administration establishes its own National Space Policy, and many have developed specific policies regarding space transportation. While successive administrations establish their own policies, each iteration of these policies often maintains provisions similar to previous iterations. Policy is also created by legislation passed by the Congress and signed into law by the President. This legislation includes appropriations bills that implement or even make policy by funding, or not funding, specific programs. Policy can also be shaped by regulations created by government agencies, such as the Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST), which can implement and further refine the broader policies enacted by the President and Congress.

In general, the space transportation aspects of these policies have been designed first and foremost to ensure that the nation has what is usually referred to as "assured access to space," that is, that the US government is able to launch satellites and other payloads into space without having to rely on a foreign power. The clearest manifestation of this policy has been with the Evolved Expendable Launch Vehicle (EELV) program, initiated in the 1990s to develop a new generation of launch vehicles to meet government and commercial needs. The Defense Department in 1998 elected to fund development of two launch vehicle families, the Atlas V from Lockheed Martin Corporation and the Delta IV from The Boeing Company, in order to meet that policy goal of assured access. That decision has had a significant impact on national space transportation policy since then.

A secondary goal of national space transportation policy has been to promote the nation's commercial space transportation industry. Both executive branch policy and legislation have sought to stimulate development of commercial systems that can also meet government space transportation needs. For example, the purpose of FAA/AST is not only to regulate the commercial space transportation industry but also to "encourage, facilitate, and promote" the industry, a dual mandate that the FAA in general had for aviation until the 1990s. NASA-led initiatives, such as funding development commercial cargo and crew transportation systems for supporting operations of the International Space Station (ISS), are in a similar vein. These policies have had limited success, at best, to date: in 2011 the United States performed no commercial orbital launches, as high launch costs pushed customers to launch systems operated by Europe, Russia, and China.

NASA's specific space transportation requirements, particularly for human spaceflight, also play a role in space transportation policy. The loss of the Space Shuttle Columbia on February 1, 2003, led to a revision in NASA's human spaceflight programs announced in January 2004, which called for the retirement of the Space Shuttle by 2010 and the development of successor launch systems, later named the Ares I and Ares V. The Obama Administration revisited that policy and cancelled those systems; debate with the Congress led to plans to develop a new heavy-lift launch vehicle called the Space Launch System (SLS).

### 42.2.1 Executive Branch Space Transportation Policy

The highest level of space transportation policy in the United States is the National Space Policy. The administration of President Barack Obama released the current version of the National Space Policy in June 2010. The policy covers all aspects of national space activities, both government and commercial. One of several "foundational activities and capabilities" in the 2010 policy is to "enhance capabilities for assured access to space." The policy reiterates that US government payloads will be launched on American vehicles unless explicitly exempted by the White House. That section of the policy also calls for modernizing space launch infrastructure, acquiring cost-effective launch services, and developing technologies "necessary to assure and sustain future reliable and efficient access to space."

In addition to the language in the National Space Policy, there is a separate, and more detailed, US Space Transportation Policy. The current version of that policy was authorized by President George W. Bush in December 2004, although as of late 2012 the Obama Administration was developing an updated version of the policy, expected to be released in the near future. As with the overall National Space Policy, the US Space Transportation Policy emphasizes the importance of assured access to space, calling it "a requirement for critical national security, homeland security, and civil missions."

The US Space Transportation Policy established the EELV program as the key launch system for medium-sized and larger government payloads, but called upon the Defense Department, NASA, and the Central Intelligence Agency to make long-term plans for how costs for the EELV should be allocated among those agencies in the long term. The policy also endorsed, for smaller payloads, a concept called Operationally Responsive Space (ORS) that makes use of smaller launch vehicles and payloads that can be prepared and launched on much shorter timescales than conventional missions in order to meet national security needs, particularly in times of crisis.

In the area of commercial space transportation, the policy states that the US government seeks to encourage the development of a commercial launch industry in the country and will make several efforts to either acquire commercial launch services or provide a regulatory environment that supports it. The policy in particular states that the government will not compete with commercial launch providers unless required to support national security. To that end, the policy states that launch vehicles using components from excess ballistic missiles can only be used to launch payloads for missions sponsored by a US government agency and provides cost savings to the government. This is a continuation of previous policies enacted to address industry concerns that retired intercontinental ballistic missiles (ICBMs) would flood the market, particularly for launches of small payloads.

### 42.2.2 Legislative Branch Space Transportation Policy

The US Congress does not treat space transportation as a separate topic addressed by stand-alone legislation, but instead typically as sections of other legislation. National security space transportation needs are addressed as part of overall Defense Department legislation, including annual authorization and appropriations bills that set policy and fund programs, respectively. In recent years, these bills have expressed concerns about the growing costs of the EELV program and a desire to introduce competition into the program. The fiscal year 2013 defense authorization bill, in the final version passed by both houses of the Congress in December 2012, includes language that withholds 10 % of the funding for EELV program in 2013 until the Defense Department provides a report describing its future acquisition strategy for the EELV program, including opportunities for new entrants to win launch contracts under the program.

Civil space transportation policy, in particular NASA's unique requirements for human spaceflight and deep space exploration, is addressed by the Congress through appropriations bills – NASA is part of the larger Commerce, Justice, Science, and Related Agencies Appropriations Bill in both the House and Senate – and, less frequently, in stand-alone authorization bills. The Congress passed in 2010 the most recent NASA authorization bill, covering fiscal years 2011 through 2013.

That 2010 Authorization Act specifically identified the development of the SLS heavy-lift rocket as national policy to "access cis-lunar space and the regions of space beyond low-Earth orbit in order to enable the United States to participate in global efforts to access and develop this increasingly strategic region." The SLS, as defined in the act, will have an initial capability of 70–100 mt to low Earth orbit (LEO) and be capable of being enhanced to a payload capacity of 130 mt. The act also requires that the initial version of the SLS be ready to enter service by the end of 2016.

The act also authorizes development of a commercial crew transportation system by NASA. That effort, first announced by the Obama Administration earlier in 2010, is patterned after the ongoing effort to develop commercial cargo transportation systems to support ISS operations after the retirement of the Space Shuttle. Two companies, Orbital Sciences Corporation and Space Exploration Technologies Corporation (SpaceX), received awards under NASA's Commercial Orbital Transportation Services (COTS) program to develop launch vehicles and spacecraft to service the ISS and also perform other launches for government or commercial customers. SpaceX's Falcon 9 rocket, developed under the COTS program, made its initial launch in June 2010 and performed COTS test flights in December 2010 and May 2012. Orbital's Antares (formerly Taurus II) rocket made its first flights in April and September of 2013.

The commercial crew program, unlike the cargo program, is focused more on the development of spacecraft rather than launch vehicles. However, advocates of the program believe that the program will open up new markets, ranging from space tourism to supporting operations of privately developed space stations, like the facilities under development by the Bigelow Aerospace. These markets will stimulate additional launch demand and that can lower costs of individual launches.

Commercial space transportation policy is addressed less frequently than national security or civil space transportation policy and usually in stand-alone bills. The most recent major change in commercial space transportation policy was the Commercial Space Launch Amendments Act of 2004, passed by the Congress and signed into law in late 2004. That legislation, enacted around the time SpaceShipOne won the $10-million Ansari X PRIZE for commercial human suborbital spaceflight, confirmed that such flights were considered launches and thus could be licensed by FAA/AST, rather than treated as high-altitude aviation and thus under the jurisdiction of another part of the FAA. The legislation also allowed the FAA to award experimental permits for vehicles undergoing test flights and not yet ready for commercial operations (and thus a full launch license) and placed limits on the passenger safety regulations it can enact for commercial human spaceflight vehicles for several years after the bill's enactment, in order to give the industry a learning period and develop best practices.

Another commercial space transportation policy issue addressed by the Congress on a regular basis is the third-party indemnification. As a party to the Outer Space Treaty, the United States is responsible for any damages caused by its space activities, including those by companies or nongovernment organizations launching from the United States. As part of that treaty responsibility, FAA/AST requires commercial launch license applicants to demonstrate financial responsibility – usually in the form of an insurance policy – to cover what the agency calculates to be the maximum probable loss (MPL) to third parties in the event of a launch accident. To help mitigate the risk of catastrophic losses that could wipe out a commercial launch provider, the US government indemnifies commercial launch providers for any losses about the MPL level, up to an additional $2.7 billion. Any losses above that level are the responsibility of the launch provider. There has never been an American commercial launch accident with third-party losses above the MPL level.

This launch indemnification system has been in place in the United States since 1988, although it requires periodic action by the Congress to renew it. On some occasions in the past, the Congress has mandated studies to determine if the indemnification system is still needed, out of concerns that its continuation could put the government at risk for a significant liability in the event of a catastrophic launch accident. The current indemnification system was extended by Congress in early 2014 through the end of 2016.

## 42.3 Government Launch Systems

In the United States, most launch systems are owned by companies and are, at least in principle, available for either government or commercial customers, although for many of these vehicles the only customer is the US government. However, there have been launch systems that are owned by US government agencies for their exclusive use. A past example is the Space Shuttle, whose orbiters, booster rockets, external tanks, and other components were built by companies but owned by NASA. (Shuttle operations were initially also performed by NASA, but contracted out in the mid-1990s to United Space Alliance, a joint venture of Boeing and Lockheed Martin.) These vehicles have typically been required to perform missions unique to the government, such as launching astronauts. Similarly, the Space Launch System (SLS) currently under development will be owned by NASA for its use performing exploration and other missions that require a heavy-lift vehicle.

In addition, there are launch vehicles that are owned by companies but, by nature of national space transportation policy, are restricted exclusively to US government customers. These vehicles include those that make use of excess ICBM components, primarily solid-fuel motors, and thus can only be used for payloads sponsored by a US government agency and not for other commercial uses.

### 42.3.1 Space Launch System

As noted in the previous section, the Congress explicitly authorized the development of the SLS in the NASA Authorization Act of 2010. The SLS was the result of a compromise between the Obama Administration and key members of the Congress after the administration announced plans in early 2010 to cancel NASA's Constellation program to develop human space exploration systems. Constellation included the Ares I launch vehicle, designed to launch the Orion crewed vehicle, and the Ares V, a heavy-lift rocket intended to support human missions to the Moon and beyond. The Obama Administration, citing cost and schedule issues, sought to cancel both and defer a decision on heavy-lift development until as late as 2015, but some key members of the Congress objected, citing concerns about the lack of a large launch vehicle to support exploration missions and the effect the cancellation of the Ares rockets would have on the nation's space industrial base.

While development of SLS was authorized in the fall of 2010, the design of the rocket was not released until September 2011, and only then after members of the Congress applied pressure on NASA to speed up the process. The SLS will, in its initial version, make considerable use of existing Space Shuttle components. The core stage will be based on the Shuttle's external tank, with four Space Shuttle Main Engines (SSMEs) mounted on the base. Two five-segment solid-rocket boosters, already under development for Constellation and based on the four-segment boosters used in the Shuttle program, will be attached to the core stage. An upper stage will be powered initially by an RL10 engine already in use on the Atlas V and Delta IV. Later upgrades will replace the SSMEs with a version specifically designed for expendable rockets and replace the RL10 engine with J-2X engines derived from the J-2 engine used on the Saturn V rocket in the Apollo program. NASA is also soliciting designs for an "advanced booster," either solid or liquid fueled, that could replace the solid-rocket boosters.

NASA's plans, as of the end of 2012, call for an initial test launch of the SLS carrying an Orion spacecraft (without crew) in 2017. The SLS will launch the Orion on a trip around the Moon before returning to the Earth. A second flight, planned for 2021, will carry a crewed Orion spacecraft on a similar circumlunar trajectory. Missions beyond 2021 have yet to be defined, but could include both launching human missions to near Earth asteroids or Earth-Moon Lagrange points, as well as launching robotic science missions.

### 42.3.2 Minotaur

At the other end of launch vehicle capabilities from the SLS is the Minotaur family of launch vehicles, developed by Orbital Sciences Corporation. These vehicles make use of excess ICBM motors and thus because of US Space Transportation Policy are restricted for use to payloads sponsored by government agencies. The Minotaur I rocket uses Minuteman ICBM rocket motors for its lower two stages, with Pegasus rocket motors used for the upper two stages. The Minotaur IV uses Peacekeeper

ICBM rocket motors for its lower three stages and a commercial rocket motor for its upper stage; the Minotaur V is similar to the Minotaur IV but with an additional, commercial motor as a fifth stage. (The Minotaur II and III designations are used for suborbital rockets, including missile defense test vehicles.)

The Minotaur I rocket has flown ten missions since its introduction in 2000, primarily carrying small military satellites and secondary payloads built by universities. The Minotaur I can place up to 580 kg into LEO. The rocket has been used for ORS missions, including ORS-1, the first operational satellite for the program, in 2011. The Minotaur IV has made three orbital flights since 2010, carrying military satellites too large to fit on the Minotaur I, with a capacity for 1,750 kg to LEO. The Minotaur V is intended for GEO or deep space missions; its first launch, of a NASA lunar spacecraft, took place in September 2013.

## 42.4 Commercial/Dual-Use Launch Systems

Most launch systems in current use in the United States are, at least in theory, available for both commercial and government use and are operated by commercial entities. In practice, most of these systems are used primarily or exclusively for US government payloads, given the limited competitiveness of American vehicles on the global commercial launch market. This has raised questions about whether some of these vehicle lines can be sustained in the long term, particularly in an era of constrained government spending.

### 42.4.1 Atlas V

The Atlas V is the latest in a series of launch vehicles that bear the Atlas name stretching back over half a century, although the current version of the Atlas has little in common with most of its predecessors beyond the name itself. The Atlas V entered service in 2002 and is the only Atlas version in use today, after the retirements of the Atlas II and Atlas III vehicles in 2004 and 2005, respectively. As of the end of 2012, the Atlas V had performed 34 launches, all successful.

What distinguishes the Atlas V from almost all other Atlas variants, with the exception of the Atlas III, is the use of a Russian engine in the rocket's first stage. The RD-180 engine, built by NPO Energomash, is a derivative of the RD-170 engine that Energomash developed in the 1980s for the Soviet Union's heavy-lift Energia launch vehicle. That first stage, which uses liquid oxygen and RP-1 propellants, is mated to an upper stage that is a version of the Centaur first developed in the 1960s by NASA, powered by a liquid oxygen, liquid hydrogen RL10 engine from Pratt & Whitney Rocketdyne. The Atlas V also uses up to five solid-rocket strap-on boosters, built by Aerojet, attached to its first stage. Versions of the Atlas V can place up to 20,500 kg into LEO and up to 8,900 kg into GTO.

The Atlas V's origins were in Lockheed Martin's entry into the EELV competition in the mid-1990s. The Air Force selected both the Atlas V and Boeing's Delta IV vehicle in 1998 on the assumption that there was sufficient commercial business, coupled with civil and military missions, to sustain both vehicles. That assumption, though, did not survive the collapse of the commercial launch market after 2000, when a number of satellite ventures either filed for bankruptcy protection or went out of business as part of a broader telecommunications market retrenchment. In 2005, Boeing and Lockheed Martin sought to merge their launch vehicle businesses into a joint venture, United Launch Alliance (ULA), in order to reduce costs in a weak market. ULA formally began operations in late 2006 after winning government regulatory approval.

While the Atlas V remains on the commercial market, it has attracted little commercial business in recent years, primarily because of higher prices and a manifest dominated today by government missions. The most recent commercial Atlas V launch was in 2009, with the next, of the GeoEye-2 commercial remote sensing satellite, had been planned for 2013 but was postponed.

### 42.4.2 Delta IV

The Delta IV is the Atlas's stablemate in the EELV program. Originally developed by Boeing, it is now, like the Atlas V, manufactured by ULA and exclusively serves US government missions. The Delta's heritage dates back to the Thor rockets flown in the early years of the Space Age, although, as in the case with the Atlas, the Delta has evolved considerably over the decades. As of the end of 2012, the Delta IV had flown 21 missions.

The Delta IV comes in several variants, depending on the number of common booster cores and strap-on solid boosters used. The Delta IV Medium uses a single common booster core, powered by a liquid oxygen, liquid hydrogen RS-68 engine from Pratt & Whitney Rocketdyne, with no strap-on boosters and a 4-m payload fairing. The Delta IV Medium-Plus uses either two or four solid-propellant GEM-60 boosters built by Alliant Techsystems (ATK) and a 4- or 5-m payload fairing, depending on the mission. The Delta IV Heavy uses three common booster cores for maximum performance. All the versions use an upper stage powered by a variant of the RL10 engine that is similar to the one used by the Atlas V. The Delta IV can place between 9,150 and 22,560 kg into LEO and between 4,300 and 12,980 kg into GTO.

The development of the Delta IV follows a parallel path as the Atlas V, converging with the 2005 decision by Boeing and Lockheed Martin to merge their launch vehicle efforts into ULA because of limited commercial demand. Even before that decision, Boeing announced in 2003 that it was pulling the Delta IV from the commercial market, citing "continued weakness" in the commercial launch market.

### 42.4.3 Delta II

A predecessor to the Delta IV that remains in service today, although on the verge of retirement, is the Delta II. Despite the similar names, the Delta II is a markedly different vehicle than the Delta IV, featuring older technologies and different design choices. Although less powerful than the Delta IV, it has been a popular choice for NASA missions in particular that do not require the lift capacity, and higher costs, of EELV-class launch vehicles.

The Delta II first stage uses the RS-27A from Pratt & Whitney Rocketdyne, an engine powered by liquid oxygen and RP-1 propellants whose variants have been in service since the 1970s. The Delta II also uses three, four, or nine GEM-40 solid-propellant strap-on motors from ATK (the Delta II Heavy, a version introduced in 2003, replaces the GEM-40 boosters with more powerful GEM-46 boosters.) The Delta II's second stage incorporates an Aerojet AJ10-118 K engine, a hypergolic motor that uses Aerozine 50 (a mix of unsymmetrical dimethylhydrazine and hydrazine) and nitrogen tetroxide propellants. The rocket can support several optional solid motors in the third stage, including the Star-48B and Star-37FM motors.

The Delta II's payload performance is significantly smaller than the newer Delta IV, with a capacity of up to 4,590 kg (5,520 kg for the Delta II Heavy) to LEO and 1,710 kg (2,040 kg for the Heavy) to GTO. That limited GTO capacity in particular shuts out the vehicle from the commercial communications satellite launch market, as those spacecraft typically weigh considerably more than what even the Delta II Heavy can launch. The rocket has had some commercial success launching commercial remote sensing satellites as well as, in the late 1990s, some of the satellites for the Globalstar and Iridium LEO communications satellite systems. In recent years, the Delta II's primary customer has been NASA, which has used it for space and Earth science missions.

Although the Delta II has a long track record of success – the last launch failure took place in January 1997 – increasing costs of the rocket as its customer base dwindled have put the vehicle on the verge of retirement. The most recent Delta II launches took place in 2011, which at the time were the last manifested missions for that rocket. In July 2012, though, NASA awarded contracts for three more missions to the Delta II, using vehicles already manufactured and current in storage. Those launches, of the OCO-2, SMAP, and JPSS-1 Earth science missions, are planned for 2014 through 2016. Unless production of the Delta II is restarted, which appears unlikely, these may be the final launches of this venerable vehicle.

### 42.4.4 Falcon

Space Exploration Technologies, Inc., or SpaceX, is one of the newest entrants into the launch market. Entrepreneur Elon Musk founded the company in 2002 to lower the cost of space access after being frustrated by the available launch options in the United States and other nations. The company's initial vehicle was the Falcon 1, a small two-stage vehicle powered by liquid oxygen and kerosene engines: the larger Merlin engine in the first stage and the smaller Kestrel engine in the second stage. The rocket could place up to 430 kg into LEO. The first three Falcon 1 launches, in 2006, 2007, and August 2008, failed to place payloads in orbit, but subsequent launches in September 2008 and July 2009 were successful.

SpaceX has shelved the Falcon 1 to focus instead on the more powerful Falcon 9. This rocket features nine Merlin engines in its first stage and one in its second stage. This vehicle was first launched in June 2010 and has made seven launches, all successful, as of the end of 2013, including three missions launching Dragon cargo spacecraft to the International Space Station (development of the Falcon 9 was partially supported by NASA's COTS program for space station resupply). One selling point of the Falcon 9 is its "engine out" capability: the rocket can lose at least one engine in its first stage at any phase of its flight and still reach orbit. This capability was demonstrated on an October 2012 flight when one engine shut down approximately 79 s after liftoff: its payload, a Dragon spacecraft, still reached orbit, although a secondary payload, a demonstration satellite for ORBCOMM's next-generation communications satellite system, was placed in a lower-than-planned orbit and reentered several days later.

A key selling point for the Falcon 9 has been its low price. SpaceX originally marketed the Falcon 9 at $35 million a launch, and while that price has increased to $54 million, it is significantly less than other launches in the same class. SpaceX introduced a "1.1" version of the Falcon 9 in 2013 with upgraded Merlin engines and stretched propellant tanks in its first stage, improving its payload performance from 9,000 to 13,150 kg for LEO missions and from 3,400 to 4,850 kg for GTO missions. SpaceX has won a number of launch contracts from commercial and government customers in recent years, from NASA to commercial satellite operators to, in late 2012, the US Air Force.

SpaceX is also developing a much larger version of the Falcon, called the Falcon Heavy. It is analogous to the Delta IV Heavy in that it uses three Falcon 9 first stages plus a second stage. The Falcon Heavy will be able to place up to 53,000 kg into LEO and 12,000 kg to GTO. SpaceX plans an initial test flight of the Falcon Heavy no earlier than late 2014; operational missions will cost between $83 and $128 million each.

### 42.4.5 Antares

Orbital Sciences Corporation, which has extensive experience with small launch vehicles, embarked on the development of the medium-class Antares vehicle (originally named Taurus II) in 2008 with a COTS award from NASA that also covered development of the Cygnus cargo spacecraft. The Antares first stage is powered by two AJ 26 engines from Aerojet (the so-called "Americanized" versions of Russian NK-33 engines originally developed for the Soviet Union's N-1 heavy-lift rocket in the 1960s) that use liquid oxygen and RP-1 propellants. The second stage uses a solid-propellant Castor 30B motor from ATK, and in the third stage, optional solid- and liquid-propellant motors.

In developing Antares, Orbital decided to develop a new launch facility at the Mid-Atlantic Regional Spaceport (MARS) at Wallops Island, Virginia, rather than a launch site at Cape Canaveral. From MARS, Antares can place up to about 4,700 kg into the space station's orbit. Delays in building that new launch site have pushed back the initial launch of the Antares from the original date of late 2010 until early 2013.

With Antares, Orbital hopes to fill a gap in US launch capability created by the impending retirement of the Delta II. As of the end of 2012, though, Orbital had only secured contracts for eight cargo missions to the ISS, in addition to two demonstration launches under its COTS award. Orbital has not disclosed pricing for Antares launches separate from its cargo missions to the ISS.

### 42.4.6 Liberty

In 2011, ATK and EADS Astrium jointly announced plans to develop a new large launch vehicle called Liberty. The two-stage rocket, similar to the Ares I launch vehicle that was to be developed for NASA's Constellation program, features a lower stage that is a five-segment version of the solid-rocket booster. ATK developed for Ares I and an upper stage based on the core stage of the Ariane 5 rocket, with a modified version of the Vulcain engine powered by liquid hydrogen and liquid oxygen. The Liberty could launch up to 22,000 kg into low Earth orbit.

ATK and EADS Astrium announced the Liberty concept in an effort to win business from companies proposing crewed spacecraft for NASA's Commercial Crew Development (CCDev) program. However, Liberty did not win a funded Space Act Agreement from NASA in the second round of the CCDev program (ATK and EADS Astrium did sign an unfunded Space Act Agreement to support continued work on the vehicle) and crewed spacecraft developers chose other vehicles – ULA's Atlas V and SpaceX's Falcon 9 – for their spacecraft.

In May 2012, ATK and EADS Astrium announced that they would develop a crewed spacecraft to be launched by Liberty, calling the overall transportation system Liberty as well. The companies submitted a proposal to NASA for the next round of the commercial crew program, called Commercial Crew Integrated Capability (CCiCap), but did not win one of the three awards made by NASA in August 2012. ATK and EADS Astrium have since put development of the Liberty spacecraft on hold, but are considering continued development of the Liberty launcher for satellites and ISS cargo missions.

### 42.4.7 Stratolauncher

Microsoft cofounder Paul Allen unveiled plans in December 2011 to build an air-launch system called Stratolauncher under the aegis of a startup company called Stratolaunch Systems. The Stratolauncher concept calls for the development of the world's largest aircraft, a twin-fuselage plane powered by six jet engines previously used on 747 jetliners. Mounted between the fuselages is the rocket, which would be released from altitude and ignite its engines to ascend to orbit. The system, flying from almost any runway at least 3,600 m long, could place up to 6,100 kg into orbit, with flight tests scheduled to begin in 2016.

Stratolaunch Systems signed up several partners to develop the system, including Scaled Composites to develop the aircraft and SpaceX to develop the launch vehicle, which was to be based on the Falcon 9 but with four to five engines in its first stage. However, in November 2012, Stratolaunch Systems said it had parted ways with SpaceX because the design of the booster had "departed significantly" from the original Falcon-based concept. Stratolaunch Systems has since reached an agreement with Orbital Sciences Corporation to develop an alternative booster concept.

### 42.4.8 Small Launch Systems

In addition to the larger launch vehicles described above, there are several smaller vehicles either in operation today or under development. These vehicles are designed to provide dedicated launches of small satellites, a growing market as technological advances allow for spacecraft weighing as little as a few kilograms to perform useful missions. While small satellites can be launched as secondary payloads on larger vehicles, small launch vehicles offer better control over schedule and orbit that is often needed for operational missions.

The best known US small launch vehicle, and the one with the most flight experience, is the Pegasus XL rocket by Orbital Sciences Corporation. The Pegasus is air launched from a customized L-1011 jetliner nicknamed "Stargazer" and uses solid-propellant motors in its three stages: an Orion 50S XL, Orion 50 XL, and Orion 38, with an optional liquid-propellant fourth stage. The Pegasus can place up to approximately 450 kg into LEO. The Pegasus XL and earlier variants have made 41 launches since 1990, including 27 consecutive launches through 2012. However, the future of the Pegasus is in doubt, with no launches planned since the launch of a NASA satellite in June 2013.

Orbital also offers the somewhat larger Taurus XL rocket, a ground-launched vehicle that makes use of some of the same solid-propellant rocket motors as Pegasus, but with a more powerful Castor 120 rocket motor as its first stage. It can place up to 1,450 kg into LEO and 1,050 kg into sun-synchronous orbits. The Taurus has been launched only nine times since its introduction in 1994, and the last two – of NASA's Orbiting Carbon Observatory and Glory spacecraft, in 2009 and 2011, respectively – failed when the payload fairing did not separate.

Lockheed Martin developed the Athena rocket in the 1990s, using Castor 120 and other solid-propellant rocket motors. The Athena I, a two-stage rocket, could place 820 kg into LEO, while the three-stage Athena II could put 2,065 kg into LEO. The Athena I and Athena II launched seven times from 1995 to 2001, including two launch failures. Lockheed Martin and ATK are working to reintroduce updated versions of those vehicles, designated Athena Ic and Athena IIc, with similar payload performances. No launches of either version have been formally manifested as of the end of 2013.

Despite the difficulties experienced by the Pegasus, Taurus, and Athena vehicles to win business, there has been renewed interest in recent years in developing even smaller, and less expensive, orbital launch vehicles. In July 2012, Virgin Galactic, a company developing a suborbital crewed vehicle, announced plans to develop a small satellite launch vehicle called LauncherOne. This vehicle, powered by liquid oxygen and kerosene engines, will place satellites weighing up to 225 kg into LEO for a projected launch price of less than $10 million. The rocket will be air launched using Virgin Galactic's WhiteKnightTwo aircraft originally developed for its SpaceShipTwo suborbital vehicle, with a first launch planned for 2016.

Virgin Galactic is also one of several companies involved in a Defense Advanced Research Projects Agency (DARPA) effort called Airborne Launch Assist Space Access (ALASA). This effort seeks to develop air-launched systems that can place up to 45 kg into orbit for $1 million per launch. In June 2012, DARPA awarded contracts to Boeing, Lockheed Martin, and Virgin Galactic to develop concepts of their proposed systems, while other companies won contracts to develop specific technologies.

### 42.4.9 Suborbital Systems

A separate class of vehicles from the orbital launch vehicles described above are the suborbital launch systems. These vehicles are not designed to place satellites into orbit but instead briefly carry payloads above the atmosphere, exposing them to the space environment and microgravity for several minutes. This area of the launch industry has been something of a backwater for many years, but is seeing renewed commercial interest thanks to the development of a number of reusable suborbital vehicles, including those designed to carry people.

NASA maintains a Sounding Rockets Program Office to support the use of expendable suborbital launch vehicles, also known as sounding rockets, for scientific research and technology demonstration applications. These vehicles include the Black Brant and Terrier series of rockets, all of which use a variety of solid-propellant rocket motors. These rockets can carry payloads weighing up to a few hundred kilograms to altitudes of several hundred kilometers; the Black Brant XII, for example, can carry a 110-kg payload to an altitude of 1,500 km or a 450-kg payload to 550 km. These missions are flown for atmospheric and space science research and to test new technologies. NASA typically launches 20–25 sounding rockets a year, including 22 in fiscal year 2012.

Several companies in the United States are actively developing reusable suborbital vehicles. Much of this work has its roots in a competition known as the Ansari X PRIZE, established by the X PRIZE Foundation in 1996. The competition offered $10 million to the first privately developed suborbital vehicle, capable of carrying at least three people that flew to an altitude of 100 km twice in a 2-week period. Scaled Composites won the competition in October 2004 with its SpaceShipOne vehicle, built with the financial support of Paul Allen.

The most prominent of these companies is Virgin Galactic, part of the Virgin Group of companies run by British entrepreneur Sir Richard Branson but headquartered in the United States. Virgin Galactic is working with Scaled Composites to develop an upgraded version of SpaceShipOne, known as SpaceShipTwo. The vehicle, capable of carrying six passengers and two pilots, will be air launched from a purpose-built carrier aircraft, WhiteKnightTwo, and use a hybrid rocket motor developed by Sierra Nevada Corporation to ascend to an altitude of about 110 km before gliding to a runway landing. SpaceShipTwo has performed a number of unpowered and powered test flights, with commercial flights scheduled to begin by late 2014.

XCOR Aerospace, a small startup company based in Mojave, California, is also developing a crewed suborbital launch vehicle. The Lynx will take off from a runway, powered by four liquid oxygen and kerosene engines developed by the company. The Lynx, carrying one pilot and one passenger, will ascend to 100 km before returning for a runway landing. The prototype Mark I version of the Lynx is scheduled to begin flight tests in 2014.

Blue Origin, a secretive company founded and financially supported by Amazon.com founder Jeff Bezos, is also developing suborbital vehicles. Its New Shepard vehicle will launch vertically under rocket power, carrying a crew module capable of hosting several people to altitudes of at least 100 km. The crew capsule and separate propulsion module will land independently, the former under parachutes. The company has not disclosed a timeline for flying the New Shepard vehicle.

Other companies are focused on reusable suborbital vehicles primarily as research platforms without the ability to carry people. Armadillo Aerospace is developing its Suborbital Transport Inertial Guidance (STIG) series of reusable sounding rockets that take off vertically and land under parachute. The company's STIG-B rocket most recently performed two test launches from Spaceport America in New Mexico in October and November of 2012. Masten Space Systems is also developing reusable vehicles that take off and land vertically under rocket power, although the company lost one of its test vehicles, named Xaero, during a test flight in September 2012 in Mojave, California.

## 42.5 Policy and Technology Implications

A key question after reviewing this fleet of existing and proposed launch vehicles is how well they implement, or are supported by, national space transportation policy. One of the central tenets of national policy, assured access to space, is largely achieved by these vehicles. Both the Atlas V and Delta IV can launch all planned government satellites, and the emergence of the Falcon 9 and Falcon Heavy vehicles offers an additional option in the near future. One exception to this assured access philosophy is in the area of human spaceflight: with the retirement of the Space Shuttle in 2011, the United States has no means to transport astronauts into orbit and will not until commercial systems enter service by 2017 and the first crewed SLS flight in 2021. However, while human spaceflight is an area of high visibility and national prestige, it does not have the same national security implications as the ability to launch military and intelligence satellites.

The secondary goal of national space transportation policy, the promotion of a commercial space transportation industry, has had mixed results. In the last decade, the United States has largely retreated from the global commercial launch market: US vehicles performed no commercial orbital launches in 2011 and only two in 2012, both SpaceX Falcon 9 vehicles carrying Dragon spacecraft to the ISS. The bulk of the commercial launch market, primarily of GEO communications satellites, is handled by Europe's Arianespace and International Launch Services (ILS), a US-based but Russian-owned company that markets Russia's Proton rocket.

However, the US government has provided renewed support for the commercial launch industry through NASA's COTS program, which supported the development of the Falcon 9 and Orbital Sciences Corporation's Antares and acted as an anchor tenant for those vehicles. The Falcon 9 in particular has won a number of commercial launch contracts that it started carrying out in 2013, which, if successful, will increase American competitiveness in the global launch market. NASA's commercial crew program also provides another opportunity to support the launch industry by stimulating demand for additional launches in new markets.

One key criterion when evaluating launch systems that is not addressed by policy is launch costs (or, more accurately when dealing with commercial launch efforts, the price of the launch services sold to various customers). That lack of discussion of launch costs in current policy is interesting, as there have long been government-supported efforts to reduce launch costs, from the Space Shuttle and EELV programs to a number of unsuccessful commercial and government vehicle development efforts over the years. Even the vehicles that did fly, like the Shuttle, Atlas V, and Delta IV, failed to achieve those planned cost reductions. Is this a failure of technology, policy, or both?

It is worth noting that, despite the existence of these efforts, cost has not been a primary factor for most major customers for launch services. The US military, for example, has placed an emphasis on assured access and reliability over cost, while commercial GEO customers, who are somewhat more price sensitive than government users of launch services, still place a greater emphasis on schedule assurance and reliability over cost. This is, in the big picture, not surprising, as the costs of national security and even commercial communications satellites can be several times that of the launch, with even greater fiscal and other costs associated with a launch failure or delay.

Several factors, though, may provide an increased emphasis on launch cost in the near future, even if it does not become an explicit policy directive. Increased costs associated with the EELV program have led for a push to allow new entrants, like SpaceX and Orbital Sciences, into the program; SpaceX won contracts in December 2012 for its first two EELV-class missions. Constrained federal budgets may accelerate this interest in lower-cost launch options in the years to come by both NASA and the Pentagon. The ability to decrease launch prices could also stimulate interest in commercial markets that are more sensitive to such costs, including space tourism, research, and launches of small satellites. A key reason why existing American small launch vehicles – Pegasus, Taurus, and Athena – have little business is that their prices remain too high for many interested smallsat - developers. Lower-cost options like Virgin Galactic's LauncherOne and DARPA's ALASA program may allow the business case for smallsat applications to close.

## 42.6 Conclusions

Although there are some issues with cost and capability, the United States has a remarkably robust array of space launch capabilities, including systems with very high reliability and performance. Launch cost is a key issue, one that is not explicitly addressed by policy now but will likely grow in the years to come given constrained government budgets. However, the emergence of new vehicles and new markets may help address those cost concerns.

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# Satellite Programs in the United States

# 43

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## Contents

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**Abstract**

The space programs of the US military and intelligence organizations are described. The services provided by these programs include telecommunications, surveillance, missile early warning, meteorology, positioning/timing, radio interception, nuclear detonation detection, and data relay. Both unclassified and classified programs are described, with less detail and more speculative information for the latter. Recent trends that indicate the focus of future programs are discussed.

## 43.1 Introduction

In this chapter what is by far the world's largest space program is described. The space budget of the US Department of Defense (DOD) has been reported in the media as being between $20 billion and $22 billion each year this century. This figure is probably an under-statement of the US military space budget given that the unclassified figures submitted to Congress come to about $9 billion to which can be added about $15-16 billion for the National Reconnaissance Office (NRO) and the National Geospatial-Intelligence Agency (NGA) based on documents leaked by Edward Snowden, plus much of the $8 billion budget of the Missile Defense Agency.

The space programs of the US military and intelligence communities are treated in this chapter as being one and the same. The NRO is a joint agency of DOD and the Central Intelligence Agency (CIA) in order to deliver space systems that serve both parent organizations.

The large number of programs is broken down in this chapter as follows:

- Telecommunications (Sect. 43.3)
- Surveillance (Sect. 43.4)
- Navigation (Sect. 43.5)
- Other (Sect. 43.6)

The descriptions include the ground elements for control of the relevant missions but exclude the user equipment. In general, only operational systems are described, with just a few of the very large number of research, prototype, demonstration, and preoperational space systems mentioned in Sect. 43.6.

## 43.2 Background

The space systems described in this chapter provide both tactical and strategic services to the US military and intelligence agencies and in some cases to those of its allies. Strategic functions include monitoring international security treaties, analyzing the security forces of current and potential adversaries, and providing information to the President and the Secretary of State. Tactical functions include supporting US military and intelligence forces around the world.

The higher cost of many US military space systems compared to commercial systems is due in part to their hardening against nuclear explosions in space, their ability to resist jamming and other forms of interference, and their ability to operate autonomously in the absence of ground control systems.

The launchers used by the DOD are not described in this chapter since they are used for civilian as well as military missions. Since 2007, United Launch Alliance (ULA), the joint venture between Boeing and Lockheed Martin, has been the sole source provider of launch services to DOD and NRO for medium and heavy lift. Despite steadily rising launch costs, the company has maintained its position based on the performance and reputation of its two vehicles, Atlas V and Delta IV, and the lack of viable competition. Smaller launcher options for DOD and NRO include Orbital Sciences' Minotaur and Pegasus. New and significantly cheaper entrants such as SpaceX's Falcon 9 have not yet been allowed to bid for DOD/NRO launches.

The following references have been used in compiling this chapter:

- Information about unclassified programs has mainly been drawn from:
  - The DOD program fact sheets
  - The DOD AU-18 Space Primer
- Information about classified programs has mainly come from:
  - *Watching Earth from Space* by the author of this chapter and references therein, especially:
    - *The US Intelligence Community* by J T Richelson

The information in these references has been updated based mainly on information in the trade press, including *Aviation Week & Space Technology*, *Air & Cosmos* (in French), and *Space News* and budgetary information reported in *The Washington Post* on August 29 2013 based on documents leaked by Edward Snowden.

## 43.3 Telecoms

### 43.3.1 Introduction

80 % of all communications to US deployed military forces travel through satellite. And 80 % of that traffic is carried through commercial communications satellites – the Department of Defense spent over $600 million in 2010 leasing services from commercial satellite operators. The remaining 20 % of the 20 % of traffic to deployed forces is carried by special purpose military communications satellites. Commercial satellites are used wherever possible so that in case of an urgent need, capacity is available on the military satellites.

The use of commercial satellites has led to some embarrassing moments for the US military. On several occasions, the transmissions from remotely controlled aircraft have been intercepted by journalists and made public. There has been no persuasive rationale offered as to why these transmissions are not encrypted other than that the remotely controlled aircraft were of a vintage that did not carry encryption facilities. Given the ubiquitous and low cost of mass market encryption/decryption technology as used, for example, in cell phones and pay-TV, many commentators have wondered why the encryption technology is supposedly too modern or expensive for remotely controlled aircraft that costs more than $1 million each. The proliferation of remotely controlled aircraft since 2003 has called for an increasing amount of satellite communications capacity – particularly the large long-duration drones that are controlled from bases in the USA even when flying in Central Asia.

The USA's specialist military communications satellites provide a mix of strategic and tactical services to forces on land, at sea, and in the air. Three parts of the radio spectrum are used for the transmissions, ultra-high frequency (UHF, below 1 GHz), X-Band (6–8 GHz), and extremely high frequency (EHF, 20–30 GHz).

Satellites currently in orbit include a mix of a new generation of systems and those of the previous generation. By 2020 it is expected that the DoD satellite communication services will be carried by 14 of the new generation systems: 4 AEHF, 6 WGS, and 4 MUOS – described in the next three sections. These 14 will be augmented by (a) EHF payloads on polar-orbiting satellites to provide Arctic coverage (Sect. 43.3.6), (b) data relay satellites (Sect. 43.3.5), and (c) commercial satellites.

In the past each service had its own communications satellites, but with the current systems the user doesn't necessarily know which satellite he is using. Connections are provided by the Global (or Regional) Satcom Support Center (GSSC) based on the availability of the appropriate bandwidth in the relevant areas – GSSC is part of the Defense Information Systems Agency (DISA) which works across all military services and defense agencies.

The remainder of this section is structured as follows:

- AEHF and Milstar (Sect. 43.3.2)
- MUOS and UFO (Sect. 43.3.3)
- WGS (Sect. 43.3.4)
- Data relay (Sect. 43.3.5)
- Interim and Enhanced Polar System (Sect. 43.3.6)

### 43.3.2 Advanced Extremely High Frequency (AEHF) and Milstar

The White House National Security Council, chaired by the President, uses the AEHF satellites (see Figs. 43.1) to control tactical and strategic forces on missions around the globe and at all levels of conflict. Three AEHF satellites are in geosynchronous orbit, launched in 2010, 2012 and 2013. They combine (a) a strategic communications mission, i.e., assured jam-proof connectivity between the President and nuclear forces and (b) protected tactical communications. These two quite distinct missions share equipment on the satellite such as a digital core processor. The strategic mission requires the satellites to be radiation hardened to survive a nuclear explosion in space and other threats, which critics have argued makes AEHF more expensive than two separate satellites would have been (one for the strategic mission, the other for the tactical).

Each AEHF weighs about 6½ tons when launched on an Atlas 5 from Cape Kennedy and is based on the Lockheed Martin A2100 spacecraft bus (also used for commercial satellites) with a Japanese IHI BT-4 apogee thruster and an electric propulsion system. The electric ion propulsion system is intended for maneuvering the satellite in its final orbit but was called into action on AEHF-1 when the apogee

Credit: USAF

**Artist's impression of AEHF in orbit**

**Fig. 43.1** AEHF Satellite

thrust motor failed. The slow evolution from the elliptical transfer orbit into which the Atlas 5 placed the satellite on August 14, 2010, and the eventual geostationary orbit took 16 months using the low thrust ion engine. A further 5 months were required for on-orbit testing until AEHF-1 became operational in March 2012. Ironically, in early 2012 Boeing announced the sale to two commercial satellite operators of four "all electric" satellites, which do away entirely with chemical propulsion. These satellites will take 4–6 months to reach their operational orbit, but are significantly lighter (and therefore cheaper) than the conventional satellites that achieve their operational orbit in days rather than months.

The space segment consists of a cross-linked constellation of two satellites with a planned extension to four. They provide communications at a variety of data rates from 75 bps to approximately 8 Mbps and broadly provide ten times the throughput of the 1990s-era Milstar satellites with a substantial increase in coverage for users. System uplinks and cross-links operate in the extremely high frequency (EHF) range and downlinks in the super high frequency (SHF) range. The communications are channeled through an antenna farm on each satellite comprising:

- Two SHF downlink phased arrays
- Two cross-links
- Two uplink/downlink nulling antennas
- One uplink EHF phased array

**Fig. 43.2** Milstar Satellite (artist's impression)

- Six uplink/downlink gimbaled dish antennas
- One each uplink/downlink earth coverage horn

Under an initial contract valued at $6.6 billion, Lockheed Martin will supply four AEHF satellites, and a further two have since been ordered to bring the total order value to about $9 billion. Northrop Grumman is responsible for the EHF payload.

Five of the Milstar satellites (see Fig. 43.2) that AEHF supersedes are in orbit, launched in 1994 through 2003. Each Milstar satellite serves as a smart switchboard in space by directing traffic from terminal to terminal anywhere on the Earth. The satellite actually processes the communications signal and can link with other Milstar satellites through cross-links. Milstar was the first US military communications satellite with this smart switchboard capability which provides flexibility for users with a reduction in ground-controlled switching. The satellite establishes, maintains, reconfigures, and disassembles required communications circuits as directed by the users. Milstar terminals provide encrypted voice, data, teletype, or facsimile communications. A key goal of Milstar is to provide interoperable communications among the users of Army, Navy, and Air Force Milstar terminals.

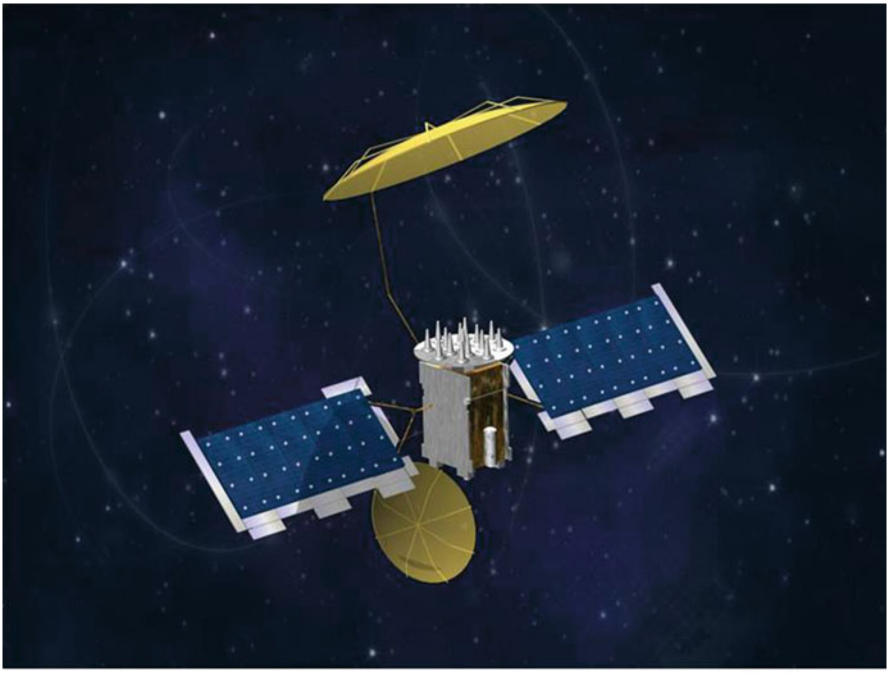
Each Milstar satellite weighs 4.5 t and generates 8 kW of electrical power. They are all in inclined geosynchronous orbit. The cost of each satellite was about $800 million. Prime contractor was Lockheed Martin Missiles & Space.

The Protected SATCOM Division of the Space and Missile Systems Center's MILSATCOM Directorate is the program office for the AEHF system and is responsible for the acquisition of the space and ground segments as well as the Air Force terminal segments. The Army and Navy acquire their own terminals.

The AEHF satellites are operated by the 4th Space Operations Squadron (4 SOPS) located at Schriever AFB, Colorado. The mission control segment controls satellites on orbit, monitors satellite health, and provides communications system planning and monitoring.

### 43.3.3 MUOS and UFO

The four Mobile User Objective System (MUOS) satellites (plus one on-orbit spare) are designed to replace the ultra-high frequency (UHF) follow-on (UFO) constellation that provides narrowband communications (64 kbps or less). MUOS (see Fig. 43.3) is designed to support users that require mobility, high data rates



Credit: US Navy

Artist's impression of MUOS in orbit

**Fig. 43.3** MUOS Satellite

(up to 384 kbps "on the move"), and improved operational availability. A 2012 US Navy information bulletin described the UHF spectrum as "the military's communications workhorse, as it is the most effective military radio frequency for penetrating jungle foliage, inclement weather, and urban terrain on the move." The current UFO constellation comprises eight operational UFO satellites augmented by two pre-UFO FLTSAT satellites and leased services on communications satellites. The UFO satellites achieved Initial Operational Capability in November 1993 and Full Operational Capability in February 2000. The final satellite in the series, UFO-F11, was launched in December 2003.

Each MUOS satellite carries a legacy payload that allows terminals compatible with the UFO system to continue in service. In addition, MUOS carries a payload that provides a military variant of the commercial 3G wideband cellular service using Wideband Code Division Multiple Access (WCDMA) technology. When fully fielded, MUOS will provide an aggregate of 40 Gbps for the military user, compared to the legacy UFO system's aggregate of 2.7 Gbps – a 15-fold increase. The increase means future users will have more than 16,332 simultaneous accesses (voice, video, data) at 2.4 kbps, compared to 1,111 accesses provided by the present UFO satellite system at the same data rate.

User information will flow to the satellite via UHF WCDMA links, and the satellites will relay this by Ka-band feeder link to one of the four Earth stations in Italy (subject to local objections being overcome), Australia, Hawaii, and Virginia that are interconnected by a fiber-optic terrestrial network. These facilities will identify the destination of the communication and route the information to the appropriate ground site for Ka-band uplink to the satellite and then relay via UHF WCDMA downlink to the correct users. MUOS uses Internet Protocol versions 4 and 6 (IPv4/IPv6) to give users connectivity to the military Internet.

The four MUOS satellites will be placed in geostationary orbit at longitudes 15.5°W, 100°W, 177°W, and 72°E plus an on-orbit spare at 75°E.

MUOS-1 weighed 6.8 t (15,000 lbs) at its 24 February 2012 launch which was the heaviest satellite ever carried by an Atlas 5 rocket, repeated on July 19 2013 with the launch of MUOS-2. Like AEHF, the MUOS satellite is based on prime contractor Lockheed Martin Space Systems' A2100 platform bus. The solar arrays produce 15.4 kW (end-of-life performance).

A key feature of MUOS (and of commercial satellites such as Inmarsat-4, Thuraya, and ACES that offer similar services to users on the move) is a large antenna that unfurls in orbit to a diameter of 28.6 m (94′ – the length of a basketball court). Each satellite has 16 WCDMA beams: four WCDMA beams on four 5 MHz carriers and UHF channel bandwidths of 17.5 kHz and 21.5 kHz.

The wideband CDMA for communications in motion is intended to be compatible with the Joint Tactical Radio System (JTRS) series. JTRS has had a troubled history, and delays in rolling it out mean that the WCDMA on MUOS-1 is an engineering version of the radio waveform and requires a software upgrade to be operational scheduled to happen after the July 2013 MUOS-2 launch. If that schedule is maintained, the system is planned to reach Initial Operational Capability in 2015.

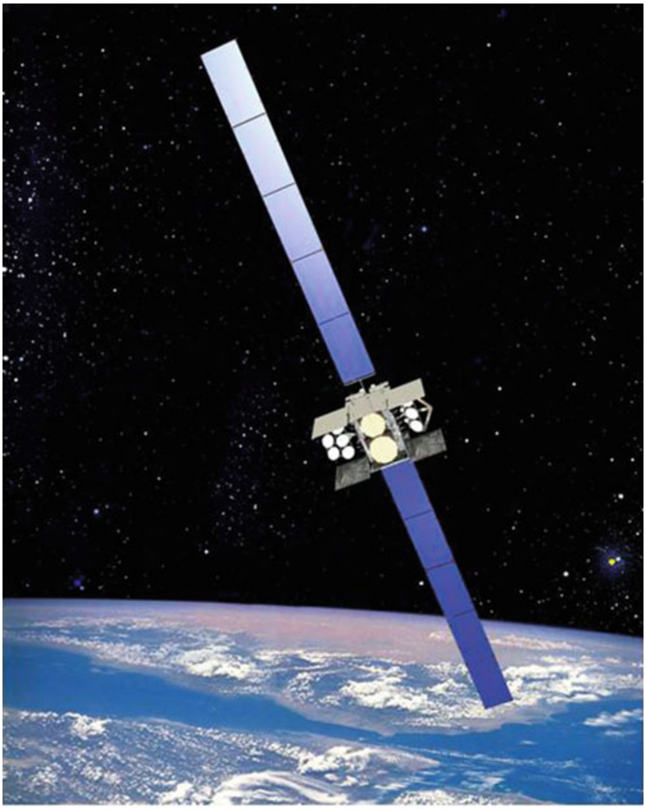
Once its on-orbit testing has been completed, MUOS is operated by the Naval Satellite Operations Command in Point Mugu, California.

The possibility of selling UHF satellite service to the US military tempted commercial satellite operator Intelsat to build a suitable payload into its IS-27 satellite that was destroyed in a launch vehicle failure 40 seconds after lift-off in January 2013. Similar commercial "hosted payload" deals have been taken up by defense agencies in several countries including Britain, France, Spain, and Australia.

### 43.3.4 Wideband Global Satcom (WGS)

The Wideband Global Satcom (WGS – previously called wideband gapfiller satellite-see Fig. 43.4) offers wideband broadcast and communications services.

The system supports continuous 24-h-per-day wideband satellite services at X-Band and Ka-Band to tactical users and some fixed infrastructure users, and it has the ability to cross-band between the two frequencies onboard the satellite. WGS supplements X-band communications that had been provided by the Defense Satellite Communications System III (DSCS-III) and augments the one-way Global Broadcast Service (GBS) satellites through new two-way Ka-band service.



Credit: USAF

Artist's impression of WGS in orbit

**Fig. 43.4** WGS Satellite

The first WGS in orbit, WGS-1, with its 2.4 Gbps wideband capacity, provided greater capability and bandwidth than all nine DSCS-III satellites combined that it superseded.

The WGS design includes 19 independent coverage areas that can be positioned throughout the field of view of each satellite. This includes:

- Eight steerable and shapeable X-band beams formed by separate transmit and receive phased arrays
- 10 Ka-band beams served by independently steerable, diplexed antennas, including three with selectable RF polarization
- Transmit/receive X-band Earth coverage beams

WGS supports communications links within the government's allocated 500 MHz of X-band and 1 GHz of Ka-band spectrum. Each WGS satellite can filter and route 4.875 GHz of instantaneous bandwidth. Depending on the mix of ground terminals, data rates, and modulation schemes employed, each satellite can support data transmission rates ranging from 2.1 Gbps to more than 3.6 Gbps. By comparison, a DSCS III satellite supported up to 0.25 Gbps.

Prime contractor Boeing has built WGS on its commercial 702 platform, which includes the Boeing xenon ion propulsion system (XIPS) for on-orbit station keeping and station changes. The gallium arsenide solar cells provide about 13 kW of power and the mass at launch is about 6 t.

Six WGS satellites have been launched into geostationary orbit in 2007, 2009 (two launches), 2012 and 2013 (2 launches) – the last three comprising the Batch II version of WGS. WGS-6 launched on August 7 2013 was funded by the Australian Department of Defense. A total of ten WGS have now been ordered, WGS-7 through -10 are the Batch III version, with WGS-9 funded by an international consortium comprising Canada, Denmark, New Zealand, Luxembourg and the Netherlands. The cost of WGS-5 through WGS-7 is about $350 million each, while WGS-8 and WGS-9 cost about $55 million more each due to being outfitted with enhancements that boost their capacity by 30 %.

Spacecraft platform control is performed by the 3rd Space Operations Squadron (3 SOPS) at Schriever AFB in Colorado Springs, Colorado. Payload commanding and network control is handled by the Army 53rd Signal Battalion headquartered at nearby Peterson AFB, Colorado, with subordinate elements A Co. at Fort Detrick, Maryland; B Co. at Fort Meade, Maryland; E Co. at Fort Buckner, Okinawa Japan; C Co. Landstuhl, Germany; and D Co. Wahiawa, Hawaii.

The sale of WGS satellites and services to countries such as Australia and Canada has been criticized by some in industry as an encroachment of DOD onto commercial territory. Commercial companies such as Paradigm (European) and Xtar (US and Spanish) offer military satellite communications services outside the USA.

### 43.3.5 Data Relay

The USA has a number of special relay satellites in high orbits so that US surveillance satellites can transmit data to a US ground station no matter where in the world the surveillance satellite is. The relay satellites are either in a geostationary orbit that is always 36,000 km above the equator or an orbit that takes it further north at a similarly high altitude. For this scheme to work, in addition to the relay satellites themselves, you have to also place special equipment on the surveillance satellites to enable them to communicate with the relay satellites.

The US military and intelligence communities have two sets of relay satellites at their disposal. First is NASA's Tracking and Data Relay Satellite System (TDRSS) which is described in various NASA publications[1]. The NRO's postulated imaging radar satellites (see Sect. 43.5.3) are said by some commentators to use TDRSS to get their images back home quickly, but other US military satellites such as the

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[1] The TDRSS page on the NASA website has links to a variety of documents describing the system and satellite: https://www.spacecomm.nasa.gov/spacecomm/programs/tdrss/default.cfm.

optical surveillance series (see Sect. 43.5.2) are said to use a military version of TDRSS that civilian commentators used to refer to as Space Data Systems (SDS) but according to information leaked by Edward Snowden is called QUASAR.

According to several commentators, seven QUASAR satellites have recently been orbited into a mix of geostationary and inclined elliptical orbits. Four, in 2000, 2001, 2011, and 2012, were placed in geostationary orbit from where in principle they can serve surveillance satellites as far as 70° north and south, i.e., to the edge of the Arctic and Antarctic regions. However, beyond about 50° north or south, the surveillance satellite in low orbit has increasing difficulty to stay locked on the QUASAR satellite as the line of sight gets closer and closer to the horizon – by the time the surveillance satellite is at 70° north (or south), the QUASAR geostationary satellite appears very close to the Earth and is difficult to track. For this reason some of the QUASAR satellites are placed in what is often called an elliptical Molniya orbit named after the Soviet communications satellites that popularized the orbit 40 years ago. A Molniya orbit is high in the sky over the northern hemisphere and low over the southern hemisphere. The Soviets chose this orbit to provide broadcasting and communications to the whole of the Soviet Union, many of whose inhabitants live far to the north. The US military chose it for the same reason – to give good coverage of all of the Soviet Union, especially the militarily interesting regions around Murmansk (69° north) and the Bering Strait (67° north) next to Alaska. Out of its 12-h orbit, 8 h will be in the high northern part, so three such satellites can provide continuous 24-h coverage between them. Three QUASAR satellites launched in 1998, 2004, and 2007 are said to be in these Molniya orbits.

### 43.3.6 Interim and Enhanced Polar System (IPS/EPS)

The Interim Polar System (IPS) provides protected communications (anti-jam, anti-scintillation, and low probability of intercept) for tactical users in the Arctic region. IPS was deployed to meet the demand for protected polar satellite communications to support submarines, aircraft, and other platforms and forces operating in the high northern latitudes that have been steadily increasing over the last 20 years. The existing IPS payloads provide EHF low data rate (75 bps to 256 kbps) communications to users above 65° north latitude by using satellites in high elliptical orbit. Initial operational capability of the IPS was achieved in 1998 with the first payload, which was launched in 1997 or 1998 and is reported to be still providing uninterrupted service. The second IPS payload was announced as being in orbit in 2007, although it may have been launched some time earlier. The third payload will replace the first payload at an unknown date in order to maintain full operational capability of the system. The satellites that host these IPS payloads are not publicly identified. The IPS payloads are manufactured by Boeing Satellite Systems.

The Enhanced Polar System (EPS) is expected to provide an essential adjunct to the MILSATCOM midlatitude systems. EPS will provide continuous coverage in the polar region for secure, jam-resistant, strategic, and tactical communications to support peacetime, contingency, homeland defense, humanitarian assistance, and wartime operations. EPS characteristics will include:

- Protected communications services and communications services without continuous system command and control
- Integrated capability allowing different levels of planners to manage their resources
- Interconnectivity between EPS satellites and midlatitude users via an EPS Gateway located at a Global Information Grid Point of Presence
- Data rates between 75 bps and 1.28 Mbps (threshold)
- AEHF Extended Data Rate (XDR)-interoperable waveform

The first operational availability of EPS is scheduled for 2016. The system will comprise two EHF communications payloads hosted on satellites operating in highly elliptical orbits, modified AEHF communications terminals, a gateway to provide connectivity into other communication systems and the Global Information Grid (GIG), and an extension of the AEHF Mission Control Segment (MCS) hardware and software to accommodate EPS. The antenna farm on the payload will include a spot beam aimed at the gateway, a user spot beam, and a user earth coverage beam. The EPS payload prime contractor is Northrop Grumman.

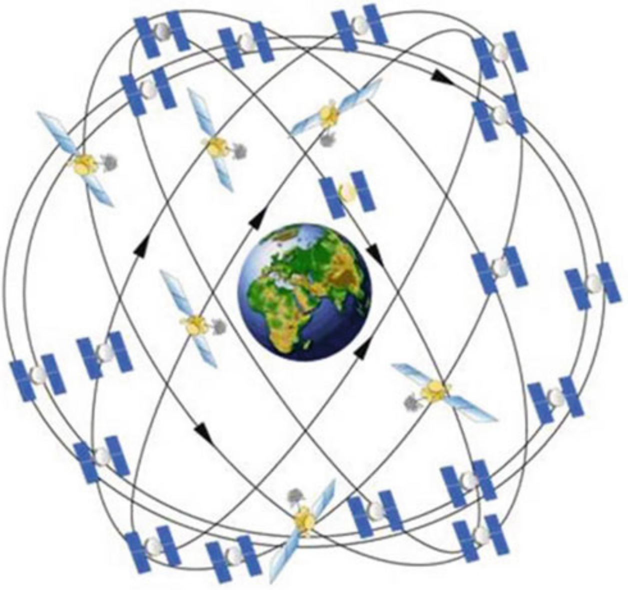
## 43.4 Global Positioning System (GPS)

The Global Positioning System (GPS) provides accurate and reliable positioning and timing to military and civil users around the world. At a minimum, the GPS constellation needs 24 satellites in six orbital planes (see Fig. 43.5) in order to ensure that at least four satellites are in view by the user at all times. The constellation flies in a semi-synchronous orbit at approximately 20,000 km above the earth.

GPS satellites have a semi-synchronous orbit, with a period of 11 h and 58 min. The 2-min offset from 12 h accommodates the movement of the Earth around the sun during a single GPS satellite orbit, i.e., the GPS orbital period is based on a sidereal day and not the solar day.

Due to better than specified reliability in orbit, the current constellation consists of about 30 satellites. The added redundancy offers improved accuracies and availability to users. As of summer 2012, the GPS operational constellation comprised ten Block IIA, twelve Block IIR, seven Block IIR-M, and two Block IIF satellites – the various Blocks will be described below and are summarized in the two accompanying diagrams: “GPS Modernization Program” (Fig. 43.6) and “GPS Program Evolution (Fig. 43.7).”

GPS offers two types of services to its user base – the standard positioning service (SPS) and the precise positioning service (PPS). The SPS is available for anyone’s use – military or civil. SPS offers 3–5 m accuracy. The PPS can only be accessed by authorized personnel – those with the correct decryption keys such as the US military or its allies. PPS accuracy is 2–4 m. There are several signals and codes that make up each of the GPS services.



Credit: USAF

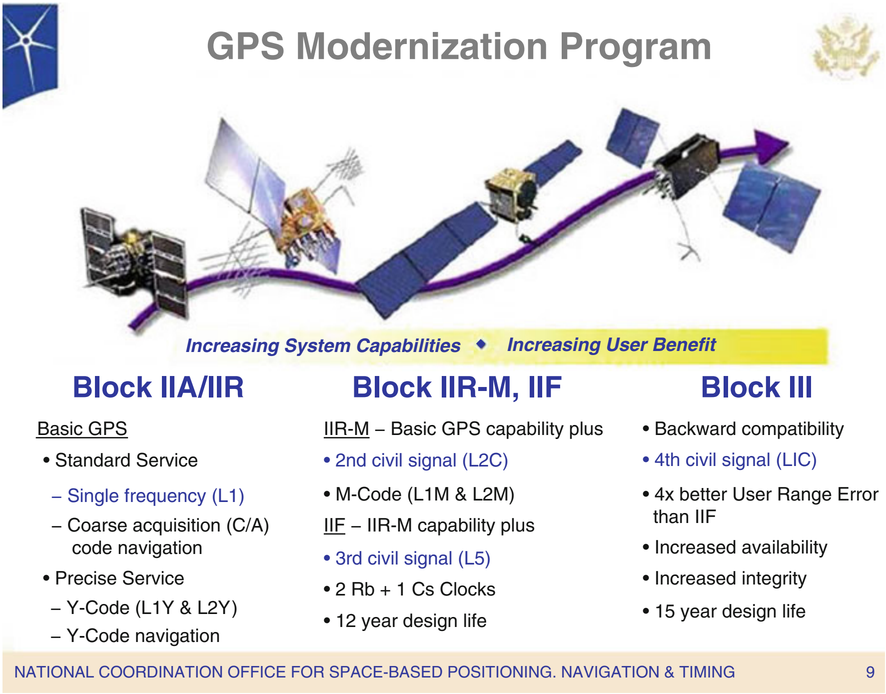
**Artist's impression of GPS Constellation (not to scale)**

**Fig. 43.5** GPS Constellation

Today, GPS transmits on the frequencies L1 (1575.42 MHz) and L2 (1227.6 MHz). The codes transmitted on these frequencies are the coarse acquisition (C/A) code and the pseudorandom P(Y)) code. Currently, the C/A code is transmitted on L1, and P(Y) is on both L1 and L2. The C/A code is what everyone receives – it is the code within the SPS. The P(Y) is an encrypted code and can only be received by those with the appropriate keys. This is the code that is obtained when a user is subscribed to the PPS.

Block IIA and IIR satellites transmit only two signals and codes – C/A on L1 and P(Y) on both L1 and L2. The Block IIR series are "replenishment" satellites developed by Lockheed Martin. Each IIR satellite weighs 4,480 lb (2,030 kg) at launch and 2,370 lb (1,080 kg) once on orbit. The first attempted launch of a Block IIR satellite failed on January 17, 1997, when the Delta II rocket exploded 12 s into flight. The first successful launch was on July 23, 1997. Twelve satellites in the series were successfully launched.

Within the Block IIR-M, the M-code, a second civil signal (L2C), and flex power have been added. L2C enables civil receivers to correct for the ionosphere. Flex power allows power to be transferred from one signal to another, thus providing some additional anti-jam capability. The first Block IIR-M satellite was launched on September 26, 2005, and the eighth and final launch of a IIR-M was on August 17, 2009. The prime contractor was Lockheed Martin.



GPS Modernization Program

Increasing System Capabilities ◆ Increasing User Benefit

**Block IIA/IIR**

Basic GPS
- Standard Service
  - Single frequency (L1)
  - Coarse acquisition (C/A) code navigation
- Precise Service
  - Y-Code (L1Y & L2Y)
  - Y-Code navigation

**Block IIR-M, IIF**

IIR-M – Basic GPS capability plus
- 2nd civil signal (L2C)
- M-Code (L1M & L2M)

IIF – IIR-M capability plus
- 3rd civil signal (L5)
- 2 Rb + 1 Cs Clocks
- 12 year design life

**Block III**

- Backward compatibility
- 4th civil signal (LIC)
- 4x better User Range Error than IIF
- Increased availability
- Increased integrity
- 15 year design life

NATIONAL COORDINATION OFFICE FOR SPACE-BASED POSITIONING. NAVIGATION & TIMING 9

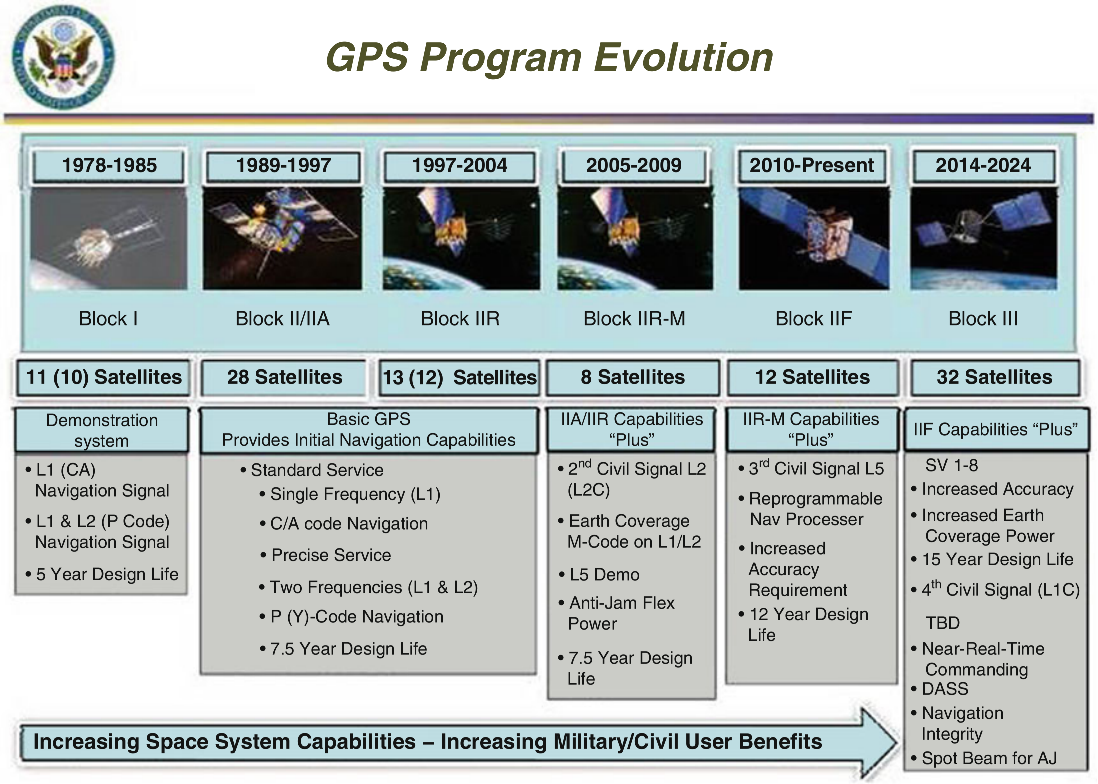
**Fig. 43.6** GPS Modernization Program

The Block IIF series are “follow-on” satellites developed by Boeing and have everything that IIR-M offers but add a third civil signal on L5 (used during “safety of life” applications). Boeing is under contract to build a total of 12 Block IIF satellites. The first was launched in May 2010 on a Delta IV rocket and the second on July 16, 2011. The spacecraft has a mass of 1,630 kg (3,600 lb) and a design life of 12 years. Compared to previous generations, GPS-IIF satellites have a longer life expectancy and a higher accuracy requirement. Each spacecraft uses a mix of rubidium and cesium atomic clocks to keep time within eight billionths of a second per day. They provide an improved military signal and variable power for better resistance to jamming in hostile environments.

The average contracted cost of a GPS-IIF satellite is $121 million although it is reported that Boeing has had to spend $306 million on each of the first three satellites. The price of the final nine GPS-IIFs was set in 2000.

The most advanced block being developed is GPS-III. It will have all the same capabilities as IIF and many added capabilities. It will have increased power in the form of a spot beam, and it will have slightly better accuracy, mostly due to cross-links that will greatly reduce the age of data. The first is expected to be launched in 2015 (a slip of a year since the Program Evolution diagram above was published).

The price of a GPS-III satellite is expected to be triple that of a GPS-IIF, i.e., more than $350 million. Lockheed Martin received a $1.5 billion contract to develop the



# GPS Program Evolution

| 1978-1985 | 1989-1997 | 1997-2004 | 2005-2009 | 2010-Present | 2014-2024 |
|---|---|---|---|---|---|
| Block I | Block II/IIA | Block IIR | Block IIR-M | Block IIF | Block III |
| **11 (10) Satellites** | **28 Satellites** | **13 (12) Satellites** | **8 Satellites** | **12 Satellites** | **32 Satellites** |
| Demonstration system | Basic GPS<br>Provides Initial Navigation Capabilities | | IIA/IIR Capabilities “Plus” | IIR-M Capabilities “Plus” | IIF Capabilities “Plus” |
| • L1 (CA) Navigation Signal<br>• L1 & L2 (P Code) Navigation Signal<br>• 5 Year Design Life | • Standard Service<br>• Single Frequency (L1)<br>• C/A code Navigation<br>• Precise Service<br>• Two Frequencies (L1 & L2)<br>• P (Y)-Code Navigation<br>• 7.5 Year Design Life | | • 2nd Civil Signal L2 (L2C)<br>• Earth Coverage M-Code on L1/L2<br>• L5 Demo<br>• Anti-Jam Flex Power<br>• 7.5 Year Design Life | • 3rd Civil Signal L5<br>• Reprogrammable Nav Processer<br>• Increased Accuracy Requirement<br>• 12 Year Design Life | SV 1-8<br>• Increased Accuracy<br>• Increased Earth Coverage Power<br>• 15 Year Design Life<br>• 4th Civil Signal (L1C)<br>TBD<br>• Near-Real-Time Commanding<br>• DASS<br>• Navigation Integrity<br>• Spot Beam for AJ |

**Increasing Space System Capabilities – Increasing Military/Civil User Benefits**

**Fig. 43.7** GPS Program Evolution

first two GPS-IIIs, with options in the contract for up to ten more satellites (six more is the baseline) in what is called the GPS-IIIA configuration. In principle eight GPS-IIIBs and sixteen GPS-IIICs will be procured later. The GPS-IIIB satellites would include a higher data rate cross-link to allow all onboard clocks to be updated simultaneously. The Block IIIC satellites are likely to have a higher power spot beam that provides more extensive anti-jamming capability. The GPS-III satellites are all built on the Lockheed Martin A2100 commercial satellite platform with refinements such as additional radiation shielding to ensure the required 15-year lifetime in the medium earth orbit (MEO) where the radiation environment is less benign than in geostationary orbit where most A2100s are located.

The headquarters for the control segment is the master control station (MCS) at Schriever AFB in Colorado Springs, operated by the 2nd Space Operations Squadron (2 SOPS) of the 50th Space Wing of the United States Air Force. In addition to the master control station, there are six GPS monitoring stations and ground antennas, located at Colorado Springs, Kwajalein Atoll and Hawaii in the Pacific Ocean, Ascension Island in the Atlantic Ocean, Diego Garcia in the Indian Ocean, and Cape Canaveral in Florida.

GPS satellites are commanded and controlled via the monitor stations, the MCS, and the ground antenna. Monitor stations are essentially high-quality GPS receivers placed at various precise locations throughout the world. These receivers track the satellites just like a normal receiver would – they obtain the satellites' ephemeris and any downlinked data. Information is then transferred to the MCS where it is processed to calculate the orbit and clock offsets of each satellite. The MCS transmits that data back to the satellite via the ground antenna to update the satellite with its true location and time. These upload corrections occur at least once per day, although the system can operate autonomously for an extended period if necessary – albeit with reduced accuracy.

The $1.5 billion OCX contract was awarded to Raytheon in 2010 to develop and deploy a major upgrade to the control segment. The initial OCX capability was expected to be online in 2015, but according to the head of Air Force Space Command, General William L. Shelton, it has been delayed by "about a year or two." An early version (Block 0) of the OCX software will be capable of supporting mission operations needed to launch and check out the first GPS-III spacecraft. The OCX contract currently covers the first two OCX Blocks plus 10 years of sustainment.

## 43.5 Surveillance

### 43.5.1 Introduction

Large elements of the US military surveillance satellite capability are classified, and the information in this chapter is drawn only from unclassified sources with the inevitable risk that the information is incomplete or wrong. The scale of the programs is enormous, including what the Head of the National Reconnaissance Office described as “the world’s largest satellite.” The following is the breakdown of the topic in this section:

- Optical Imaging Satellites (Sect. 43.5.2)
- Imaging Radar Satellites (Sect. 43.5.3)
- Missile Early Warning Satellites (Sect. 43.5.4)
- Nuclear Detonation Detection Systems (Sect. 43.5.5)
- Signals Intelligence Satellites – Non-Maritime (Sect. 43.5.6)
- Maritime Signals Intelligence Satellites (Sect. 43.5.7)
- Weather Satellites (Sect. 43.5.8)

### 43.5.2 Optical Imaging Satellites

Since the 1980s the US military has relied on a series of surveillance satellites referred to by the media as Keyhole satellites although the name for the more recent satellites is Enhanced Imagery System (EIS). They are large expensive spacecrafts, each weighing 10–15 t and costing about $1.5 billion (of which a third is for the launcher) – one of the most recently launched was said by NRO to have cost $2 billion less than originally projected, which suggests a multibillion dollar price tag. They orbit at between 300 and 900 km altitude and provide optical images that are said to have a resolution of 8–10 cm (3–4 in.) and less detailed infrared images. There are thought to be six in orbit at the start of 2014 launched in 1995, 1996, 2001, 2005, 2011, and 2013, and there must be some doubt about whether the two older ones are still fully functional. The latest four are upgraded versions that provide very wide coverage as well as detailed images. They can rotate their camera to dwell on a scene as they pass across the sky. The infrared feature means that they can take nighttime images.

General Bruce Carlson (see Fig. 43.8) when he was the Director of the National Reconnaissance Office that buys and operates these satellites promoted a cost-saving concept called Next Generation Electro-Optical reconnaissance satellite, or NGEO. He said that it “will require a little bit of up-front investment” but will result in a modular and flexible satellite allowing NRO to insert new technology more rapidly than at present as well as reducing costs. He was determined to halt the “erosion in the [NRO’s] science and technology base” that he described as “the seed corn for the future.” Improving the technology to put into its expensive operational satellites is also addressed using tiny low cost “cubesat.” NRO had 12 cubesats under construction in 2009 according to NRO official Karyn Hayes-Ryan. She noted that they can be built in less than 6 months and thus enable NRO to “keep pace with Moore’s Law.” Batteries, solar cells, computer processors, gyroscopes, and radios were some of the technologies she listed as being tested on cubesats. As well as quickly and cheaply testing new ideas in space, this approach helps train people and is “more risk tolerant” according to Ms. Hayes-Ryan.

General Carlson noted that many of the current satellites have lasted far longer than expected, and they deliver useful intelligence mainly because of “the young people that write software” to adapt the images the satellites produce. He joked that

**Fig. 43.8** Gen. (Retired) Bruce Carlson

"we have satellites inside our very aging constellation that are old enough to vote and some, that are still operating, are old enough to drink. We don't let them drink, but they are old enough to drink." On another occasion he quipped that "half the constellation is geriatric." He pointed out however that because of the improvements in software "if you look at the product that we got 10 years ago and compare it to the product that we have today, in many cases, it's an order of magnitude better in quality whether it's accuracy or clarity or timeliness."

A seventh satellite similar to the six just mentioned may also be in orbit at about 800 km altitude and is said to be a stealth satellite, impervious to detection from the ground. Launched in 1999 it was part of a program called MISTY that is thought to have to been canceled in 2006 when projected costs got out of hand. Intelligence specialist Jeffrey Richelson who first broke the story about the MISTY satellites is skeptical about their stealthiness. He notes that civilian observers were able to keep track of the first MISTY satellite launched in 1990 and watch its various maneuvers.

The EIS satellites are thought to resemble the Hubble Space Telescope (see Fig. 43.9) in shape and size and are supplied by the same prime contractor, Lockheed Martin. This suggested resemblance was reinforced in 2012 when the NRO donated two unused optical assemblies (essentially telescopes) to NASA similar in size to those of Hubble. The telescopes are thought to have been left over from the canceled program to develop a replacement for the EIS satellites, called the Future Imagery Architecture. The telescopes weigh 1.7 t each and have the same sized primary mirror as Hubble, 2.4 m diameter, but lack cameras (detectors, filters, prisms, etc.), stabilization, power, and so on. They have a wider field of view than Hubble, and the optical quality of the mirror surface is not too

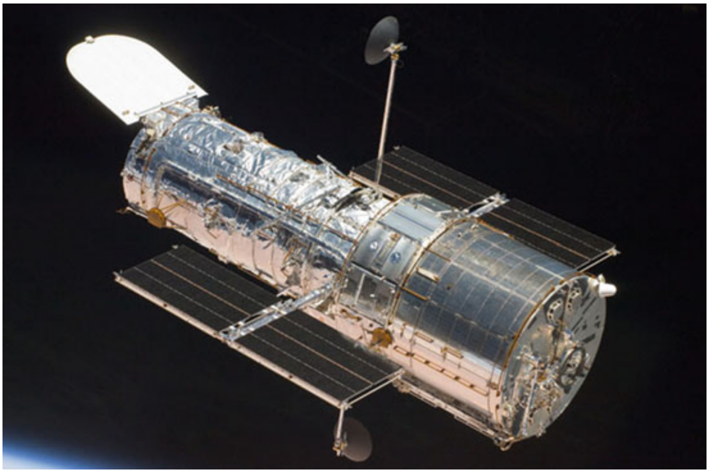


**Fig. 43.9** Hubble Space Telescope

dissimilar – about 60 nm versus Hubble's 30 nm. Budget figures leaked by Edward Snowden indicate that development of a new series of satellites began in 2012 called the Evolved Enhanced CRYSTAL System (EESC). The funding figures also suggest that production of EIS satellites is being run down.

The US military has been a major purchaser of commercial satellite images (such as those of France's SPOT series) for many years. In 2003, the National Geospatial-Intelligence Agency (NGA) placed two contracts guaranteeing to purchase $150 million per annum of imagery from each of the two suppliers and offering about half of the $500 million cost of building and launching each of the high resolution optical satellites. The action by NGA followed on from a $100 million contract for high resolution imagery in 1999 to a third company. A smaller contract followed in 2004 to that third company, and in 2005 that company merged with one of the 2003 winners leaving DigitalGlobe and GeoEye as NGA's two high resolution commercial suppliers. In 2010 the NGA reinforced its commitment to using commercial imagery with the award of contracts valued at $7.3 billion in total over 10 years to the two companies, although cutbacks driven by the Federal budget deficit may reduce the per year value of these contracts somewhat, partially as a consequence of which the two companies combined in 2013 under the name DigitalGlobe.

The formation of the NRO as a joint venture of the DOD and the CIA illustrates that the data from imaging satellites is used by two distinct communities – the military and the intelligence agencies. The friction between the requirements of the two communities surfaces from time to time, e.g., the urgent, tactical needs of the military in today's conflict zone versus the background gathering of information about tomorrow's enemy by the intelligence agencies. Budget pressures are said to have increased this tension and even to have contributed to the relatively early retirement of General Carlson as NRO Director.

The NGA, with a budget of about $5 billion per annum, is the arm of the military and intelligence communities that “develops imagery and map-based intelligence solutions for US national defense, homeland security, and safety of navigation.” In other words they process the imagery from spy satellites.

### 43.5.3 Imaging Radar Satellites

In the summer of 2008, the US Administration declassified the fact that the country has radar imaging satellites. This was hardly Earth-shattering news since the “secret” had been widely known and discussed for more than a decade. It is also common knowledge that US efforts to develop a new generation of imaging radar satellites had become so expensive that the effort was canceled in 2008. Perhaps this more cost-conscious approach explains why the number 2 official at the NRO, Betty Sapp, was able to tell a Congressional Subcommittee in April 2010 that “the NRO received an Unqualified Opinion on its fiscal year 2009 Financial Statement.” More surprisingly, she added that “this was the first clean audit for a defense intelligence agency since 2003.”

As of early 2014 there are said to be seven operational radar imaging satellites in orbit, launched in 1997, 1999, 2000, 2005, 2010, 2012, and 2013 which means that the longest serving ones must be near the end of their life and/or may not be operating at full performance. The three most recently launched are said to be of a new generation with enhanced performance and are produced by Lockheed Martin. These TOPAZ satellites (often called “Lacrosse” or sometimes “ONYX” by the media) are thought to weigh about 4 t and are extremely large (50 m across with their solar arrays deployed) in order to generate the 10–20 kW of power needed to drive the radar – and correspondingly expensive at $1½ billion each. They provide imagery through cloud and in the dark with a resolution of about 1 m. They orbit at about 1,000–1,100 km altitude with orbital inclination of about 60 (or 120), while earlier models orbited about 400 km lower and were considerably heavier (14 t). Ground-based imagery taken by amateur observers appears to show a gold colored circular or ellipsoidal radar dish of about 50 m diameter – probably with a mesh surface rather than a solid one. Leaked budget figures show that procurement of a Block 2 series of the current TOPAZ satellites began in 2013.

The USA has turned to the international commercial marketplace to augment the TOPAZ radar images. In 2008, the NGA began to buy small quantities of radar imagery from Canadian company MDA which owns and operates the Radarsat satellites. Then in early 2010 the NGA placed contracts to buy up to $85 million worth of data over a 5-year period from each of the three foreign imaging radar satellite families: Germany’s TerraSAR-X and TanDEM-X, Italy’s four COSMO/SkyMed satellites, and Canada’s Radarsat-1 and Radarsat-2. US Southern Command has also purchased some Israeli TecSAR imagery probably to help in the war on drugs in Central and South America.

### 43.5.4 Missile Early Warning Satellites

For the past 40 years, the US satellites used to spot missile launches (also called early warning satellites) that have been labeled as Defense Support Program (DSP) satellites.

The first DSP was launched in November 1970, although a series of experimental satellites, with the designations MIDAS and RTS, had been launched throughout the 1960–1966 period to demonstrate the concept of launch detection and try out various techniques – different orbits, sensors, data recovery methods, and so on. The general idea was to watch for the bright flash of light and flare of heat given off by a rocket motor. They proved very successful at spotting Soviet and Chinese missile launches. DSP data allowed the launch site to be pinpointed to within 3–15 km and the launch heading to within 5–25° depending on various factors such as the relative location of the launch and the DSP satellite. There were a few false alarms, but only for smaller missiles such as submarine-launched missiles in the northern hemisphere summer (due to the glint of the sun on the sea).

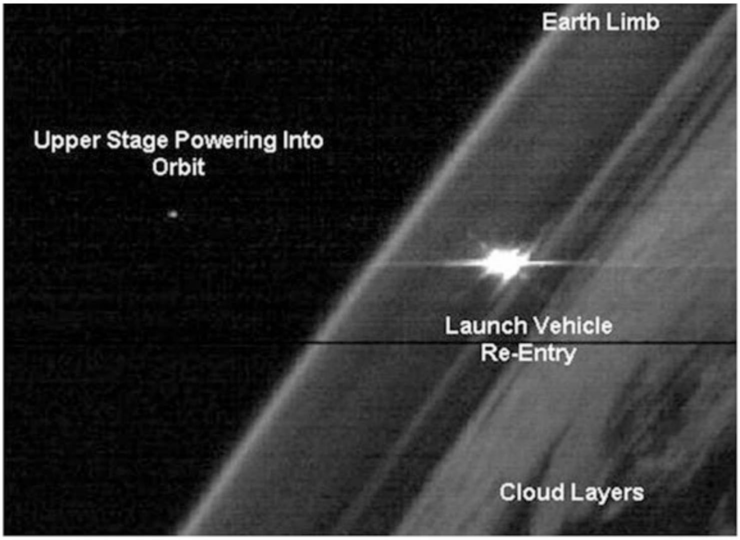
Any bright flash triggered the DSP sensors, but software algorithms sorted out the missile launches from ammunition dump explosions, forest fires, gas pipeline fires, the burn-up of satellites reentering the earth's atmosphere, military jet aircraft using afterburner – even the July 1996 explosion of TWA Flight 800.

As the capabilities of DSP satellites have grown, so have their weight and power. Unlike the old lightweight, low-power satellites, the newest generation of DSP satellites weighs over 5,000 lb, and the solar arrays generate 1,285 W of power. The current DSP satellite is approximately 33 ft long and 22 ft in diameter. The system comprises the satellite vehicle, also referred to as the bus and the sensor. The satellites are placed in geosynchronous orbit. Global coverage can be efficiently achieved with three satellites. Additional satellites can provide dual or triple coverage, providing for more accurate and timely event reporting.

The DSP satellite spins around its Earth-pointing axis, which allows the infrared (IR) sensor to sweep across each point on the earth.

The DSP sensor detects sources of IR radiation. A telescope/optical system and a photoelectric cell (PEC) detector array, comprised primarily of lead sulfide detectors and some Mercad-Telluride cells for the MWIR detection capability, are used to detect IR sources.

The replacement for the DSP missile warning satellites is gradually and belatedly being launched. The first two elements of the highly elliptical orbit (HEO) part of what is now called the Space-Based Infrared System (SBIRS) constellation were launched in 2006 and 2008, piggybacking on other unidentified (for security reasons) US military satellites. A third payload is to be launched soon (the date of launch is classified to prevent identification of the hosting satellite). The first SBIRS in geostationary orbit was launched in 2011 and the second in 2013. Lockheed Martin Space Systems in Sunnyvale, CA, is the SBIRS prime contractor; Northrop Grumman Electronic Systems in Azusa, CA, as the payload subcontractor; and Lockheed Martin Information Systems & Global Services in Boulder, CO, is the ground system subcontractor.



Credit: USAF

Space-Launch, Orbital Insertion Engine and Launcher Re-Entry detected by SBIRS HEO-1

**Fig. 43.10** SBIRS HEO-1 Image

The technology used in SBIRS is much more powerful than in DSP. The sensor sweeps across the Earth below every second or so, and if it spots an event of interest, another sensor dwells on that event to pick up as much detail as possible. Unlike DSP, the output of the sensor is an image not just a location, so further analysis can be performed on it.

The sophistication of the facilities on the ground has also been enhanced – more powerful computer processing to analyze the information and faster relaying of results to the troops, ships, or planes that can do something about it. Even before the first SBIRS was launched, the timeliness and quality of DSP information had improved because of this. One industry official claims SBIRS will be ten times better than DSP, able to detect dimmer and more fleeting targets, and presumably the effects of the upgraded ground facilities will improve that even further.

The second SBIRS piggybacking on an unnamed military satellite is also sending back high-quality information. Fig. 43.10 shows the track of a missile above the clouds as seen by SBIRS, indicating that the trajectory can be spotted and analyzed in quite some detail.

Already 7 years behind schedule, the first geostationary SBIRS satellite fell foul of a very modern problem in 2009 in that its software was found to be faulty, resulting in a delay and modification that cost $750 million. The faults were so bad that USAF Colonel Robert Teague said “the [software] design and architecture had fundamental flaws. The solution essentially required starting from scratch.” General Robert Kehler, the head of the USAF Space Command, sounded resigned to even more delays and cost increases when in the fall of 2009 he said that “I don’t know if there will be any other impacts to schedule and cost. I'm not optimistic or pessimistic. We are where we are with SBIRS." What is now considered to be the full constellation of two geostationary and two elliptical satellites costing about $15 billion is due to be operational in 2014, but the system won't achieve full use of any GEO satellite staring sensors until the ground systems are modified, around 2018.

SBIRS is an integrated "system of systems" consisting of ground components as well as the satellites described above. The ground component consists of control stations such as the Mission Control Station located at Buckley AFB, Colorado, which is responsible for consolidating event data from dispersed legacy DSP ground systems. Remote ground stations (including mobile and deployable stations) receive missile warning data from the satellites and feed the data via secure communication links to ground stations for processing. The ground stations assess system reliability, attempt to identify the type of launch occurring, and generate a launch report. Crews send these reports to the NORAD operation centers at Cheyenne Mountain AFS, Colorado; the Alternate Missile Warning Center at Offutt AFB, Nebraska; and other command centers.

Because of the lengthy delays and cost overruns in deploying the SBIRS satellites, an alternative approach was begun leading to the launch of a flight demonstrator in September 2011. The Commercially Hosted Infrared Payload (CHIRP) was hosted on the geostationary commercial telecommunications satellite, SES-2, developed by Orbital Sciences. The sensor payload was supplied by SAIC of McLean Virginia. CHIRP is a wide field of view staring sensor designed to detect and track the heat signature of missiles at launch. The budget of $216 million is considerably lower than the >$1 billion budget for the SBIRS satellites, but now that those are finally being deployed, the CHIRP concept seems likely to be discontinued.

### 43.5.5 Nuclear Detonation Detection System

The GPS satellites described above carry an additional payload suite to support a Nuclear Detonation Detection System (NDS). The NDS payload is also carried by the DSP early warning satellites described above (which are gradually being phased out) and was initially the primary mission of the VELA satellites. The sensor array includes optical, x-ray, dosimeter, and electromagnetic pulse (EMP) sensors which detect and measure light, x-ray, subatomic particle, and EMP phenomenology to pinpoint the location and yield of a surface or airborne nuclear detonation. A nuclear explosion starts off with a short very intense flash then a short dimming, while expanding gas overtakes the fireball and masks it from view until the gas has thinned and cooled enough for the fireball to be visible again – this dual flash enables the NDS to distinguish a nuclear explosion from other events. The information sensed on the GPS NDS system is relayed to the ground-based Integrated Correlation and Display System (ICADS) via a dedicated channel, L3 (1381.05 MHz). NDS supports several tasks, such as treaty monitoring and nuclear force management.

GPS-III satellites will carry a newly designed nuclear detection payload, details of whose performance are classified.

### 43.5.6 Signals Intelligence Satellites: Non-maritime

The first US communications intelligence (COMINT) satellite was launched in 1968. Called CANYON it was the first of a series that is thought to continue today although the name has changed over the years – to CHALET then VORTEX then MERCURY and currently NEMESIS and ORION. The name changes were to some extent caused by security lapses such as that by British spy (and pedophile) Geoffrey Prime and US spy Christopher Boyce.

The technology of these eavesdropping satellites is impressive. They are located 36,000 km out in space in the geostationary arc. Being so far from the ground, the satellites need enormous radio antennas to pick up radio signals. The MUOS antenna (see Sect. 43.3.3, above) is 28.6 m diameter when unfurled in orbit. But the secret eavesdropping satellites are thought to have already been 50 m wide by 1994 and 90 m by 2006 – at least one newspaper report claimed they had dishes 150 m wide (almost 500 ft). The Head of the NRO, General Bruce Carlson, said that the satellite launched on 21 November 2010 from Cape Canaveral was “the largest satellite in the world” – thought to be one of the ORION series mentioned below.

The first satellite to “watch” the earth was in fact an electronic intelligence (ELINT) satellite – the tiny GRAB satellite. GRAB was launched into orbit in 1960 and provided hitherto inaccessible information about radar systems deep inside the Soviet Union. GRAB worked by receiving radio signals across a very wide range of frequencies and relaying them to a station on the ground. The satellite didn’t process the signals in any way, just acted like a “bent pipe” in taking radio signals that it heard at its 1,000 km altitude and beaming them downwards to a friendly station. By having a station suitably located near the border, signals from 5,500 km inside the Soviet Union could be picked up. Signals from two Soviet radar systems, one associated with SAM-1 anti-aircraft missiles the other with missile early warning, were detected and could then be analyzed. The advantage of knowing the characteristics of an adversary’s radar was not only that you could in future know what it was when you detected it, but you could design electronic countermeasures to jam it or confuse it. GRAB was the first of a long line of what became known as ELINT satellites.

The success of GRAB encouraged the USA to use satellites extensively for analyzing its enemy’s radars and other military signals. The tiny GRAB evolved into massive satellites with enormous antennas as discussed above. Many of these satellites were placed in geostationary orbit, 36,000 km above the Earth, hence the need for their giant antennas. One series already mentioned above, initially targeting communications intercepts, began with the launch of CANYON in 1968[2] which evolved a decade later into CHALET. A second series that was targeted at data from missile tests began in 1970 with the launch of the first RHYOLITE satellite (later renamed AQUACADE). This series evolved to pick up communications transmitted across the Soviet Union via microwave towers. It was succeeded in 1985 by the first

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[2] The names of US spy satellites are always written in uppercase – the reason for this pretentious habit is not known to the author.

of two MAGNUM satellites. In 1994 a new generation of satellites began to appear. As we approach the present day, details about the current US eavesdropping satellites become more and more vague.

In addition to satellites in geostationary orbit, another group of eavesdropping satellites has been picking up radio signals in what is called a Molniya orbit discussed in the previous chapter – this is an elliptical orbit that is at its maximum height over the northern hemisphere and at its lowest over the southern. Their maximum height is similar to a geostationary satellite with a correspondingly broad view of the Earth below. The big advantage is that they cover northern latitudes better than from geostationary orbit, but the disadvantage is that they move along their orbit from north to south and thus are over the northern area of interest only for 8 or so hours a day. Three satellites in Molniya orbit are sufficient to provide continuous coverage over a given area. Initially called JUMPSEAT satellites, these evolved into the TRUMPET satellites that were launched in 1994, 1995, and 1997. The first in what is said to be a TRUMPET replacement series was launched in 2006.

There are thought to be about a dozen US ELINT satellites currently in orbit. Leaked 2011-2013 budget documents show that three series are currently in operation called RAVEN (unfunded since before 2011), NEMESIS (unfunded in 2012 and 2013) and ORION. Recent launches of satellites that fall into one or other of the COMINT categories are said to include NRO-26 in January 2009, NRO-32 in November 2010, and NRO-15 in June 2012.

The cost of these satellites is astronomical. Press reports of the January 2009 launch of the 6 t NRO-26 referred to it as a “highly upgraded ORION electronic eavesdropping satellite” and said that “the combined cost of the spacecraft plus booster is roughly $2 billion.” Leaked budget documents show that a “SIGINT High Altitude Replenishment Program (SHARP)” is underway costing about $800 million per annum. This expensive development budget suggests that the satellites that eventually emerge from this program will continue to cost in excess of $1 billion each. Recent cost overruns of several types of US spy satellites have become public knowledge, and ELINT satellites are no exception. An attempt to move to a more cost-effective approach was discussed in the trade press for several years and would have involved a larger number of cheaper satellites – but it seems to have been a failure, since the large expensive type is still being launched every 2 or 3 years.

The high cost of these monster satellites means that they are designed to last for 15 or more years – it would be too expensive to replace them more frequently. But communication is an area which changes dramatically every few years, so the expensive long-lasting satellites risk becoming obsolete before they have served their term.

### 43.5.7 Maritime Signals Intelligence Satellites

The USA has for many years deployed constellations of satellites in orbit groups of 2, 3, or 4 satellites so that they could triangulate the signals from a ship using the different time and direction of the ship's radio signals as seen by each satellite in the group. The various series of US satellites originally had friendly names (at least for use publicly) starting with Poppy in the 1960s then White Cloud in the 1970s and 1980s. More recently these satellite groups are referred to as NOSS (Naval Ocean Surveillance Satellite) followed by a −1, −2, or −3 to signify which generation (White Cloud being NOSS-1) and the program has the unfriendly official name, INTRUDER.

The pair of satellites (the USAF designates one of them as "debris" presumably in an attempt to disguise their mission) launched as NRO-34 in April 2011 is said to be the fifth pair in the NOSS-3 series.

A pair of NOSS satellites, each weighing about 3 t, plus the rocket on which they are launched into orbit costs about $600 million – there are thought to be 20 or so in orbit altogether, spaced so as to give as near as possible continuous coverage of the ocean areas of interest. A database of all ship movements is maintained based on NOSS information plus data from Navy and Coast Guard air and sea surveillance. Civilian as well as military ships are tracked reflecting the threat from terrorists and the interest in the navies of countries such as China and Iran.

In addition to detecting ships and working out their exact location by triangulation, these satellites allow the ships' radar signals and radio communications to be collected for later analysis. In recent years the US military have acknowledged that specific launches are in the NOSS category but not that they are a group – civilian observers have detected additional objects close to the acknowledged one, but the military refer to those objects as "debris." The current INTRUDER (NOSS-3) satellites come in pairs as has been recorded by many ground-based observers just by watching them with binoculars. The satellites are about 1,000 km high with an orbital inclination of about 63°, and one of the pair trails the other by about 250 km. The height is a compromise between being as close to the Earth as possible in order to detect faint emissions and being as high as possible to get a broad view. The relatively small separation of the pair ensures that they both see the same target, thus allowing the signals to be compared and the target's location and direction to be triangulated.

There is occasional press and web speculation that INTRUDER satellites possess radars of their own and thus detect ships that are observing radio and radar silence. Other reports say that INTRUDER satellites can detect the faint radio emissions from a ship's engines and the magnetic effects of a ship's hull.

### 43.5.8 Weather Satellites

The Defense Meteorological Satellite Programme (DMSP) has been providing weather information for the Department of Defense for half a century (initially it was called Program 35).

Two primary operational DMSP satellites are always in near-circular, sun-synchronous, 835 km altitude, near-polar orbits with a period of 101.6 min and an inclination of 98.75°. The primary weather sensor on DMSP is the Operational Linescan System, which provides continuous visual and infrared imagery of cloud

Credit: USAF

**DMSP's Operational Linescan System produces day & night visual & infrared imagery, such as this night-time view of East Asia showing Japan (right), S Korea (centre) with N Korea almost entirely dark above it, and China (left)**

**Fig. 43.11** DMSP Image of East Asia

cover over an area 1,600 nautical miles wide (see Fig. 43.11). Global coverage of weather features is accomplished every 14 h providing essential data over data-sparse or data-denied areas. Additional satellite sensors measure atmospheric vertical profiles of moisture and temperature. Military weather forecasters can detect developing patterns of weather and track existing weather systems over remote areas, including the presence of severe thunderstorms, hurricanes, and typhoons.

The DMSP satellites also measure space environmental parameters such as local charged particles and electromagnetic fields to assess the impact of the ionosphere on ballistic-missile early warning radar systems and long-range communications. Additionally, these data are used to monitor global auroral activity and to predict the effects of the space environment on satellite operations.

DMSP-5D3-F18 was launched in 2009 on an Atlas V 401, and DMSP-5D3-F19 in 2014. Compared with earlier versions the current Block 5D-3 satellites include upgraded instruments, increased power capability, improved on-orbit autonomy (60 days), enhanced design-life duration of 5 years, solid-state data recorders, and a UHF downlink which enables data to be sent directly to tactical users.

The next generation DMSP military weather satellites and civilian National Oceanic and Atmospheric Administration (NOAA) satellites were to have been merged into the National Polar-Orbiting Operational Environmental Satellite System (NPOESS). In 2010, with $6 billion having been spent on NPOESS already and the total budget still rising, the program was canceled. The DOD initiated the Defense

Weather Satellite System (DWSS) to replace it, but in 2012 that too was canceled due to budget constraints. One more Block 5D-3 DMSP has been built and is in storage at the plant of prime contractor Lockheed Martin, tentatively scheduled for a launch in 2020. The Air Force had identified problems with the suite of microwave and ultraviolet sensors on the final two DMSP satellites but has made the necessary fixes to them. The remaining satellite should ensure a continuing service until well past 2020 (depending on unpredictable reliability of the in-orbit satellites), although Air Force Secretary Michael Donley admitted in 2012 that their technology is out of date.

The DMSP 5D-3 satellites weigh 1¼ ton of which 350 kg is the sensor payload, and the solar panels produce 2.2 kW of power. The satellites are over 7 m long with solar panels deployed.

As part of the NPOESS convergence plan, DMSP operations were transferred from the Defense Department to the Commerce Department in 1998, with funding responsibility remaining with the Air Force. Satellite operations were moved to Suitland, Md, where NOAA’s Office of Satellite Operations provides the command, control, and communications for both DMSP and NOAA’s Polar-Orbiting Operational Environmental Satellite system. Although NPOESS has been canceled, NOAA continues to operate the DMSP satellites using a common civil/military ground system.

Tracking stations at New Boston Air Force Station, NH; Thule Air Base, Greenland; Fairbanks, Alaska; and Kaena Point, Hawaii, receive DMSP data and electronically transfer them to the Air Force Weather Agency at Offutt Air Force Base, Nebraska. Tactical units with special equipment can also receive data directly from the satellites.

The Space and Missile Systems Center at Los Angeles AFB, Calif., is responsible for development and acquisition of DMSP systems.

## 43.6 Other Satellites

### 43.6.1 Space-Based Space Surveillance (SBSS)

The first Space-Based Space Surveillance (SBSS) satellite was launched in 2010 able to detect debris, spacecraft, or other distant space objects without interference from weather, atmosphere, or time of day. SBSS is especially useful for monitoring small objects in geostationary orbit – ground-based optical telescopes are the alternative solution for this function. Under a $189 million contract, Boeing has overall responsibility for the SBSS system, including the ground system and initial mission operations and including Ball Aerospace which is providing the satellite and sensor. The 1 t satellite has a sensor sensitive to visible wavelengths with a large aperture that provides a wide field of view. The sensor is mounted on a two-axis gimbal so that it can be quickly and efficiently moved between targets. It has twice the sensitivity and triple the probability of detecting threats of alternative techniques such as the MSX Space-based Visible Sensor (SBV), which ceased operation in December 2008. The SBSS satellite is in a 630 mile high circular sun-synchronous orbit (inclination 97.8°). It is operated from the Satellite Operations

**Fig. 43.12** Mitex Mission Badge

Center located at Schriever AFB, Colorado Springs. Initial Operational Capability was delayed due to faulty electronics which reset when passing through the South Atlantic Anomaly (a low-hanging spur of the ionosphere) requiring a software upload in April 2012.

The USAF is reviewing the requirements for follow-on satellites that would make up a constellation in space taking into account the results from the SBSS-1 satellite and from improvements in ground-based technology such as the $110 million Space Surveillance Telescope at White Sands Missile Range, New Mexico. In early 2014 Head of US Air Force Space Command Gen William Shelton announced that the function of monitoring objects in geostationary orbit would be undertaken by a system called Geosynchronous Space Situational Awareness Program (GSSAP). The first pair of GSSAP satellites will be launched into geosynchronous orbit in late 2014 on a Delta 4M+ rocket and a second pair in 2016. They carry electro-optic sensors and the prime-contractor is Orbital Sciences Corp. It is expected that each pair of GSSAP satellites will be able to move around the geostationary arc inspecting objects, a technique trialled by the Mitex pair of satellites launched in 2006 (see 43.6.2).

### 43.6.2 Mitex

The two Mitex satellites launched in 2006 offer another way to monitor objects in geostationary orbit – go there and look around. The 225 kg satellites are small and thus difficult to detect from the ground. Their ability to inspect geostationary orbiting objects was demonstrated in December 2008 and January 2009 when they were commanded to approach the malfunctioning 2½ ton DSP-23 early warning satellite that was drifting eastwards across the geostationary arc at about 1° per week from its 8.5°E longitude starting point – posing a threat to other satellites as it drifted. Officially the Mitex microsatellites are testing a range of technologies for the Defense Advanced Research Projects Agency (DARPA), the US Air Force, and the US Navy (Fig. 43.12). These include avionics,

**Table 43.1** OTV Flight Schedules

| | OTV-1 flight | OTV-2 flight |
|---|---|---|
| **Launch** | April 22, 2010 | March 5, 2011 |
| **Landing** | Dec. 3, 2010 | June 16, 2012 |
| **Mission length** | 224 days | 469 days |

advanced communications, fuels that spontaneously ignite on contact, solar cells, and new software. One was built by Orbital Sciences, the other by Lockheed Martin. The GSSAP satellites (see 43.6.1) are widely seen as successors to Mitex.

### 43.6.3 Research Satellites

US military technology proving and mission demonstration satellites are typically the subject of two or three launches each year. The satellites are often members of a series with names such as TacSat, Operationally Responsive Space (ORS), STPSat, Falconsat, etc. Increasingly, cubesats and other forms of micro- and nano-satellites are part of the mix. Given their ad hoc and nonoperational nature, they will not be described here – with the following exception.

The most widely reported USAF research space mission in recent years has been that of the X-37B series, so that will now be briefly described.

Two X-37B robotic spaceplanes (mini, unmanned versions of the Space Shuttle) have been into orbit and reentered successfully. The schedules of the flights of Orbital Test Vehicle (OTV)-1 and Orbital Test Vehicle (OTV)-2 are shown in Table 43.1. Each vehicle weighs about 5 t (barely one twentieth that of the Space Shuttle), and they were both launched from Cape Canaveral, Florida, on an Atlas V 501 rocket and landed at Vandenberg Air Force Base, California. Their orbits have not been publicly announced, but amateur enthusiasts have documented variations of orbit during each flight, generally in the 300–400 km altitude region with an inclination of about 40°. OTV-2 was in a 330 × 340 km × 42.8° orbit until a series of burns lowered it to 280 km 3 weeks before its reentry.

OTV-1 was launched for the second time on December 11 2012 and was still in orbit in April 2014, 16 months later (the 469 day duration of OTV-2 was exceeded on March 26 2014).

X-37B program manager Lt. Col. Tom McIntyre noted that "with the retirement of the space shuttle fleet, the X-37B OTV program brings a singular capability to space technology development. The return capability allows the Air Force to test new technologies without the same risk commitment faced by other programs."

The details of the X-37B's mission, which is overseen by the Air Force's Rapid Capabilities Office, are classified, as is its payload. The US Air Force's deputy undersecretary for space programs, Richard McKinney, described it in 2010 as "a test vehicle to prove the materials and capabilities, to put experiments in space and bring them back and check out the technologies. This is, pure and simple, a test vehicle so we can prove technologies and capabilities."

The X-37B project is managed by the USAF's Rapid Capabilities Office in Washington; the vehicle was developed by Air Force Research Laboratory offices AFRL/RV at Kirtland AFB, New Mexico, and AFRL/RB (Air Vehicles) at Wright-Patterson AFB, Ohio, with Boeing Phantom Works. This sets it apart from other USAF space projects which are mostly managed out of Los Angeles and indicates a closer connection with the "air" side of the Air Force.

## 43.7 Future Prospects

The short-term upgrades and replacements for the various satellites described in this chapter have been covered alongside the description of the current systems. There are some general trends across all of the programs including the following:

- There is an increased, but still not universal, willingness within the US military and intelligence communities to use commercial satellite services.
  - In telecommunications, the military is a major purchaser of ad hoc commercial services, but has avoided the long-term relationships with commercial suppliers of the type adopted in the UK, Spain, and elsewhere.
  - In the surveillance world, the US military dominates the world marketplace for optical imagery. Recognizing its ability to influence the commercial market, it has underpinned the financing of the combined DigitalGlobe/GeoEye company, by entering long-term data and service purchase agreements with it. In parallel, it continues to build and operate very sophisticated systems itself without any sign of a letup.
  - The GPS navigation system remains a DOD program despite the fact that the service is the mainstay of an enormous global commercial business. With the entry of Russian, Chinese, and European systems with performance similar to GPS, and all providing the navigation signal free of charge, DOD will almost certainly have to continue funding the system.
- DOD space systems have with rare exceptions been late and over budget. Many new systems in telecommunications and surveillance have been canceled in recent years because of this, some of which have been mentioned in the previous sections.
  - The NRO Director from 2009 to 2012, General (Ret.) Bruce Carlson, worked wonders in overseeing the successful deployment of several much-delayed and much-needed surveillance systems in 2010–2012. It remains to be seen if NRO can continue this successful record after his departure.
  - Systems such as MUOS (Sect. 43.3.3) and SBIRS (Sect. 43.5.4) have been placed in orbit despite the fact that their support systems will not be fully available for some years to come. GPS-III (Sect. 43.4) is likely to follow suit.
- There is some recognition in the US military that large sophisticated satellites are sitting ducks for anti-satellite weapons and that more and simpler satellites might provide a more robust service. However, this intellectual analysis has largely failed to influence the latest US military space systems, which are generally larger than the previous generation. This situation is broadly at odds with the trend in the commercial space marketplace where small satellites have

established an important niche for customers willing to seek a compromise of price versus performance versus schedule.

- For the USA, “interoperability” usually means that the partners have to be compatible with US systems and often are required to purchase US equipment. The dominance of US forces in NATO means that this tendency is likely to continue.

## 43.8 Conclusions

The US military space program continues to dwarf (a) the military space programs of all other countries combined and (b) of US civilian agencies such as NASA. The USA is unique in deploying military satellites of all types and on a global basis, and there is little sign that this will change in the next decade.

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# Russian Space Launch Programs

# 44

Igor Ivanovich Kuznetsov

## Contents

**Abstract**

The Russian launch program can be considered today as the most complete launch program. This chapter provides a historical overview on the Russian launch program. An overview of the current Russian launcher development program follows. It provides information on the various launchers and launch sites. The chapter continues with providing information on the expected evolution of Russia's launcher development program until 2030 and beyond.

## 44.1 Introduction: A Historical Overview

Russia has a long history in space launcher technologies. Since the 1950s, Russia (former USSR) has built its own space launcher capabilities, which resulted to several outstanding achievements. In 1957 the Soyuz launcher, initially built as

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Intercontinental Ballistic Missile (ICBM), placed the first artificial satellite to Earth orbit and in 1961 the first human into space. During the 1960s, the space race with the USA for the Moon has challenged launcher development to limits of what was technically possible. The need to be able to launch heavier cargoes and to reach distant orbits, and possibly Moon and beyond, resulted to launcher development projects known as N-1 heavy rocket series, followed by the development of the most powerful rocket engines ever built, known as NK-33.

After the 1960s, when the Moon race was over and the deep space human exploration seemed to be difficult to defend politically, the interest of USSR space program turned to the low Earth orbit utilization (e.g., long-term human habitation in space), surveillance and security, dual-use technologies, scientific and telecommunications independence, and others. Since the 1970s, the Russian space program became more open for international cooperation. Intersputnik and Intercosmos became the organizations for international cooperation in telecommunications and science, respectively. In 1980s, a new Zenit rocket development program started. This included rockets with liquid booster technology which at that time was expected to replace the Soyuz launchers to be used for human-made spaceflights. Today, its current modification is used for sea launch commercial operations or for the "Land Launch" space program.

In the 1970s, following the new space shuttle technology development in the USA, the USSR was building its own prototypes known as Buran with the most powerful heavy-lift rocket ever built called Energia. Because of the political and economic turbulences during the late 1980s and the breakdown of the USSR in early 1990s, the very expensive projects Energia and Buran were abandoned. Consequently, the Buran space shuttle conducted only one fully automated orbital flight in 1988.

Besides the traditional space launcher technologies represented by the Soyuz and Proton rocket family, the big interest has been on the development of small launchers mostly for military and defense purposes. During the early 1990s, the Rockot space launcher vehicle was successfully tested from Baikonur Cosmodrome and now is one of the most reliable commercial launch technologies operating from Plesetsk launch site. Until the 1990s, the Russian launcher and space programs were under the strict military control, and technology development was basically split into two USSR geographical areas of Russia and Ukraine. These are today seen as separate national activities, but there is still a strong relationship remaining from the past in working together. The economic and political transition in Russia for a number of years has dramatically affected space activities and has had a crucial influence on launcher development. Nevertheless, Russia over the years became an important launch provider for the global commercial satellite providers and became more open for international cooperation on technology development. Russia's capability is able to offer human space flights and cargo supply to space stations and become an important driver for investments in space programs in Russia. Thus, Russia remains to be one of the great global space powers and is able to manage high-quality launch services. Deep space exploration, human space programs to the Moon and beyond, and new launch site construction remained as parts of the future planning and launcher development for Russia.

## 44.2 Current Status

Russia has committed a lot of efforts and resources to maintain and further develop its space launcher fleet. Sustainable access to space is traditionally a key element of Russian space strategy. Crucial investments are devoted to improving of its launch capabilities and to develop new technologies. Currently, Russia has a unique and sustainable launch capability for human spaceflights in low Earth orbit and is the sole provider of human transportation to the International Space Station. Since the 1990s, when Russia has opened its space activities and launching capacities for international and commercial uses, Russian launchers rank among the leaders of the global launch market due to their high quality, cost efficiency, and compliance with the customer requirements. From 1995 to 2011, Russian commercial launches accounted for about 40 % of the overall launch services in the global space market. Moreover, space market began to be a very important national budget source.

Due to an increasing demand on commercial satellite launchers, Russia has been able to keep and secure its space launcher fleet. Russia currently operates four types of launch vehicles (LV) and three types of upper stages (US) (see Table 44.1).

The current launch vehicles in operation are Rockot with 107 t of launch mass, Soyuz-FG and Souyuz-2 1A and 1B with 309 t of launch mass, Ukrainian built Zenit-2SLB with 463 t of launch mass, and Proton-M with its 702 t of launch mass. Soyuz, Zenit, and Proton launchers have also the upper stages – fregats, for ability to place spacecraft (SC) at the accurate orbital position.

Russian launcher vehicles are traditionally used for launching spacecraft to orbits of different altitudes and inclinations and to escape trajectories: SC with a mass of ~22.0 t is placed into low Earth orbits (LEO), SC of up to 6.15 t – to geostationary (GSO) or geostationary transfer (GTO) orbits, and SC of up to 3.3 t – to GSO.

Currently a new space launch system is under development, which should in the future become a mainstay of the Russian fleet and possibly replace several existing launch vehicles. The planned Angara rocket family would provide a launch capability from 2 to 40.5 t into low Earth orbit (LEO). Its main purpose will be to secure Russia's independent access to space in the future. Angara will use environmentally friendly fuel based on kerosene and liquid oxygen. The light version of Angara 1.1 and 1.2 will replace the small launcher types as Rockot. The medium size version of Angara 3 will replace the Ukrainian Zenit rocket. The heavy-lift Angara 5 will replace the Proton rocket. Also a super-heavy-lift Angara 7 is under development, which is expected to be able to launch from 45 to 75 t into LEO and would be possibly used for the deep space exploration and manned missions.

Russian launch vehicles are operated from two main launch sites, Baikonur and Plesetsk, while the third one in Vostochny is currently under construction.

Baikonur Cosmodrome is the world's largest space launch facility. Since the fall of USSR, it has been under a rent agreement between Kazakhstan and Russia until 2050. Baikonur now consists of six land starting complexes, with six launching pads for carrying out launch vehicles such as Soyuz, Proton, Zenit, and others are

**Table 44.1** Operated Russian launchers

| Launcher | Rockot | Soyuz-FG/Soyuz-2 1A/1B | Zenit-2SLB | Proton-M |
|---|---|---|---|---|
| Upper stage | – | Fregat | Fregat-SB | DM-03, Breeze-M |
| Launch mass, t | 107.0 | 309.0 | 463.0 | 702.0 |
| Payload mass for LEO, t | 1.95 | 6.9/7.1/8.25 | 13.9 | 22.4 |
| PL mass (t) | | | | |
| For 800 km SSO | 1.15 | 4.4/4.7 | – | – |
| For GTO | – | 1.7/1.95 | 3.95 | 6.15 |
| For GSO | – | 0.65/0.9 | 1.8 | 3.3 |
| Launch sites | Plesetsk | Plesetsk, Baikonur | Baikonur | Baikonur |
| Start of operation, year | 1994 | 2001/2004/2006 | 2008 | 2001 |

Note: *PL* payload, *LEO* low earth orbit, *SSO* sun-synchronous orbit, *GSO* geostationary orbit, *GTO* geostationary transfer orbit

intended like the Ukrainian-developed Dnepr launchers. The Baikonur area also includes more than 30 technical complexes for assembly, tests, and prelaunching preparations of launching vehicles, including the oxygen-nitric factory with a production capacity of 300 t of cryogenic products per day. More than 2,500 launch vehicles and ICBM have been launched since the cosmodrome has been created. Currently, Baikonur is the only launch site operated by Russia with the capability to launch manned space flights and satellites to geostationary orbit.

Plesetsk Cosmodrome was originally developed as an Intercontinental Ballistic Missile (ICBM) launch site, but it has also been used for launching numerous satellites. In particular, Plesetsk due to its far north geographical position is used for military satellites placed into high inclination and polar orbits. Providing a launch service from this far north launch provides several advantages since the range of falling rocket debris impact is mostly at uninhabited Arctic and polar areas. The Soyuz and Rockot are launched from the Plesetsk Cosmodrome.

Since January 2011, the construction on the new Russian cosmodrome in Vostochny has begun and is expected to be completed around 2020. The new launch site will enable Russia to launch most missions from its own territory and reduce its dependency on the Baikonur Cosmodrome situated in Kazakhstan. This new site will be foremost intended for civilian payload launches. It is planned to build seven launch pads, including two pads for manned flights and two for space cargo mission.

Russia has also developed cooperation in the launcher domain with other global space actors. The most significant one is its cooperation with the European Space Agency in the Soyuz program which is launched from the Guiana Space Centre. This program has recently played a significant role in technology developments for the Soyuz launcher itself. It was necessary to modernize Soyuz to fit the specific environment conditions and to build a brand new launch pad. The Soyuz program at Guiana Space Centre is the first Russian type launcher capabilities to ever be built outside Russian (or former Soviet) territory.

## 44.3 Areas of Activities

In the field of launcher developments and sustainability of space activities, Russia takes into account several needs and trends. Today there is an expanding scope of space objectives; use of toxic propellant components for certain existing launch vehicles (LV) and upper stages (US); space debris generation; growing complexity of LV operations, including the allocation of drop zones; the necessity to upgrade the engineering; and technological levels of production. In order to respond to these, the Russian plan stipulates:

- Completion of the upgrading of existing LV and US.
- Establishment of the advanced Angara launch facility at the Plesetsk launch site.
- Construction and development of the Vostochny launch site to support the full range of space activities including manned missions to the stellar bodies of the solar system.
- Establishment of scientific, engineering, and technological resources to enable the development of next generation launchers implementing feasible configuration and high performance. The abovementioned launchers will be competitive in the global market and will be used to solve space-related objectives in accordance with the needs of the country and the international cooperation programs providing the basis for manned missions, including those to the Moon and Mars.

## 44.4 Future Developments

The development of Russian launch facilities and vehicles might be divided into four main periods, including several technology development stages: (a) until 2015, (b) until 2020, (c) until 2030, and (d) after 2030.

### 44.4.1 Until 2015

The first stage is considering developments until 2015. Completion of the modernization of the existing Proton and Soyuz type launchers is expected, and certification of the upgraded Soyuz-2 1A launch vehicle for manned missions is foreseen. In the field of small- and medium-sized launcher development, the main direction is focusing on space launch systems with more environment-friendly technologies with main focus on launch vehicles that are currently in use at the Plesetsk launch site.

By 2015, the Russian launcher fleet will include five types of launcher vehicles (LV) and four (+ one) types of upper stages (US) and one apogee module. According the predictions until 2015, several current and new launchers should continue or come into new service. It is expected that Russia will operate new Angara 1.2 and Angara A5 from the Plesetsk launch site in the nearest future, as well as the Souyz-2 1 V (with the Volga upper stage), Soyuz-2 1A and 1B, and continue to provide the Rockot small launcher services. Russia will continue to use Baikonur Cosmodrome for Zenit and Proton launchers as well as Soyuz-2 1A and 1B (see Table 44.2).

At the same period until 2015, the construction of the Vostochny launch site should be well on the way. It is expected that it will be already available for the launches of automatic space craft (SC) using Souyuz-2 type launch vehicles. Likewise, the continuation on research and development and experimental activities would continue, supporting the development of the Vostochny space launch system based on a heavy launcher vehicles (LV) featuring an oxygen/hydrogen upper stages (US).

### 44.4.2 Until 2020

The second stage of the Russian launchers future development is considering the period until 2020. Using the scientific and technical heritage of Angara, a multipurpose heavy class launch system is foreseen to be established. This system will be used as a part of the Advanced Manned Transportation System (PPTS), an Apollo type capsule, which should replace the current and long-in-service Soyuz-manned transportation system. This heavy launch system will be based on environmentally friendly propellants and using automated spacecrafts. The new system should be fully operational from the newly built Vostochny launching site. In the field of upper stages development, a new oxygen/hydrogen system will be commissioned. In order to enhance the performance and cost efficiency of the advanced launcher systems, development and implementation of high-end technologies for rocket structures, cruise engines, and electronic systems will take a place until the period of 2020.

### 44.4.3 Until 2030

Following the future global trends, Russia is planning until 2030 to invest in new research and development activities. In particular, the new experimental activities relating to advanced space launch systems would include accumulation of science and technical resources for the development of fly-back booster rockets. Russia would also continue in its deep space exploration efforts. It intends to develop a new super-heavy launch systems with capacity over 50 t.

### 44.4.4 After 2030

In accordance to the long-term plans of the human space exploration activities and technology developments, Russia will after 2030 focus on the completion and beginning of operation of reusable first stage launchers. There will be also

**Table 44.2** Russian launchers in 2015

| Launcher | Rockot | Angara-1.2 | Soyuz-2 1V | Soyuz-2 1A/1B | Zenit-2SLB | Proton-M | Angara-A5 |
|---|---|---|---|---|---|---|---|
| Upper stage | – | | Volga | Fregat | Fregat-SB | DM-03, Breeze-M | DM-03/Breeze-M/KVTK |
| Launch mass, t | 107.0 | 171.0 | 160.0 | 309.0 | 463.0 | 702.0 | 775.0 |
| Payload mass for LEO, t | 1.95 | 3.8 | 2.8 | 7.1/8.25 | 13.9 | 22.4 | 24.5 |
| PL mass (t) | | | | | | | |
| For 800 km SSO | 1.15 | 2.5 | 1.4 | 4.4/4.7 | – | – | – |
| For GTO | – | – | – | 1.7/1.95 | 3.95 | 6.15 | 6.0/5.4/7.5 |
| For GSO | – | – | – | 0.65/0.9 | 1.8 | 3.3 | 3.2/2.9/4.5 |
| Launch sites | Plesetsk | Plesetsk | Plesetsk, Vostochny | Plesetsk, Baikonur, Vostochny | Baikonur | Baikonur | Plesetsk |
| Start of operation, year | 1994 | 2013 | 2013 | 2001 | 2008 | 2001 | 2013 |

a significant effort to accumulate scientific and technical resources, to enable and conduct the development of space launch facilities, and to conduct a manned mission to Mars. It would require launchers capable to lift a 130–180 t of mass, space tags featuring development of high propulsion systems, and generally new approaches for secure human-manned missions in the harsh environment of deep space.

## 44.5 Conclusions

Russia has already been successfully active for almost 60 years in space endeavors. The challenge ahead is to sustain and secure and strengthen its position during the next decades. The abovementioned activities and strategic plans will ensure the establishment of the science, engineering, and technological basis for full-fledged participation of Russia in commercial markets, research and scientific activities, or manned space flights. Moreover, Russia is prepared to fully participate on and to be a valuable partner for further steps in deep space exploration missions to Mars and to other international programs for exploration and exploitation of outer space.

# European Space Launch Capabilities and Prospects

# 45

## Anna Clementina Veclani and Jean-Pierre Darnis

## Contents

**Abstract**

This chapter provides an overview of European access to space capabilities – Ariane 5, Vega, and Soyuz. In first place, it recalls the security reasons and the events that led European space fairing nations to join efforts in developing a common launch system. In second, European access to space is described in terms of launch program organization and development as well as of technical

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aspects and exploitation of launchers. Finally, a look at evolutions of current capabilities and new-generation launchers offers the perspective on European space transportation, along with some concluding remarks.

## 45.1 Introduction

The ownership and availability of space systems respond to the need and will to exercise and protect states' sovereignty in a number of crucial fields, first among them, national security, economy, and technological prestige. Notwithstanding, the development of space technologies has been historically driven by security and defense motives, in particular by a vision of worldwide strategic posture: that was the case, starting from the 1950s, for the US, Russia, and France, where launchers and space assets were conceived as key elements of nuclear dissuasion. Today, the most advanced countries rely on space systems for the planning and conduct of security and military operations, both at home and abroad, taking advantage of communication, navigation, intelligence, surveillance, and reconnaissance applications. This is also true at the EU level, where member states are gradually shaping a Common Security and Defense Policy (CSDP), for which capabilities for common missions are being developed, space assets included.

At the same time, also civil applications progressively emerged, thanks to technology transfers, originally serving communications, meteorological, agricultural, and energy policy objectives and currently providing the most diverse services for everyday life and for many other policy sectors. Among the latter is certainly security, for which space-based applications offer a great support, for instance, for disaster prevention and response, for the fight against illegal immigration and drug/arms trafficking, and so on. Over time, and with the technological and commercial maturation of the most common applications, the intrinsic characteristic of space technology, being dual use, has allowed to gradually envisage unitary space systems for both military and civil purposes, maximizing their use and allowing the rationalization of resources. As a result, today, space systems of civil, military, and dual-use nature significantly contribute to the security, prosperity, and well functioning of both societies and states. In this context, access to space is the primary condition of any other space activity, program, asset, and service.

In addition, given that national security and defense largely depend on space systems, it is vital to guarantee the protection and reliability of critical space infrastructures. Maintaining and ensuring such integrity entails not only the availability of assets for space situational awareness (SSA), but also of responsive and flexible launch capabilities to deploy and replace them, therefore guaranteeing backup and a satisfactory grade of redundancy. At the same time, technological non-dependence is needed to master all the relevant technologies related to space transportation. Indeed, if Europe relies on externally produced technologies and capabilities, security of supply may not be guaranteed, while limiting the capabilities to respond to the evolving needs of security.

In a comprehensive logic, then, access to space can be appreciated as a fundamental capability for both "security *from* space" and "security *in* space," supporting any kind of space system and representing itself a dual-use capability that exploits cross-cutting and key enabling technologies, while contributing to European technological non-dependence.

The European spacefaring nations' awareness of the importance of an autonomous launch system dates well back the constitution of the EU and even of ESA. Given the abovementioned considerations, today such conviction is still very much relevant and consolidated across the EU, ESA, and their member states. Indeed, the Council of the EU, the ESA Ministerial Council, and the Space Council have stressed in several occasions over the last years their commitment to the guarantee and improvement of a European autonomous, reliable, and cost-effective access to space, considered a starting point for an independent exploitation of the whole European space infrastructure. The EU has therefore a major interest in launchers, all the more in light of the shared competence in space matters provided by the Lisbon Treaty.

This position is also shared by the European defense community, which in the last 30 years, given it could rely to a great extent on European access to space, invested in other important space capabilities and applications to advance their defense systems, also aware that Europe could have never afforded a dedicated space transportation system for defense purposes. Notwithstanding, in the US and European defense environments, innovative, rapid, and affordable small launch systems on demand, even airborne, are currently studied for delivering responsive space assets (i.e., small and microsatellite constellations) meeting the urgent operational needs expressed by military users and/or enhancing critical SSA capabilities.

Between 2011 and 2012, Europe has achieved major successes with respect to space policy, including in the field of, and thanks to, space launch capabilities. Indeed, the first launch of the Soyuz rocket from the Guiana Space Center (*Centre Spatial Guyanais*, CSG) allowed to release the first two operational Galileo satellites in orbit, while Vega successfully accomplished its qualification flight carrying diverse scientific satellites. In addition, ESA signed contracts for the launch of the successive Galileo satellites with Soyuz and Ariane 5 as well as of two Copernicus (former GMES) Sentinels aboard Vega. These achievements clearly show the relevance of disposing not only of capabilities for an independent access to space, but also of different vehicles – heavy, medium, and small rockets – that provide for flexibility in terms of launch requirements. The European family of launchers is today complete and will guarantee, at least in the short term, Europe's strategic independence, the success of national and EU's missions, and higher competitiveness on the global market of the launch company Arianespace.

This chapter intends to provide a comprehensive and updated overview of European access to space capabilities and strategies. To this purpose, in first place, it is necessary to recall the motives and the events that pushed European space fairing nations to join efforts in developing a common launch system (Sect. 45.2). In second, European access to space will be described in terms of launch program organization and development (Sects. 45.3 and 45.4) as well as of technical aspects and exploitation of launchers (Sects. 45.5 and 45.6). Finally, a look at envisaged evolutions of current capabilities and new-generation launchers will offer the perspective on the future of European space transportation (Sect. 45.7). Concluding remarks will complete the chapter ( Sect. 45.8).

## 45.2 The Origins of European Launch Capabilities

Back to the 1960s and 1970s, most of the emerging space fairing nations realized the high price of depending on the American and Soviet allies to place their satellites into orbit. In fact, at that time, the US policy on launching services provided to third countries was particularly strict. NASA maintained a narrow schedule, did not provide assistance for launch and transfer-to-orbit operations, and allowed only the launch of scientific satellites which did not interfere with its own and/or contain superior technology. Indeed, operational telecommunication satellites were deemed detrimental to INTELSAT, within which the US maintained a monopolistic position. As a result, all European space states had to deal with such policy and negotiate contracts with NASA. That was the case of Italy, France, and Germany with their innovative experimental satellites Sirio and Symphonie. The difficult negotiation related to the Franco-German satellite Symphonie has been considered the main reason for France to extensively invest politically, financially, and technologically in a European launchers program, along with Italy and Germany.

On the other sphere of influence, even China experienced similar restrictions applied by the USSR. In other words, all spacefaring nations opted for the development of autonomous launch capabilities because of being faced with the constraints imposed by third parties.

As a result, from the 1960s onwards, European pioneer countries in space activities, such as France, Germany, Italy, and the UK, made a start on intergovernmental cooperation with the European Launcher Development Organization (ELDO 1962) and the European Space Research Organization (ESRO 1964). The interwoven history of these two organizations, caught in the middle of the Cold War, was dominated by coordination difficulties, financial problems, and, above all, political disagreements.

ELDO concentrated on the development of the Europa rocket (Europa-I first, abandoned for Europa-II), while ESRO on experimental satellites. While ELDO failed its unique launch in 1971 when Europa-II exploded during the flight, ESRO was successful in developing a number of satellites launched on US rockets. This made the European partners losing interest in the project on access to space as it was originally conceived. In 1972, it was France, which could count on a more solid national experience in the field of space transportation, proposing to transform its L3S launcher (*Lanceur à Trois Etages de Substitution*) into a European program. Once approved, the project was brought and developed within the newly created European Space Agency (ESA), into which ELDO and ESRO were to be merged in 1975. The resulting launcher was called Ariane and flew for the first time in December 1979 from the spaceport of Kourou, in French Guiana. Following this success, the undertaking Arianespace was created in 1980, with the aim of managing and commercializing the launcher. Arianespace was the first company in its kind, providing launch services on a commercial basis.

Since then, five different launchers, Ariane 1, Ariane 2, Ariane 3, Ariane 4, and Ariane 5, were developed and launched almost 300 times, acquiring over the years a relevant share of the global commercial market. Eventually, as said, the European launchers family was extended to, and completed by, Soyuz and Vega.

## 45.3 Launcher Program Description

Similarly to the origins, today the European launcher program is undertaken within the ESA framework, whereby public and private actors share roles and responsibilities. Beside ESA, member states with their national space agencies, the industry, and the company Arianespace play a major role in the European space transportation sector.

The program is run under the direction of the ESA Launchers Directorate, as an optional program for research and development, along with "sub-optional" programs. ESA is responsible for the management of the overall program, including:

- Approving the budget, collecting funding, overseeing the progresses, and monitoring costs
- Defining the strategy for European access to space and the related launch systems developments, while guaranteeing their qualification over time and envisaging their technical evolutions
- Managing the tenders system, entrusting to entities and industries the definition, design, and development of launchers.
- Concluding arrangements (convention) with the service provider Arianespace for the procurement of launches, marketing, and exploitation of vehicles
- Concluding agreements with French space agency (*Centre National d'Etudes Spatiales*, CNES) for the management and use of the CSG

ESA has been able to build on its years of experience of developing launchers under the program, namely, of Ariane 5 and Vega as well as of infrastructures at CSG.

As for Soyuz at CSG optional program, based on agreements between ESA and the Russian space agency, the former is the manager in charge of providing the launch infrastructure, while the second, as the prime supplier, provides for the Russian segment of the program (the vehicle), coordinating the work of all industries involved. It is a program with the participation of seven ESA member states with the strong support of the French space agency CNES. Arianespace is the commercial operator.

The main contributing national agencies of the European launcher program, such as CNES, the Italian Space Agency (Agenzia spaziale italiana, ASI), and the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR)

**Table 45.1** Ariane 5 and Vega programs – ESA member states' contributions

| Member state | Ariane 5 production (%) | Vega development (%) |
|---|---|---|
| Austria | 0.4 | / |
| Belgium | 6.3 | 6.9 |
| Denmark | 0.7 | / |
| **France** | **52.7** | 25.3 |
| Germany | 19.1 | / |
| Ireland | 0.2 | / |
| **Italy** | 9.2 | **58.4** |
| Netherlands | 2.8 | 3.2 |
| Norway | 0.6 | / |
| Spain | 3.2 | 4.6 |
| Sweden | 1 | 0.6 |
| Switzerland | 2.8 | 1 |
| UK | 0.3 | / |

also play a direct role providing technical assistance in the principal programs, namely, Ariane 5, Vega, and the Future Launcher Preparatory Program (FLPP).

In 2009 the launcher program received 659 million Euros, while representing ESA's first budget item over 2004–2009 (excluding third parties' contributions for all other programs), with a growth rate of the 7 % in the same period (Euroconsult 2010). An inversion in this trend is found in 2010 and 2011, when the program was allocated 556 million Euros and 612 million Euros, respectively (ESD Partners 2010, 2011). In 2009, the first two contributing member states were France (36.1 %) and Italy (31.2 %) followed by Belgium (16.2 %), Sweden (14.6), and Germany (14.2 %) (Euroconsult 2010).

Within the ESA launcher program were/are carried out Ariane 5 and Vega research and development programs, their support programs (see Sects. 45.5.2 and 45.5.4), new launcher programs and dedicated technological research and demonstration activities (see Sects. 45.4 and 45.7), Soyuz at CSG program, and activities at the spaceport (investment, maintenance, and upgrade of launch infrastructures).

As shown in Table 45.1, Ariane 5 and Vega programs involved a total of 13 ESA member states and their principal contributors are France and Italy, respectively. France has funded 52.7 % of Ariane and Italy 58.4 % of Vega.

The launcher program is governed by ESA's industrial principle of "geographical return," whereby companies in different ESA countries receive industrial contracts roughly proportional to their governments' original contributions. The system of tenders for Ariane 5 and Vega foresees a prime industrial contractor for each launcher responsible for the development and production (see Sect. 45.4).

The launchers are subsequently handed over to Arianespace, responsible for marketing and commercializing them and for operations, adapting the vehicles to the needs of the different missions, both institutional and commercial, in all payloads classes, on a wide range of orbits. The prime contractor industries likewise take part

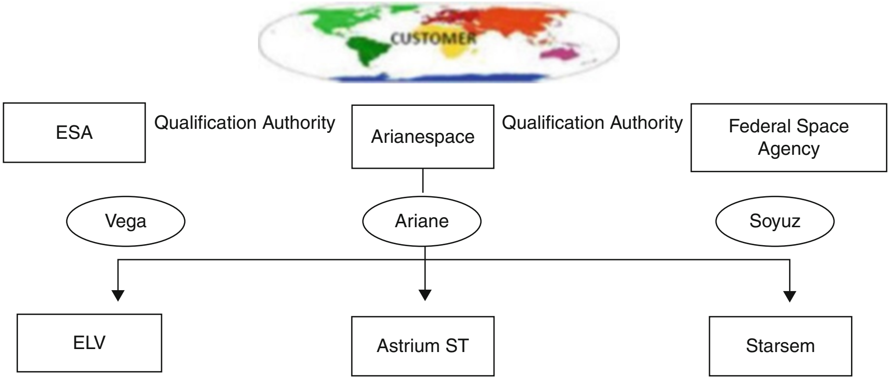

**Fig. 45.1** Exploitation organization (Source: Elaboration of the authors)

in the integration of components at the European space center, together with Arianespace's technical staff. Figure 45.1 schematizes the exploitation organization.

Arianespace is a public-private international company whose capital is owned by 21 shareholders from ten different European countries. The largest share is held by France, which through its seven shareholders controls 64.1 % of the total shares, followed by Germany with 19.84 %. The eight other countries control the remaining 16.05 % with shares not exceeding 4 % per shareholder. The relative majority (34.68 %) is held by CNES, while another significant share (about one third) by the suppliers of Ariane 5, in particular by the aerospace giant EADS.

All launches are operated from the CSG, French Guiana ("*Territoire d'Outre-Mer*," under French sovereignty). Based on longstanding agreements between ESA and the French government, the agency covers two-thirds of the spaceport's costs and France one third, while CNES maintains it operational. ESA also takes part in the definition of the industrial policy and makes sure that the European image of the center is preserved and promoted, while CNES guarantees the safety of both the personnel and the site, authorizes launches, and coordinates all the related operations. In addition, French security and military forces assure the security of the spaceport and of the whole surrounding area (sea, air, and land).

The complex governance of the European launch program, which bears advantages and shortfalls which are out of the scope of this chapter, has the merit to reflect the balances and the cohesion of the system, where all actors, private and public, are associated with the European launchers' strategy in all its aspects: technological, economic, and commercial.

## 45.4 Launch Program Development

As already mentioned, ESA, as manager of the launcher program, selects the prime contractors for the different launcher programs, which in turn share the work with

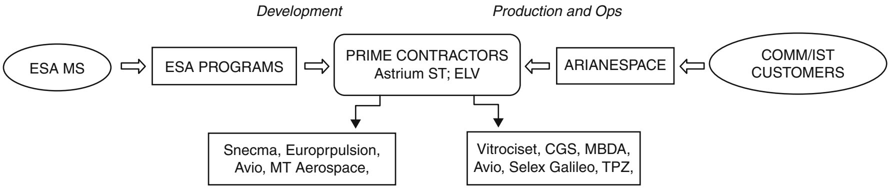

**Fig. 45.2** Industrial organization (Source: Elaboration of the authors)

subcontractors. The prime contractor for Ariane 5 is EADS-Astrium ST and that for Vega is the European Launch Vehicle (ELV), an Italian joint venture between the Italian space agency (ASI, 30 %) and Avio (70 %). The two entities include more than forty among European industries and research centers each; as a consequence, development and production facilities are spread all over Europe, while assembly sites are located both in Europe and at CSG. The relations among ESA and its member states, the industry, the launch company Arianespace, and customers is synthesized in Fig. 45.2.

The companies and centers involved have different technological specializations in the space transportation sector, such as propulsion; materials, processes, and structures; avionics and guidance, navigation, and control; propellant management devices; and thermal control. Notwithstanding, given that launchers are composed of stages and each of these is an integrated propulsion system, the main technology involved in research and development is certainly propulsion. The latter is at the base of any rocket and space vehicle (i.e., orbit transfer vehicle, reentry systems, manned or unmanned systems) and possibly of emerging missions such as on-orbit refueling, servicing, maintenance, repositioning, and recovery. Practical examples are the ESA's Automated Transfer Vehicle (ATV) and the Intermediate eXperimental Vehicle (IXV; see Sect. 45.7.1). The propulsion segment also encompasses all methods of propelling, including chemical, electric, and advanced systems. By definition of the US Department of Defense, propulsion is one of the most important key enabling technologies in the space domain, that is, "cross-cutting technologies that not only support multiple missions area, but do so in ways that promise major advances in capability over a relatively short time – to the extent that they represent the possibility of breakthroughs to new levels of capability or system effectiveness, thus amplifying their return on investment" (Department of Defense 2001). Adding to propulsion, other key enabling technologies involved in launchers are related to materials, in particular lightweight, high-temperature materials with structures and shielding suitable for vibration, acoustic, and thermal control and protection.

Propulsion also represents a dual-use technology, being at the base not only of space launchers, but also of missiles (both ballistic and ICBM, warheads excluded). As a matter of fact, Ariane 1 was directly built on the experience gained with the French missile Diamant. Today, solid propulsion used for the first three stages of Vega and for the boosters of Ariane 5 is also the basis of the most advanced ballistic missiles and missile defense systems. That is the case of the French M51, new-generation strategic submarine-launched ballistic missiles. Other technological similarities between launchers and missiles are to be found in the guidance, navigation, and control (GCM) system. Such analogy revealed all its security implications even during the Vega program, when the French industry was not authorized by national security authorities to transfer the flight control software to the Italian partners.

Without going into further technological convergence details, it can be argued that space transportation technologies bear a strategic value and mastering them is of paramount importance also for European technological non-dependence, which, as already highlighted, bears security implications.

Propulsion and all other abovementioned technologies that supported Ariane 5 and Vega are continuously studied and improved, along with system concepts, within the Future Launcher Preparatory Program (FLPP; see also Sect. 45.7.1). The program builds on the experience gained by the prime contractors EADS-Astrium ST and ELV to further advance and attain technology maturity (Technology Readiness Level, TRL), while anticipating costs and saving time when actually developing and producing future vehicles. Beside industry, FLPP involves ESA's Technical and Quality Management Directorate (TEC), ASI, CNES, and DLR for technical support.

In addition, ESA has set cooperation with Russia for the development of technologies for next-generation launchers, which is not excluded to lead to future joint developments and production.

At the national level, space agencies such as ASI, CNES, and DLR also carry out specific launcher research and development programs, which results normally complement and support further advancements within ESA. For instance, France has established a preparatory program funded by the French Investment Plan for Future to identify solutions for the successor to Ariane 5, named Ariane 6. Such program is carried out by CNES (in-house) and is complementary to the FLPP.

In addition, at the domestic level, academic and research institutions also play a major role in fostering innovative technologies. In Italy, for instance, the Italian Aerospace Research Centre (*Centro Italiano Ricerche Aerospaziali*, CIRA) has significantly contributed to the Vega program and is involved in some national initiatives, such as the project Lyra (see also Sect. 45.7.3), for the evolution of the launcher and possibly of the future ESA launcher, in particular in the segments of GCM (algorithms) and materials.

## 45.5 Launch Vehicle Description

### 45.5.1 A Look at the Past: From Ariane 1 to Ariane 4

The Ariane family of launchers, from 1 to 4, operated in sequence, with short overlapping, from 1979 to 2003. These vehicles were characterized by slight structural differences, evolving on a homogenous technological path. They were based on three stages with a different combination of boosters and kinds of propellant, allowing version after version the increase of performances in terms of weight to be lifted. Indeed, whereas Ariane 1 launched satellites up to 1.5 tons, Ariane 4 – thanks to its six configurations – carried payloads ranging from 2 to 4.9 tons into geostationary transfer orbit (GTO).

Ariane 4 is considered the "workhorse" of the Ariane family, having proved to be one of the best launchers in its category, both in terms of reliability and performance: it was launched 116 times and was successful in 113, placing 155 satellites into orbit. Between 1988 and 2003, Ariane 4 covered 50 % of the global commercial market, marking the success of Arianespace, which became the reference company for launch services worldwide.

In spite of these accomplishments, at the beginning of the 1990s, the evolution of satellites' technologies and characteristics, as well as ESA's plans for the development of space laboratories and human flights, imposed the reconsideration of launch requirements towards heavier payloads, suitable for telecommunications satellites and of modules for the International Space Station (ISS).

### 45.5.2 Ariane 5

Faced with the abovementioned challenges, ESA decided to design a new launcher, thereby abandoning the three-stage architecture and opting for a fix two-stage structure, while increasing the propulsive capacity. Chemical propellants were substituted by solid and cryogenic ones, and based on the mission requirements, different upper stages could be selected (storable propellant or cryogenic).

Developed in only 6 years, Ariane 5 has been inaugurated in 1996; however, it failed its maiden flight as well as three other in the early years of operations (1997, 2001, and 2002), making it necessary to rely on Ariane 4 stocks for some more missions before discontinuity in 2003.

Today, the heavy-lift Ariane 5 carries out the most complex institutional and commercial missions in its two configurations. The first, ECA, with a launch capacity of 10 tons for geostationary transfer orbit (GTO), is used for the launch of heavy telecommunications satellites. The second, ES, with a capacity of 20 tons in low Earth orbit (LEO), is used for the launch of the ATV which supplies the ISS. Ariane 5 ES has successfully launched four ATVs and the last spacecraft of this kind is due to launch in 2014. The same variant can also serve sun-synchronous orbits (SSO) for Earth observation satellites, such as ESA Envisat, and escape orbits for scientific payloads. With the appropriate forthcoming modifications, the ES configuration will be also used for three launches of the Galileo constellation, placing four satellites at a time in medium Earth orbits (MEO). Indeed, by using a storable propellant upper stage, which can perform multiple burns, this very last variant will be able to deploy payloads into the selected orbits.

Normally, Ariane 5 can provide both single launches for heavier payloads and launches with two satellites (double launches), a dual strategy that had proved advantageous in the 1980s with Ariane 3.

Ariane 5 exploitation is supported by a continuous program, the Ariane Research and Technology Accompaniment (ARTA), aimed at guaranteeing the qualification of the vehicle for its entire operational lifecycle and regards both the flight and ground segments. Activities include the analysis of flights results, the correction of anomalies, the identification of obsolete components and required modifications, and maintenance of ground testing facilities. Initially financed by ESA for the period 1996–2010, it was extended to 2013.

Ariane 5 has been launched, on average, five to six times per year, mostly relying on the commercial telecommunications satellite market and only partly on the institutional one. Among the latter, ESA and national civil missions were not only important, but also some European military satellites for telecommunications, Earth observation, and early warning, such as payloads of Syracuse (F), ComSatBw (D), Skynet 5 (UK), Spainsat (ES), Helios (F), and Spirale (F).

### 45.5.3 Soyuz

The Russian rocket Soyuz, in continuous production since 1957, joined the family of European launchers following an agreement signed by ESA and Russia in 2005 and was launched for the first time from the European spaceport in October 2011. The European version of the most used and reliable rocket in the world has been adapted to launches of satellites of up to 3.2 tons from an equatorial latitude into GTO, MEO, and LEO. It is a four-stage vehicle that can be used for medium-weight telecommunications satellites as well as for navigation, Earth observation, and scientific research, including the launch of constellations, like Galileo. This is made possible by its Fregat upper stage that can be restarted up to seven times to serve a wide range of orbits. In addition, since in its longstanding career Soyuz has successfully operated manned flights, the launch infrastructure at the CSG has been designed so that it could eventually be modified for human spaceflight should this be decided by ESA.

Soyuz is expected to improve the competitiveness of Arianespace in the category of small GTO and medium non-GTO missions, for both commercial and institutional customers. As for the latter, as mentioned, the rocket has been selected for six more launches of the European navigation system, carrying two satellites at a time. In addition, it is worth noting that the availability of the European version of Soyuz operated from the European spaceport has allowed France to launch two governmental missions of a significant strategic value, namely, the dual-use Pleiades Earth observation constellation and ELISA electronic intelligence demonstrator satellites. Finally, launching Soyuz from the CSG makes it easier to respect the US International Trade in Arms Regulations (ITAR).

### 45.5.4 Vega

Vega officially joined the European family of launchers with its maiden flight in February 2012, accomplishing a multipurpose institutional mission. Indeed, it carried a primary payload, a scientific laser relativity experiment (LARES), an educational microsatellite (ALMASat-1), and seven ESA pico-satellites (CubeSats). The small vehicle has three solid propellant stages – P80, Zefiro23, and Zefiro9 – and a liquid propellant upper module, AVUM. This fourth stage can be restarted up to five times to release satellites into different orbits. Vega is designed for the institutional market of small satellites, with growing opportunities in the microsatellites class (from 10 to 150 Kg), given that it will be able to place in LEO and SSO several payloads at the same time. It will constitute the ideal solution to launch environmental scientific satellites or satellites for Earth observation up to 1.5 tons in weight, or to readily replace satellites within constellations, avoiding the delays associated with double launches of Ariane 5 and the complex procedures associated with liquid propellant refueling. This last possibility is particularly relevant for security and defense purposes, for which responsiveness and availability at a short notice are priorities.

For the preparation of the smooth exploitation of Vega, the launcher is supported by the Vega Research and Technology Accompaniment (VERTA). The program includes the procurement of five demonstration flights aimed at proving the flexibility of the vehicle in terms of the nature of the missions (science, technology, Earth observation, etc.) and of configuration of satellites (single or clusters). In this last respect, the program should further consolidate its multiple-payload launch capability. Finally, it provides production accompaniment and technological development, such as the creation of a new Italian software (GNC) to be provided for the first VERTA flight. The VERTA launches will carry four ESA diverse missions (Proba-V, Aeolus, LISA Pathfinder, and the Intermediate Experimental Vehicle – IXV) and one of the Copernicus (former GMES) Sentinels.

In its further developments Vega will need to enhance its performances, considering market trends showing increases of the number of LEO/MEO satellites for institutional civil and military missions as well as of related payloads' masses. Indeed, even if Vega had been operational, it would have not been suitable to launch the Italian dual-use COSMO-SkyMed constellation because of excessive weight.

### 45.5.5 The Guiana Space Center (*Centre Spatial Guyanais*, CSG)

As already recalled, all launches are operated from Europe's spaceport. At CSG several facilities are available for all launchers: an arrival area managed by local authorities, a Common Payload Preparation Complex (*Ensemble de Preparation Charge Utile*, EPCU) where satellites are processed, an Upper Composite Integration Facility (UCIF) where satellites and launcher elements are integrated, dedicated launch sites for each vehicle, and a Mission Control Centre, Jupiter (MCC). As for Ariane 5, given that production of some launcher elements is carried out at the CSG, some dedicated facilities were built to host the related companies Regulus and Europropulsion.

Concerning Ariane, preparation activities on the spacecraft and launcher are carried out at the Ariane launch site ELA3 (*Ensemble de Lancement n°3*), where they go through final operations before launch. Facilities to these purposes include the Final Assembly Building (*Bâtiment d'Assemblage Final*, BAF), the Launch Table, and the Launch Control Centre (CDL3). In the BAF the integration with launcher elements is finalized, whereas on the Launch Table the lower and upper components of the launcher are assembled to be transferred to the launch pad ZL3 (*Zone de Lancement n°3*) for the final preparation and countdown. In this process the CDL3 checks the launcher status all along the campaign and up the launch. The launch campaign formally begins upon arrival of the satellite to CSG and ends with the ground support equipment shipment after launch.

As for Soyuz, satellite and vehicle final preparation activities and launch are carried out at the Soyuz launch site ELS (*Ensemble de Lancement Soyuz*) which includes the launch vehicle assembly and integration building (MIK), the Launch Pad (*Zone de Lancement*, ZL), the Launch Control Building *(Centre de Lancement Soyuz*, CDLS), and support buildings.

Finally, Vega launch site SLV (*Site de Lancement Vega*) is built on ELS1 (*Ensemble de Lancement n°1*), that is, where Ariane 1 and Ariane 3 used to be launched. Vega and Ariane 5 share some facilities, such as the CDL3 and the UCIF.

The CSG is located on the coast and very close to the equator, between the latitudes 2° and 6° North and the longitude of 50° West, providing ideal operations conditions for missions into GTO in terms of both security and performances. Indeed, the launch trajectory over the ocean reduces the possibilities of damages to third parties, and the proximity to the equator reduces the energy required for orbit plane change maneuvers (payload mass gain).

Thanks to CNES and ESA, a network of telemetry stations was also set up, starting in the 1980s. This allows Arianespace to provide customers with launcher telemetry and tracking ground station support as well as post-launch activities. The network of tracking sites is structured around the Ariane traditional trajectory eastward, stretching from Kourou to West Africa: the local system Galliot, Natal in Brazil, Ascension Island in the South Atlantic, Libreville in Gabon, and Malindi in Kenya. As for launches in different directions, such as northeast or north, it is necessary to conclude agreements with governmental authorities disposing of suitable stations for the selected trajectory. The existing network and ad hoc agreements will be also used for Vega and Soyuz, which will be mostly flying northward and eastward respectively. However, some modifications will still be needed; therefore, renovations to the entire system has been undertaken.

## 45.6 Launch Vehicle Exploitation

As already recalled, Arianespace is the company in charge of commercializing the three European launchers. For over 30 years, the company has served both private and institutional customers, but in particular has become the global point of reference for commercial missions. Starting with Ariane 1, used to launch the governmental INTELSAT satellites, the company has gained major successes in the satellite telecommunications sector, especially thanks to Ariane 4. Today, with

Soyuz and Vega, Arianespace can cover the whole range of launch requisites, thereby expanding its market for both commercial and governmental missions.

In terms of market demand forecast, over the period 2012–2018, 25–26 payloads planned for launch every year, among which six will be European institutional payloads (25 %), will be accessible to Arianespace (ESA Launcher Programme Board 2011). Of the total, 18 will be for GTO (71 %), including 1 European institutional payload, and 7–8 (29 %) will be for non-GTO, of which 5 are European institutional payloads. Based on the complete family of launchers, about 19 payloads per year are compatible with Ariane 5, 4–5 with Vega, and 1–2 with Soyuz (ESA Launcher Programme Board 2011).

As a matter of fact, if the GTO missions will remain predominant and launched by commercial actors, the non-GTO missions lower in number will be driven by institutional demand. Among the latter there will be some important EU and national programs from the point of view of security. In fact, European launchers will be used for deploying satellites of the Galileo and Copernicus constellations, while they should be granted preference for national military and dual-use missions for telecommunications, Earth observation, and early warning, such as payloads of Sicral2 (I-F), Athena-Fidus (I-F), Skynet 5 (UK), Pleiades (F), Ingenio/SeoSAT and Paz/SeoSAR (ES), and CERES (F). Notwithstanding, institutional demand remains low in Europe and can neither guarantee alone the sustainability of the space transportation sector nor the efficiency and reliability of launch services. As a result, the commercial market remains of paramount importance for Arianespace.

It is widely recognized that in order to remain competitive on the global market, production costs for Ariane 5 should be reduced and industrial processes should be improved. These, however, are heavily influenced by the “geographic return” principle. In this sense, both within Arianespace and ESA, the economic and industrial strategies are being reconsidered, along with the double launch concept which is proving increasingly inefficient and expensive. In fact, although double launches allow to apply lower prices to customers, they require greater efforts in terms of the pairing of satellites and the scheduling of launches. Possible connected delays are particularly serious in case “passengers” are military satellites, bearing in mind the possible consequences for national security or even space security.

Such overall reflection has become even more urgent in light of Arianespace’s financial losses in 2009 and 2010, which have forced shareholders and ESA member states to adopt exceptional and costly measures in order to recapitalize the company and support Ariane 5 prices.

## 45.7 Future Prospects

The evolution of Ariane 5 – known as Ariane 5 Midlife Evolution (ME) and its successor, the so-called Next-Generation Launcher and in particular Ariane 6 – have been subject of debate within ESA and its member states, at the 2012 Ministerial Council and will be subject of decision in the next ESA Ministerial Council planned at the end of 2014. The main supporter of Arian 6 is France, while

Germany favors Ariane 5 ME. Notwithstanding technical and operational considerations related to one launcher or another, the real question to be answered by ESA and its member states is how to cut off public support to Ariane 5 exploitation, which governments are increasingly reluctant to provide. The latter have already experienced a failure with the European Guaranteed Access to Space (EGAS) program, which was supposed to make Arianespace self-sufficient by financing for 6 years (2004–2010) part of the production costs of Ariane 5. Finally, the Ministerial Council will have to decide on the future of the other European launcher, namely on the consolidation and related funding of Vega, which could also see Germany as a new contributor to the program.

### 45.7.1 Future Launcher Preparation Program (FLPP)

Studies and research activities to prepare the development of the NGL were initiated in 2003 within the FLPP, with the aim of carrying out concept studies, technology maturation activities, and demonstrations. The program, implemented in four phases, includes the development and flight of the Intermediate eXperimental Vehicle (IXV), which lays the basis for atmospheric reentry technologies potentially supporting next-generation launchers, planetary exploration, sample-return missions, space planes, and crew (i.e., hypersonic air vehicle) and cargo transportation. Technologies and missions of this kind are both of scientific and strategic values, with a view to future security and defense scenarios.

As for NGL, after having explored different system concepts and provided demonstrators, the most appropriate appears to be a medium-weight modular vehicle for single launches of unmanned missions on a wide range of orbits, obviating to the double "passenger" problem and offering the customer the guarantee of a price proportional to the payload weight. However, the number of stages and kind of propulsion are yet to be defined. The lift capacity envisaged is between 3 and 6.5 tons, while additional strap-on boosters would allow for flexibility based on mission requirements. In the long term, such a launcher could be a valid replacement for Soyuz at CSG, which could see discontinuity by 2018/2020 as evolutions are not envisaged. If a development program was to be decided, NGL could fly around 2020.

### 45.7.2 Ariane 5 Post-ECA Program

Ariane 5 ME, for which work has begun within the Ariane 5 Post-ECA Program preparatory phase in 2009, would be a medium-term solution increasing the performances of Ariane 5. This would be made possible thanks to the new VINCI motor and the cryogenic upper stage engine, which would increase the launch capacity by about 20 % (two more tons). Furthermore, the re-ignitable engine would allow for launches over a wider range of orbits. Ariane 5 ME, substantially gathering in a single launcher the functionalities of the two current configurations of Ariane 5, would maintain unvaried production costs, while allowing, supporters argue, to gradually abolish financial support to exploitation thanks to improved responsiveness to market demand. The inaugural flight is due around 2017 if the ESA member states approve its full development phase at the abovementioned Ministerial Council. In any case, proponents assure, concepts developed for Ariane 5 ME will be applicable to the NGL, thereby reducing costs and risks associated with the development of whichever future vehicle.

### 45.7.3 Vega Evolution

In the framework of the VERTA program and of national initiatives, studies are also ongoing on potential evolutionary configurations of the Vega launcher. Specifically, it is envisaged an enhancement of the propulsion and weight lift-off capacities by increasing the propellant load of the first stages of the vehicle, the P80 (VERTA) and the Zefiro23 (Avio project), leading to a P100 (or P120) and a Zefiro40 respectively. As a whole, the two upgrades would enhance the launcher capacity lift to 2 tons in LEO.

Other initiatives are also undertaken at the national level under the aegis ASI and DLR, in particular regarding the evolution of the third and fourth stages of Vega. ASI, through the project Lyra, is developing a demonstrator for a single liquid propulsion stage (oxygen-methane) to replace both upper stages. In line with the three-stage approach, DLR, with its two Venus studies, is considering the opportunity of utilizing on Vega a single storable propellant upper stage with the German engine Aestus II, today used for Ariane 5 ES. In alternative, Vega would remain a four-stage launcher, with a new storable liquid propellant upper stage intended to replace AVUM only. This German contribution to Vega, if it were to be formalized within ESA, would “Europeanize” the launcher, given that today the fourth stage AVUM is designed and produced by Russia and Ukraine.

### 45.7.4 New European Launch Service

In this context, ESA has recently launched an invitation to tender for a feasibility study for a New European Launch Service (NELS) and has selected, on a competitive basis, two consortia, one jointly led by Astrium Space Transportation and ELV, the other by OHB. The study should investigate options for a new access to space model economically self-sufficient, with no need for public support to launchers exploitation. The innovative principle behind NELS is that ESA member states participating in a future optional program for development would contribute on the basis of “fair contribution,” rather than of “geographic return.” As a result, the industrial share of work would be based on best technical competence and cost-effectiveness. Such initiative has involved commercial and institutional customers in its early stages of definition, gathered in the European Customers Requirements Group, composed of representatives of France, Germany, Italy, the UK, European Commission, EUMETSAT, ESA, Avanti, Eutelsat, Hispasat, Inmarsat, SES, and

Telenor. The aim was not only of defining requisites for launch services, but also of creating a European customer base that will formally commit to the use of the European launch service.

During the assessment phase – lasting 12 months – a major milestone is envisaged after 3 months (September 2012), when the contractors will have to inform ESA on the first elements of NELS requirements in terms of missions, performance, launcher service costs, etc.

## 45.8 Conclusions

Today, the three European launchers – Ariane 5, Soyuz, and Vega – secure an independent access to space for European governments and institutions, as well as for global institutional and commercial customers, providing services and solutions for the whole range of launch requirements. European security missions – related to both “security *in* space” and “security *from* space” – do and will depend and rely on such capabilities. In the ESA framework, accompaniment programs, such as ARTA and VERTA, guarantee that the two launch systems remain reliable all along their exploitation, while further research and development programs and technological activities, such as Ariane 5 Post-ECA and the FLPP, lay the basis for the future. These programs also allow Europe to master and maintain know-how and enabling technologies for its non-dependence. However, in a longer-term perspective (2020–2030), ESA, its member states, and the industry are expected to find economic and industrial strategies to renovate and maintain such capabilities, as the current European launch model, albeit successful for 30 years, is no longer considered economically sustainable. This clearly emerges from the ESA’s approach applied to NELS, which underlies the awareness that the current budget constraints in member states impose new development and operational concepts allowing the delivery of the best products at the best price for both governmental and commercial customers. European governments, with the support of the EU, are still committed to invest in research and development in the space transportation sector with the aim of guaranteeing an independent access to space for Europe, rather than of sustaining the launcher industry by financing production costs. In this context, at the 2014 Ministerial Council, ESA member states will have to choose the option – between Ariane 5 ME and Ariane 6 – that best suits such objectives, with an eye on the improvement of the development and exploitation governance.

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# European Institutional Satellite Programs

# 46

Lucia Marta

## Contents

### Abstract

European supranational actors are getting increasingly involved in space programs for security applications: ESA, with its activities in the development of space capabilities with dual-use applications; EUMETSAT with its three main meteorological missions; and more recently the EU with Copernicus (former GMES) and Galileo programs. These programs are civil and under civil control, while purely military programs are not developed yet at European level and remain in national hands. The multiple uses of space technologies, the enlarged definition of security, and the dual-use approach have allowed the inclusion of security-related applications in civil programs. European supranational actors are therefore "security providers" for the benefit of European institutions, countries, and citizens. This chapter aims at providing an overview of these programs and their applications and highlights some considerations about the "European way" to ensure security at supranational level through space assets and applications.

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## 46.1 Introduction: How Europe Is Using Space to Support Security Functions

The added value provided by space programs in the field of security is widely recognized in Europe, both by experts and institutions.[1] The best example is the European Space Policy (2007; DG ENTR website http://ec.europa.eu/enterprise/policies/space/esp/security/index_en.htm) –jointly adopted by the European Union (EU) and the European Space Agency (ESA). This document is the maximum expression of the European global and strategic vision of space activities and includes a chapter concerning the relevance of space for security.

European space nations such as France, Germany, Italy, Spain, and the UK develop national space programs for defense and security purposes (they will be discussed in Part 4, ▶ Chap. 52, "The Indian Space Launch Program" of this handbook). European space nations have also established bilateral and multilateral ad hoc agreements to exchange and share satellite-based information for security and military needs, mainly in the domain of Earth observation (EO), with more or less success (see Part 4, ▶ Chap. 51, "The Japanese Space Launch Program" of this Handbook).

In parallel, European nations progressively brought several policy areas (among others, economic, social, and scientific), primarily under the Community and then the Union frame, following a path that ultimately led to a common supranational[2] reality and institutional organization. Defense policies instead have remained under national control or, at best, under the partial control of intergovernmental institutions and procedures: the same applies to related space programs.

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[1] Concerning EU official institutional documents and studies, it is worth recalling here some of them stating the crucial role of space for security: "The security dimension of GMES," GMES Working Group on security, September 2003. Council Joint Action 2004/552/CFSP, 12 July 2004, on aspects of the operation of the EU radio-navigation system affecting the security of the EU (OJ L246, 20/7/2004). "ESDP and Space," Council of the EU, 16 November 2004. "Report of the Panel of Experts on space and security" Working Group (March 2005). "Generic space system needs for military operations," Council of the EU, and in particular the EU military committee, February 2006. "Generic space system needs for civilian Crisis management operations," EU committee for civilian crisis management, June 2006. More recently, in 2008, the 5th Space Council adopted a resolution establishing four new priority areas of action, one of them being space and security: see Council Resolution "Taking forward the European Space Policy," adopted by the Competitiveness Council meeting on 26 September 2008, and European Parliament Resolution of 10 July 2008, on Space and Security (2008/2030(INI)). As far as studies are concerned: FRS and other authors "The cost of non Europe in the field of space based systems," study for the European Parliament, SEDE, 2007. More recently Darnis and Veclani (2011), Pasco (2011), and Pavlov (2012)

[2] As the Oxford dictionary puts it, "supranational" is here intended as "having power or influence that transcends national boundaries or governments."

However, the expanding dual-use approach and the broad sense applied to the security concept[3] favored the involvement of supranational actors in space activities for security applications, despite their nature or competences.

So, at supranational level, satellite programs in the security domain exist and they will be described in this chapter. Differently than within a sole or a federal country, European programs' ownership and exploitation are split among three main institutional space players: the ESA, EUMETSAT, and the EU. Each of them has very different nature, purpose, goals, and even membership, but all of them contribute to the same effort, that is, supporting security functions for the benefit of European countries and citizens through the development of space technologies and on the basis of cooperative efforts.

Launch services are an essential component in the implementation of security and defense programs. Without a reliable, available, and secured launch capability, European space missions run the risk of not being launched into orbit – and therefore of not being operational – in a secured way, whenever it is necessary and at an affordable cost. European launchers are developed by ESA as an optional program (countries' financial participation is on a voluntary basis). However, they will not be addressed in this chapter as they are not satellite programs as such: the topic is rather addressed in Part 3, ▶ Chap. 32, "Earth Observation for Security and Dual Use" of this handbook.

After presenting an overview of the European institutional programs for security applications, the chapter will highlight some considerations about the way European institutions and organizations are jointly answering to security needs, both in the old continent and worldwide.

## 46.2 The Three Existing European Institutional Actors Contributing to Security

The European Space Agency is the main space player in Europe and the leading space R&D agency in terms of resources and programs. During almost 40 years of successful space activities, the Agency has focused on the development of programs for peaceful purposes.[4] Despite some declarations at ESA high level

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[3] Security is here intended to mean in general sense, whether that is in the military sense or as a way to respond to natural or man-made disasters. Defense or military programs instead are here intended as programs developed since their conception with purely high defense performances and purposes.

[4] Indeed, ESA's convention says at art. 2 that the purpose of ESA is "To provide for and promote, for exclusively *peaceful purposes*, cooperation among European states in space research and technology and their space applications" (italics added by the author). ESA recognizes that this article does not prevent the Agency from being active in the security and defense field; rather it prevents the Agency to develop aggressive programs. See ESA presentation, ESA in the domain of security and defense, 16/02/2011.

concerning the possibility to deal with security and defense programs,[5] not all ESA member states may agree with such evolution of the Agency, which needs consensus and a clear political will, both among nations and within each member state (in particular, between the scientific and military communities).

For the time being, ESA sources of funding are civil and are provided by MS through their national space agencies to fund mandatory and optional programs.[6] However, ESA is the only supranational player which has resources, facilities, and skills to develop large and complex common space programs for security in Europe. This is why EU and EUMETSAT entrust the ESA with the R&D and procurement phases of their programs' space components, and this is why it is logic to look at the ESA also for future common programs related to security and defense.

In the frame of the structured cooperation stemming from the 2007 and 2008 Space Councils, the European Defence Agency (EDA) and ESA have signed an administrative agreement (2011) to launch joint initiatives. The growing implication of ESA in security and defense space applications can be observed,[7] but for the time being, no military space program as such has been concretely decided in this context.

Concerning EUMETSAT, the European Meteorological Organization for more than 30 years has provided its member states (MS) with meteorological data, which are fundamental piece of information in security and defense missions. Following the early participation of some European countries to the international Global Atmospheric Research Program together with the USA, the USSR, and Japan, primarily ESRO[8] and then ESA were responsible for the development of the Meteosat program (Meteosat-1 was in orbit in 1977). Quite soon European authorities understood the importance of developing a common European independent system for meteorology to furnish free data access to national authorities and operators. In 1986 the EUMETSAT convention was established, with the objective to develop and operate in orbit meteorological satellites on behalf of its (initially) 16 member states. Since 1988, EUMETSAT continues developing and operating innovative satellite programs, which will be described later in this chapter.

Last but not least, at European Union (EU) level, space initiatives for security are being developed since relatively recent times. At the end of the 1990s, the EC started to be actively involved in space and security activities, mainly through R&D projects which led to the development of Copernicus (former GMES) and Galileo

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[5] "Historically the core of ESA's activities is funded through civilian budgets, but ESA is not limited by its convention to civilian activities. Its convention only refers to 'peaceful purposes', which is the wording used in the UN Treaties" (Dordain 2012).

[6] Exception is made for SSA-PP which has benefited from a small contribution from MoDs of some MS. See ESA presentation "ESA and the domain of security and defense," February 2011.

[7] Examples of recent ESA initiatives in the field of security will be reported in the ESA dedicated paragraph of this chapter.

[8] European Satellite Research Organization, which together with ELDO (launchers) and the ESC (space conference), led to the creation of ESA in 1975.

flagship programs. More recently, initiatives like the Space Surveillance and Tracking support program (SST)[9] or the Draft Code of Conduct on outer space activities[10] confirmed the growing EU interest in this domain.

Copernicus and Galileo are both civil programs under civil control, although their support to security and more in particular to the Common Security and Defence Policy (CSDP) was lately recognized and accepted.

Copernicus initiative was established by the Baveno Manifesto in 1998. The Balkans' conflict helped to confirm that Europe needed independent satellite-based resources to guarantee European nations' and citizens' security. The concept of security in Copernicus, initially oriented exclusively toward environmental protection, was enlarged to other security-related issues, at least those expressed within the nascent CSDP. Saint Malo declaration was issued in December 1998, and 1 year later "Global Monitoring for Environmental Security" program became "Global Monitoring for Environment *and* Security" (European Commission 1999). The potential use of Copernicus for defense purposes was also mentioned as a result. Copernicus' technological features, its global reach, its cooperative nature, and the addressed large security concept immediately brought the dual-use dimension to the attention of the ESA and the EC.[11]

The paper "The security dimension of GMES" (GMES Working Group 2003) had identified five core security missions for Copernicus and their potential end users. This stemmed from the analysis of the European policies linked to conflict prevention and crisis management activities.[12] The list of security missions was not intended to be exhaustive and could include in the future the domain of "justice and

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[9] See Part 1, ▶ Chap. 10, "Space as a Critical Infrastructure" of the handbook. Concerning the EU initiative, COM (2013)

[10] The Council of the EU adopted a draft for a Code of Conduct for Outer Space Activities, which has been endorsed as a basis for consultations with third countries. Two more recent versions of the draft were endorsed in 2010 and 2012.

[11] Joint task force, composed of ESA and the EC, met for the first time in 2001. In the annex 2 of the issued document, it is stated that "Dual-use (civilian-military) aspects of satellite systems have not so far figured highly on Europe's agenda. But through the Satellite Centre of the Western European Union (WEU), Europe has gained some experience in dual-use. Integration of the WEU Satellite Centre in the EU may open new avenues for shared utilisation." http://esamultimedia.esa.int/docs/wisemen_report.pdf. Accessed 27 Aug 2012.

[12] Wide core security missions included the following:

1. Prevention and response to crisis related to natural and technological risks in Europe
2. Humanitarian aid and international cooperation
3. Conflict prevention including monitoring of compliance with treaties
4. Surveillance of borders
5. Common Foreign and Security Policy and European Security and Defence Policy to support the missions outlined in Article 17.2 of the Treaty of the European Union (humanitarian and rescue tasks, peace keeping tasks, and tasks of combat forces in crisis management including peacemaking).

home affairs." Copernicus' wide security missions have been detailed and organized in services, which will be described later on in this chapter.[13]

Galileo is the second EU flagship program, conceived in 1999 when the EC, at the request of the Council, proposed the radio navigation and positioning system that would allow independent services in support of safe and secure transport and of the Common Foreign and Security Policy (CFSP).[14] Galileo has quickly turned into a dual-use system due to its potential security and defense-related applications. In 2006 EU Transport Commissioner stated this possibility, which meant that Galileo may be used also for military purposes, including in support to the ESDP.[15] Indeed, Galileo is designed to provide four kinds of services, one of which will include integrity function (Safety of Life service), while another service will provide two encrypted signals (Public Regulated Service) and will serve mostly security and defense public authorities.

Following this brief introduction which provides a background about the main actors involved, the origin, and the purpose of their activities, the following paragraphs will provide some more details concerning the programs itself and notably, when relevant, their governance and funding, some technological elements, main industrial issues, their applications and relevance for security, their international dimension, and future prospects.

## 46.3 Programs Description

### 46.3.1 The ESA Evolution and Its Dual-Use Programs

ESA's evolving relationship with security and defense areas started in 2000 when ESA and CNES co-funded the Charter on Space and Major Disasters. Documents and meetings followed as well as agreements with other EU bodies (EU, EDA, etc.) to further involve ESA's unique skills in the development of common space programs and applications for security and defense. However, such evolution requires possessing procedures and facilities to guarantee the access to authorized and cleared personnel only, the proper management and storage of classified data and information, the development and testing of sensitive hardware, and so on.[16]

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[13] In 2008 the GMES forum in Lille (France) launched the first five core services of GMES: atmosphere monitoring, land monitoring, marine monitoring, emergency, and security. Today these general missions have been further detailed and the three core security services have reached the preoperational phase.

[14] Communication from the Commission of 10 February 1999 – "Galileo – Involving Europe in a new generation of satellite navigation services."

[15] The duality of the system was also endorsed by the European Parliament: European Parliament Resolution of 10 July 2008 on Space and Security (2008/2030(INI)).

[16] For instance, in order to manage the development of Galileo program according to its security requirements, ESA needed some adaptations to the centers hosting development activities and initial operations. In particular in ESTEC the highest security provisions have been put in place. See ESA presentation, op. cit. February 2011.

Consensus is needed among the Agency MSs about the "enlargement" of ESA's activities and structures, requiring by the way additional funding, and despite ongoing discussions, for the time being no formal decision on concrete military space programs has been taken.

Nevertheless, on the basis of the abovementioned Framework Agreement (2011), ESA and EDA are cooperating on the following initiatives:

- ESA and EDA run two different but parallel studies on a common ground segment system of systems in the field of EO for military and civil applications, respectively.
- ESA and EDA jointly funded and managed a demonstration mission on space-based services for unmanned air systems (UAS).
- ESA, EDA, and the EC are running a trilateral exercise concerning the identification of critical space technologies for European non-dependence.
- ESA and EDA are also cooperating in relation to an SSA program (definition of military users' requirements; see paragraph on SSA in this chapter).
- Last but not least, ESA is exploring a European integrated architecture in support to crisis response (GIANUS concept) following an explicit request of the 7th Space Council (EDA and the EU request) (7th Space Council Resolution 2010).

Military satellites programs as such are not developed yet by the Agency. However, examples of dual-use programs developed by ESA (other than EU and EUMETSAT programs that will be mentioned below) are also the EDRS program (European Data Relay System) or the AIS service (EMSA, DG MARE, and ESA program for automatic identification system mainly to avoid boats' collision).

### 46.3.2 The SSA Program

It is worth recalling also the Space Situational Awareness (SSA) program being currently funded at ESA level, and, as it will be explained later, at EU level too. This makes the program an interesting example to consider in terms of cooperative European approach to address security issues (on Earth and in space).

This program is considered as strategic (European Space Policy), especially since the dramatic increase of debris in space augmented risks of damages and collisions of space infrastructures and humans in space.[17] Collisions not only result in the damage or destructions of infrastructures that cost amount of money and R&D efforts and potentially the loss of human lives, but also the interruption of space-based services, with strategic and commercial consequences for the owners

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[17] The following examples deserve to be mentioned the Chinese antisatellite missile test, held on January 2007 and which created a considerable amount of debris in orbits, and the collision between Iridium 33 satellite (US) and Cosmos 2251 satellite (Russia) in February 2009, creating further debris and testifying the risk of collisions among satellites in such a congested environment. Last but not least, in March 2012 the high risks of collision between of a debris with the ISS were detected and forced astronauts to reach escape capsules.

and operational consequences for the users. In order face this challenge, it was considered as necessary to access and disseminate timely and accurate information, data, and services concerning the space environment, including the identification and tracking of space objects.

There is agreement on the fact that a European SSA program should be based on the networking and correlation of different kinds of existing technical equipments, ground radars in the first place. Most of them are nationally owned,[18] some of them are operated by ESA. In addition, other non-European systems exist (the US or Russian space surveillance network and assets) and may ideally be part of a future global network. International cooperation is indeed a key issue as Europe is strongly interested in a certain degree of autonomy of the program, but is aware that full independence will be very hard to achieve. SSA program could be led in cooperation with other nations (as the USA) and international partners and initiatives (as the 11-nation Inter-Agency Space Debris Coordination Committee (IADC)) to exploit existing assets and experience in this domain.

ESA authorized the Space Situational Awareness Preparatory Program (SSA-PP, optional program with the participation of 13 countries (SSA Programme Overview 2012) at the Ministerial Council in 2008. The SSA program is made up of three main segments: Space Surveillance and Tracking (SST) Segment (which has the highest security and military implications), Space Weather (SWE) Segment, and the Near-Earth Objects (NEO) Segment.[19] The SST segment mainly consists in creating a catalogue of space objects and their orbits, used for prediction and warning of possible collisions. Such a catalogue, however, could also be "misused" as it allows the identification of space objects that were not supposed to be tracked (reconnaissance satellites) and make them lose their strategic value or make them potentially vulnerable to antisatellite weapons. Therefore, the establishment of a suitable governance and data policy is cornerstone in order to create a common European SST service which is at the service and not against European interests.

At the last ESA Ministerial Council (2012), the program has been founded again but limiting activities to the (less sensitive) NEO and SW segments, in order to continue to develop, test, and validate essential capabilities. The NEO segment, in particular, has reached an important step, thanks to the recent opening of a NEO Coordination Centre located in ESRIN facilities (near Rome) that will serve as the central access point to a network of NEO data sources and providers being

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[18] We recall here the program Tira (Germany) and Graves (France) which are the only existing infrastructures for SSA, while other countries have displayed radars for different purposes – mainly scientific – but that can be put in network with SSA functions.

[19] Near-Earth Objects are comets and asteroids orbiting the Sun and whose orbits are close to the Earth. "Dramatic proof that some of these could strike Earth came on 15 February, when an unknown object thought to be 17–20 m in diameter exploded high above Chelyabinsk, Russia, with 20–30 times the energy of the Hiroshima atomic bomb. The resulting shock wave caused widespread damage and injuries, making it the largest known natural object to have entered the atmosphere since the 1908 Tunguska event" (ESA website).

established under ESA's SSA program. Moreover, a space surveillance data analysis capability was created also at ESA's ESAC (space astronomy center, near Madrid) as a test bed for ITC technologies for the development of future operational centers.

SSA program is, for the time being, a civil program under civil control with clear dual-use applications. The most interested European countries may decide to continue developing the "military side" of the SSA program (notably the SST segment) on a purely bilateral basis instead of including it in a larger ESA or EU frame. In the paragraph concerning the EU, some considerations are reported on this very issue and in particular on the role that the EU may play.

## 46.3.3 EUMETSAT: Providing Meteorological Information for Security and Defense Purposes

### 46.3.3.1 Overview

EUMETSAT is an intergovernmental organization that provides a wide range of meteorological services. Its decision-making body is the Council, where member states (26) and National Meteorological Services (NMS) are represented. The director follows the directives of the Council and ensures the proper management of the organization and its programs. "EUMETSAT responds to the evolving needs of the National Meteorological Services (NMS) of its Member States and Cooperating States. This ensures that EUMETSAT's mandatory programs and services continue to be relevant to the NMS information and forecast services for the *protection of life, property and the economy*." (EUMETSAT website, http://www.eumetsat.int/Home/Main/AboutEUMETSAT/InternationalRelations/SP_1225964706459?l=en)

### 46.3.3.2 Governance and Funding

EUMETSAT is in charge of operations related to programming, tasking, data acquisition, pre-processing, and distribution. Data from its three space-based missions are received by EUMETSAT HQ or by NMSs directly, who process the data, create, and distribute services at national level.

Indeed, NMS are the exclusive licensing agents for EUMETSAT and may be civil or military administrations. In Italy, for instance, the National Air Force (and more particularly the Centro Nazionale di metereologia e climatologia aeronautica) is the national hub for the collection and redistribution of data from satellites and other sensors, including EUMETSAT data. In other countries NMS may be civil national administrations (as it is the case in France, where the NMS Meteo France depends on the Ministry of Ecology, Development and Energy). In any case, the use of EUMETSAT data is guaranteed at national level for security and defense purposes. Besides data for defense and security applications, EUMETSAT provides other kind of data which can be accessed in different ways (though the website of the organization or even directly by the user).

EUMETSAT's budget consists of national contributions on the basis of their gross national income (GNI). In 2010, Germany was in the first place (19.2 %), followed by the UK (15.6 %), France (14.7 %), and Italy (12.8 %). ESA, which is responsible for the development of the space segment of EUMETSAT programs, participates also to their funding, notably by funding major parts of the developing costs of the first satellite of a series. Hence, ESA is developing agency of EUMETSAT satellites and procures them on its behalf.

### 46.3.3.3 Technological Elements

(a) *Meteosat First Generation (MFG)* mission is a series of satellites in geostationary orbit (the first (Meteosat-1) was launched in 1977 and the last (Meteosat-7) was launched in 1997) that provides full and continuous coverage of the Earth for weather forecast. Meteosa's primary instrument is the Meteosat visible and infrared imager (MVIRI) – a high-resolution radiometer with three spectral bands. Meteosat-7 provides the Indian Ocean Data Coverage (IODC) service.

    *Meteosat Second Generation (MSG)* followed the MFG and is composed of four geostationary meteorological satellites (three of them launched between 2002 and 2012) and a ground segment. The program will operate until 2020. Its improved channel capacity allows the transmission of more data in less time, enlarging the range of applications and related users. Twelve spectral channels onboard (instead of three as in the MFG) allow more precise data collection and different measurements. Meteosat SG can take pictures every 15 min of the same Earth zone. It covers Europe, Africa, and part of the Atlantic Ocean. MSG is designed to support short-range forecasting, numerical weather forecasting, and climate applications over Europe and Africa (EUMETSAT website, http://www.eumetsat.int/Home/Main/Satellites/MeteosatSecondGeneration/Services/index.htm?l=en) The imagery service is the first mission of MSG, while a secondary mission consists of receiving and re-transmitting distress signals, thanks to the small communication payload carried by the satellite.

(b) *MetOp* is a series of three polar-orbiting meteorological satellites which form the space segment component of the overall EUMETSAT Polar System (EPS). The aim of this program is to provide long-term data sets over weather forecasting and climate monitoring.

    MetOp-A was launched in 2006, MetOp-B in September 2012, and Metop C is to be launched in 2016: the three are expected to furnish improved data on temperatures and climate for 14 years globally. Metop satellites carry US (4 out of 11) and European instruments (EUMETSAT website, http://www.eumetsat.int/Home/Main/Satellites/Metop/MissionOverview/index.htm?l=en).

    The EPS is a program developed in the framework of European-US cooperation, notably between EUMETSAT and the NOAA (National Oceanic and Atmospheric Administration).[20] According to the EUMETSAT-NOAA

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[20] In particular, Metop contributes to the larger program called Initial Joint Polar-Orbiting Operational Satellite System, which contributes to international initiatives such as the World Meteorological Organization (WMO) Global Observing System, the Global Climate Observing System, the United Nations Environmental Program (UNEP), the Intergovernmental Oceanographic Commission (IOC), and other related programs.

agreement, the two parties exchange data, furnish instruments to be onboard of satellites, and provide backup information

Metop services include weather forecast and climate monitoring, affecting different sectors such as economical, industrial, touristic, and also crisis response. The Metop Direct Readout Service provides local user stations with the real-time transmission of data (limited to the instantaneous observation of the satellite).

(c) The third EUMETSAT mission is *Jason-2*, deriving from a family of satellites forming the Ocean Surface Topography Mission, supporting weather forecast, climate monitoring, and operational oceanography. The Jason-2 program, in particular, is the result of an international endeavor linking two operational and two research administrations: EUMETSAT and NOAA, and CNES and NASA.

This mission concentrates on studying oceans. Some immediate applications include sustainable management of ocean resources, monitoring of fishing vessels and merchant shipping fleets, protection of people and property at sea, and harbor management. Security functions are related also to this kind of applications. Among other things, Jason-2, in orbit since 2008, supports prevision of extreme ocean-atmospheric events such as the well-known phenomenon called El Niño.

#### 46.3.3.4 Industrial Issues

As stated in EUMETSAT official documents (EUMETSAT 2011), the organization "strives for maximum cost-efficiency and best value for money, and will remain committed to a procurement approach based on *full open competition*, but with a clear *preference for European* industrial solutions, where the capabilities and a competitive European environment exist" (italics added by the author). EUMETSAT procurement rules aim at being as far as possible compliant with the Community rules on public procurements, meaning on the bases of open tenders.[21]

Concretely, this means that the R&D phase funded by EUMETSAT (normally up to 1/3 of the total) and the funding of recurrent satellites should be governed by EUMETSAT open competition based procurement policy (both for goods and services[22]). Calls for tenders may appear on EUMETSAT website and are open to European companies. EUMETSAT's funds managed by ESA are not supposed to be governed by the *geo-return* principle. Still a certain geographic distribution persists as ESA is instructed to maximize efficiency at minimal costs (open competition is applied at subcontracting and supply level) (Hobe et al. 2010, pp. 235–236). With regard to the part of R&D activities covered by ESA funds

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[21] Contracts and tenders procedures are explained in EUMETSAT, *Financial Rules*, 2010.

[22] "Restricted tender may be applied after approval of the Council." Moreover, "contracts may be concluded directly without open competition" in some case, precisely listed in the financial rules, *op.cit*, art. 26, including contracts not expected to exceed 100,000€.

(normally up to 2/3), ESA procurement policy including *geo-return* ESA principle, applies.

Thales Alenia Space is the prime contractor for the complete Meteosat family (including 11 satellites of 1st and 2nd generation since 1977). The third generation is under preparation. Thales group is also prime contractor for MetOp satellite ground segment, in the frame of the EUMETSAT Polar System. Jason-2 spacecraft was the responsibility of Thales and CNES, while instruments onboard and the launch service are the responsibility of the American partner.

EADS Astrium is the prime contractor for the MetOp space segment and has responsibility for major subsystems in the MSG program (power supply system, attitude and orbit control system, propulsion system, and also the development of the **SEVIRI instrument**).

As for other space programs, the abovementioned prime contractors rely on the high number of suppliers from several European countries.

### 46.3.3.5 Applications, Users, and Relevance for Security

EUMETSAT's main applications for security and defense in Europe consist of furnishing updated and precise meteorological services to public users (armed forces, security forces, etc.). Free access to services is granted when they are requested to fulfill "official duties." The latter are intended as all activities of a NMS (internal or external to its territory) resulting from legal, governmental, or intergovernmental requirements relating to defense, civil aviation, and the safety of life and property (EUMETSAT 2010, p. 8)

As regards security issues, it is worth mentioning also the existence of data denial mechanisms in the Metop program. This agreement between NOAA and EUMETSAT establishes the conditions for using data from US instruments (4 are onboard Metop satellites). Data denial is applied both to local and global distribution mechanisms and consists in denying Metop data broadcasting to certain users on request of NOAA when deemed necessary by US authorities. For example, in case of war or crisis, NOAA may communicate to EUMETSAT the contents of the denial data set and the list of users or geographical regions to be denied the access. Priority users consist of users that are never subject to data denial, namely, public duty users and defense forces.

### 46.3.3.6 International Dimension

The international dimension is very developed in this field mainly because meteorology is a global effort of global interest, not only for weather forecasting but also climate monitoring. As previously said, EUMETSAT itself originates from transatlantic cooperation with the NOAA, and today it continues to involve the USA in missions such as Jason or EPS.

EUMETSAT has formal cooperation agreements with a number of international agencies (UN agencies, regional agencies involved in meteorological activities) and with space or meteorological administrations from China, India, Japan, Korea, the USA, Canada, and the Russian Federation too.

EUMETSAT is also developing projects in Africa to furnish support through data, training, and workshops (EUMETSAT website, http://www.eumetsat.int/Home/Main/AboutEUMETSAT/InternationalRelations/Africa/index.htm?l=en). It is worth mentioning also that since July 2012 EUMETSAT participates in the International Charter on Space and Major Disasters, initiated in 1999, to provide EO data to international partners requesting them to manage and recover from natural disasters (Charter Web Site 2011).

As already mentioned, participation of EUMETSAT in Copernicus focuses on oceanography, atmospheric composition, and climate and land monitoring. EUMETSAT is already providing data for Copernicus from its Meteosat, Metop, and Jason satellites and is planning to do so in the future with MTG and EPS satellites' second generation (EUMETSAT contributing to global monitoring for environment and security).

#### 46.3.3.7 Future Prospects

Future programs include *Meteosat Third Generation (MTG)* being developed by ESA and EUMETSAT: the initial part of the R&D phase for the first two satellites is currently ongoing in the frame of ESA MTG program. EUMETSAT is in charge of procuring 4 satellites (the first two are funded by ESA) and launch services (the first is scheduled for 2020), while it will be responsible for developing ground segments and operations. The constellation will consist of 6 heavier satellites compared to the first two generations, with 16 channels. Instruments onboard will include an interferometer, the infrared sounder (IRS), with hyper-spectral resolution in the thermal spectral domain, and the Sentinel-4 instrument (high-resolution ultraviolet visible near-infrared (UVN) spectrometer) (EUMETSAT website http://www.eumetsat.int/Home/Main/Satellites/MeteosatThirdGeneration/MissionOverview/index.htm?l=en). The constellation will be made up of imaging satellites (4) and sounder satellites (2) to analyze the atmosphere layer by layer and be more precise in data collection and analysis.

Activities are ongoing also to define the *second generation (EPS-SG) of MetOp* satellites, which will be part of the future Joint Polar System to be defined with NOAA. EPS-SG is supposed to enter its design and development phase in 2012. Some proposals of instruments to be carried by the SG are being put forward and include instruments provided by EUMETSAT, ESA, and also DLR and CNES, as well as NOAA (EUMETSAT website http://www.eumetsat.int/Home/Main/Satellites/EPS-SG/Instruments/index.htm?l=en).

Last but not least, the mission *Jason-3* was approved by EUMETSAT in 2010. Jason-3 is the result of the cooperation between EUMETSAT (20 of the 26 members agreed to be involved and fund the program), NOAA, CNES, and NASA. Jason-3 is under development and is planned to be launched in 2014. The European Commission is considering funding part of the operations of Jason-3 as it will feed Copernicus marine monitoring services with valuable data (EUMETSAT website, http://www.eumetsat.int/Home/Main/Satellites/Jason-2/MissionOverview/index.htm).

## 46.3.4 European Union: A New Actor in the Space Domain for Security, from Dual-Use Flagship Programs to the SST Initiative

### 46.3.4.1 Copernicus: Overview

Copernicus (former Global Monitoring for Environment and Security, GMES) is a complex program consisting of three main components: the space component (made up of Contributing Missions owned by EU MS and third parties, the Sentinels, developed as "gap fillers," and their ground segments), the in situ component (land, air, and sea sensors managed mainly by the European Environmental Agency), and the service component (managed by the EC with the participation of the private sector and European agencies). Developed at the end of the 1990s with EC and ESA R&D budgets, Copernicus will enter its operational phase very soon. In 2012, the EC decided to rename this program from GMES to Copernicus.

#### Governance and Funding

Copernicus is considered a communitarian program even if national assets[23] are part of the system: indeed, national assets are exploited to feed services with data. The overall governance for the exploitation of Copernicus is still under discussion. While the management of Copernicus services will follow a decentralized approach, the overall management and administration of the system will likely remain in the hands of the EC, provided that Copernicus communitarian funding will be granted for operations from 2014. Officially, this fundamental decision is not taken yet. In fact, in June 2011 the EC proposed that the program is left out of the EU overall budget running from 2014 to 2020 (COM 2011a) (MFF). The EC proposed that a specific Copernicus fund should be established, which should be managed by the EC and to which member states contribute according to their gross national income (GNI) (COM 2011b). The estimated funding needed from 2014 to 2020 is about 5,8B€ globally. Most of the stakeholders (including the European Parliament, the ESA, most MS, the Council, or other consultative bodies of the Union) disagreed with such a proposal. Following intense discussions, the Copernicus program was re-inserted in the general Multiannual Financial Framework (MFF), which is by the way still under negotiation by the budgetary authorities.[24] The funding of Copernicus by the EU through its MFF is more than just a matter of

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[23] Examples of contributing missions today include the German TerraSAR-X, Tandem-X, Enmap, and RapidEye missions; the French SPOT and Pleiades satellite series; the Italian COSMO-SkyMed and Prisma missions; the Spanish SeoSAR, SeoSAT, and DMC-Deimos missions; the UK DMC mission; the ESA/Belgian Proba mission; and Eumetsat's MSG and MetOp missions. Given the cooperation agreement between ESA and Canada, the latter will contribute also to GMES through its Radarsat missions.

[24] In June 2013, the Council the Parliament and the Commission reached a political agreement over the MFF, which will be adopted in autumn 2013, in order to be exploited from January 2014. See http://ec.europa.eu/commission_2010-2014/president/news/archives/2013/06/20130627_1_en.htm. Accessed 29 June 2013.

financial resources: it is also a matter of "paternity" of the program, and consequently it would influence the approach to its overall governance and decision-making. The financial envelop allocated by the EU to the program for the period 2014–2020 has a maximum amount of 3,7B€.

The uncertainty of the EU commitment puts at risk the investments made in the last years:

> Since its founding in 1998 – the EC explains - the overall funding allocated to Copernicus until 2013 by the EU and ESA has reached over € 3.2 billion including the development and initial operations of the services, the space and in situ infrastructures. For the service component, the EU has provided funding of up to € 520 million, and ESA up to € 240 million. For the space component, ESA made some € 1,650 million available and the EU € 780 million (to finance FP7 and Copernicus Initial Operation) including access to space data from national satellites (COM 2011b).

While the operation of the Contributing Missions is the responsibility of their national owners or operators, the operation of the Sentinels once in orbit still needs to be decided. Some of them (relating to climate, marine, and atmosphere monitoring) will likely be operated by EUMETSAT, due to its experience in these specific fields of application. Other sentinels will be operated by ESA ad interim, but a long-term solution is still under discussion in the wider frame of Copernicus governance debate.

As far as services are concerned, their operational governance is under discussion too, although some of them are set up in a preoperational or operational way (like the Emergency Management Service), with the involvement of existing EC agencies, ESA, national authorities, and private service providers. Last but not least, the ownership itself of all the tangible and intangible assets developed under the Copernicus program is still questioned; in its last proposal for regulation, the EC states that the owner may be "the Union or a specifically designated body or fund," with regard, of course, to existing ownership rights (EU 2013).

### Technological Elements

As already anticipated, the Copernicus space component includes Contributing Missions and the Sentinels. Contributing Missions will essentially include the following technical assets:

- "Synthetic Aperture Radar (SAR) sensors, for all weather day/night observations of land, ocean and ice surfaces;
- Medium-low resolution optical sensors for information on land cover, for example, agriculture indicators, ocean monitoring, coastal dynamics and ecosystems;
- High-resolution and medium-resolution optical sensors – panchromatic and multispectral - for regional and national land monitoring activities;
- Very High Resolution (VHR) optical sensors for targeting specific sites, especially in urban areas as for security applications;
- High accuracy radar altimeter systems for sea-level measurements and climate applications;
- Radiometers to monitor land and ocean temperature;

- Spectrometer measurements for air quality and atmospheric composition monitoring" (ESA 2012).

  Once Contributing Missions available to feed Copernicus services were identified, Sentinels' missions were conceived as "gap fillers," essentially in the environmental domain. The following five missions (a constellation of at least two satellites each) are being developed[25]:
- Sentinel-1 C-band SAR: Sentinel-1 is a polar-orbiting, all-weather, day-and-night radar imaging mission for land and ocean services.
- Sentinel-2 "Superspectral": Sentinel-2 is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring providing, for example, imagery of vegetation, soil and water cover, inland waterways, and coastal areas. Sentinel-2 will also deliver information for emergency services.
- Sentinel-3 "Ocean": Sentinel-3 is polar-orbiting, multi-instrument mission to measure variables such as sea-surface topography, sea- and land-surface temperature, ocean color, and land color with high-end accuracy and reliability.

The first three Sentinel missions are planned to be launched in 2013 on light or medium launchers (Soyouz from Kourou, Vega, or Rockot) and will be placed in sun-synchronous low Earth orbit (between about 690 and 800 km). Missions are supposed to last 7 years (ESOC 2012).

Later on, three more Sentinels are planned to cover atmospheric monitoring:

- Sentinel-4 is a payload that will be carried by a Meteosat Third Generation-Sounder (MTG-S) satellite in geostationary orbit.
- Sentinel-5 is a payload that will be embarked on a MetOp Second Generation satellite, also known as Post-EPS.
- Sentinel-5 Precursor satellite mission.

Control systems to operate the Sentinels once in orbit are developed and tested at ESOC, ESA's European Space Operations Centre, in Darmstadt (Germany). The ground segment will include hardware and software to link the ground with the satellite. The ESA has also developed and is operating ad interim a Centralised Data Access System to provide access to a wide range of sources and missions, including Contributing Missions and Sentinels.

### Industrial Issues

At European level different procurement policies and principles apply in this domain, depending on the funding sources used. If funding comes from ESA, then ESA *geo-return*[26] principle applies. If EU funds are used, then procurement

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[25] The GMES Space Component (GSC) made up of Sentinels will likely include the Jason CS mission, expected to be launched in 2017, to complement the work of Sentinels providing more precise information, thanks to the radar altimeter package it will carry on.

[26] Geo-return, or geographic return, or just retour, is the procurement principle establishing that almost the totality of a member state investment in ESA programs will go back to its country under the form of industrial contracts for the participation of its companies and firms to the funded programs.

involves *open competition* and *best value for money* principles, enforced by the European Union.

In both cases, few European firms are effectively capable of ensuring the development and assembling of satellites and related systems.

EADS Astrium and Thales Alenia Space are the two main transnational firms having been contracted to develop the space component of Copernicus and its services, and both benefit from a large network of European suppliers and subcontractors.

The relation between the EU, ESA, and industries in the development of Copernicus started immediately during the R&D phase: under the 6th and 7th framework program for research and technology (from 2002 to 2014) and through ESA projects. Now that Copernicus is approaching the operational phase, the private sector will continue to be involved mainly in the form of service providers and, of course, for future generations of Copernicus components. It is not clear yet which pricing policy, if any, will be applied to (some?) end users and to which extent private companies will make profits with the provision of Copernicus services. Up to now the EC and ESA stated that an open and free policy to access data and services will be pursued as a general rule (with due exceptions in respect to security concerns). In the same vein, although some studies have advocated that Copernicus will create high-skilled jobs and will develop the downstream sector in Europe,[27] this socioeconomic will be seen eventually, when all services will be operational.[28] Concerning Copernicus Contributing Missions, they are the result of public investments, private ones, or a mix of both under PPP[29] initiatives at national level. It is worth recalling here the evolving role of private companies in this domain: some of them are increasingly (co-)financing space activities, as it happened in the Satcom sector. Private firms participate not only in the funding (Spot 6 and 7, for instance, completely funded by Astrium) but also in the provision of EO-based services, both to European public authorities and to commercial customers. Therefore, under certain conditions, Copernicus may experience in the future new forms of co-funding involving private firms.

### Applications, End Users, and Relevance for Security

Today, Copernicus service component foresees a range of services in the following thematic areas:

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[26] Geo-return, or geographic return, or just retour, is the procurement principle establishing that almost the totality of a member state investment in ESA programs will go back to its country under the form of industrial contracts for the participation of its companies and firms to the funded programs.

[27] See for instance studies listed here: http://copernicus.eu/pages-principales/library/study-reports/. Accessed 17 July 2013. Studies were committed by the EC to companies like Space Tec, Booz & Company, Technopolis, or ECORYS.

[28] See for instance Giannopapa (2011).

[29] Private Finance Initiative/Public-Private Partnership.

- *Land monitoring* (applications include land cover change, water quality and availability, forest monitoring, global food security, etc.).
- *Marine environment monitoring*. Applications include marine safety, marine resources, marine and coastal environment, climate and seasonal forecasting.
- *Atmosphere monitoring*. Applications include monitoring of greenhouse gases, reactive gases, ozone layer and solar UV radiation, and aerosols.
- Emergency Management. Applications include support to the management of natural disasters, man-made emergency situations, and humanitarian crisis, thanks to the provision of almost real-time geospatial information.
- *Climate change*, to better monitor and understand climate change (desertification, sea level, food security, etc.).
- *Security*, services including, for the time being:
  - Border control
  - Maritime surveillance
  - Support to EU external action

In such wide range of services, three general user communities can benefit from Copernicus. They can be organized in institutional end users (including military, even if with a marginal interest) at national, European, and even international level; private end users, including insurance companies, NGOs, or companies in the field of oil or natural resources exploitation; and the scientific community, which also represents a category of users interested in Copernicus data and services.

As far as the security service is concerned, it is worth mentioning that it will rely mainly on Contributing Missions (rather than on Sentinels) due to their specific features, such as resolution, revisiting time, access to data, and encryption. Although most space infrastructures are already available, a number of issues still make the security service less mature than others. Security-related issues to be solved include the definition of security itself: perimeter of security services, identification of precise missions, and related end users. With regard to the last point, in some cases (e.g., support to the EU's European External Action Services (EEAS)), end user communities are better identified and organized compared to other services (like maritime security). Other issues relevant to security include the sensitive use of national EO data for security purposes, the absence of a clear data policy shared among the main stakeholders, and last but not least, the necessity to ensure that Copernicus products are not misused by unauthorized users for harmful purposes.

Some security preoperational services are running in the frame of the 7°FP R&D project G-MOSAIC (http://www.gmes-gmosaic.eu/). In this project, security services were activated to support the EU's European External Action Services (EEAS) in scenarios related to crisis management and assessment (Nicaragua-Costa Rica border 2010; Ivory Coast, Yemen and DRC). Also in the case of Libya conflict, G-MOSAIC was activated. End users included French and Italian ministries of defense, DG RELEX/EEAS,[30] the United Nations Peace Keeping

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[30] Directorate General for External relations / European External Action Service.

Department, and the African Regional Centre for Mapping of Resources for Development.

These first deployments demonstrate the variety of end users (European, international, European, military and civil), which for this specific service are mostly institutional rather than private.

### International Dimension

The potential of Copernicus in the frame of international cooperation agreements is recognized, and in some cases clear procedures and rules are established to ensure fair, secured, and controlled access to Copernicus services. Indeed, third parties (international organizations, national administrations, etc.) may be potential end users of Copernicus. The first year of experience in the Emergency Management Service clearly shows the interest brought to the service by third parties, as the UN.[31] It is also important to bring to mind the more general engagement of the EU toward the African continent[32] and its regional organizations. One of the headings of the EU-Africa Joint Strategy includes the use of information and communication technologies (including space) for security and development goals.

Moreover, international partners may actively contribute to the Copernicus program, as it is the case for Canada (Canadian Space Agency 2012), through national programs and the award of ESA contracts on Copernicus service elements and space components.

With regard to non-European end users or partnerships with third parties, some aspects need to be considered and solved: in the case of security services more than in others, some political- and security-related restrictions and controls will need to apply in order to ensure that Copernicus resources (data and services) are not misused and that Copernicus remains an independent tool at the service of European security.

### Future Prospects

As far as Sentinels and services are concerned,[33] the EC and the end users have built a continuous dialogue and close relationship to define services, including in their evolution and improvement. ESA may be actively involved in these kinds of discussions in order to turn user needs and requirements into technological updates on the space and ground infrastructures. Copernicus 1st generation is still in its preoperational phase, but in the long term (between 2020 and 2025), Sentinels will

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[31] See the EMS official website, where recent activations are reported.

[32] The Africa-EU strategic partnership, a Joint Africa-EU Strategy (12/2007), including the following domains: Environmental Sustainability and Climate Change; Science, Information Society and Space. http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/er/97496.pdf. Accessed 25 Aug 2012. It was followed by a Joint Africa EU Strategy, Action Plan 2011–2013.

[33] With regard to GCMs, national competent authorities, civil and/or military, will determine future generations of their programs on the basis of national and users requirements.

need to be replaced with a third spacecraft of the same family (1-C, 2-C, etc.) incorporating improvements. The main goal is to ensure that Copernicus remain a user-oriented program.

As far as contributing missions are concerned, national space agencies are already planning the second generation of their spacecrafts (e.g., ASI is preparing COSMO-SkyMed 2nd Generation, DLR is planning TerraSar-X 2nd Generation too, etc.).[34] Indeed, ensuring the continuity of the service provision in the long term is also paramount for the success of Copernicus, with regard not only to user communities but also to truly consolidate the downstream sector.

#### 46.3.4.2 Galileo: Overview

Galileo is the EU navigation and positioning program consisting of a constellation of 30 satellites to be positioned in geostationary orbit. In October 2011 the first two Galileo satellites were deployed. Launched onboard Soyuz rockets from the European Spaceport in Kourou, their signals have demonstrated the interoperability success with the GPS system,[35] without risk of signal interference among the two. The next two Galileo satellites were launched from Kourou in October 2012. The presence of four satellites in orbit allows for the implementation of the so-called In-Orbit-Validation (IOV) phase and for the launch of the Initial-Operation-Capability (IOC) phase after 2015.

The operational phase will follow, with the deployment of the full constellation (26 operational satellites) on a circular medium orbit at about 23,220 km above the Earth and the completion of the wide network of ground stations. Ground operation centers will be hosted in Italy (Fucino) and in Germany (nearby Munich).

##### Governance and Funding

Differently than Copernicus, Galileo is a fully European program. ESA is in charge of the R&D phase and IOV phase and co-finances the Galileo program of about 50 %.

The EU remains the sole owner of the infrastructures and the services. The governance structure initially established for Galileo, based on a PPP model between the EU and European firms, was unclear and not very efficient. Roles of public and private players were sometimes conflicting and not a clear delegation of competences or accountability was identified (Veclani et al. 2011). This led to the reorganization of the public governance in 2007 and the decision to fund the program with public resources only. It was clarified who was responsible for the management of the program (the EC) and who was politically responsible for it (the EU, with EP and Council political oversight and budget allocation). It clarified also the support of ESA as procurement and design agent and the role

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[34] More information about current, planned and under discussion programs, see http://earth.esa.int/pub/ESA_DOC/ESA_Bulletin142_GMES.pdf. Accessed 16 Aug 2012, pp. 30–31.

[35] Space signal demonstrates Galileo interoperability with GPS, 12 July 2012, ESA (2012). Moreover, Galileo is developed to be operational also with GLONASS positioning system.

of a specific EU Agency (European GNSS Authority (GSA)[36]) for commercial and security issues to guarantee that European public interests are duly taken into account. This new governance set-up, based on the 2008 Regulation, has allowed the program to be on track since then. More recent documents[37] further specify the governance of the system, in particular, as far as the bodies in charge of its Security Accreditation is concerned.

With regard to the funding issues, between 2007 and 2013, about 3,4B€ was spent by the EU and ESA's member states. For the coming years (deployment and full operational capability phase), the European Commission proposes that Galileo and EGNOS[38] are financed at a level of 7B€ within the Multiannual Financial Framework (MFF 2014–2020) (COM 2011c). Council and EP have reached an agreement concerning the financing of Galileo at the level of 6.3B€ for the next 7 years (Council and European Parliament).

## Technological Elements

The Galileo full infrastructure will consist of:

- A constellation of 30 satellites in medium Earth orbit (MEO). Each satellite will contain a navigation payload (with two European cutting-edge atomic clocks) and a SAR transponder. Each satellite will weigh about 700 kg of mass and will be launched at 23,222 km (http://www.gsa.europa.eu/galileo/programme) of altitude.
- 30–40 sensor stations.
- 2 control centers.
- 9 mission uplink stations.
- 5 telemetry, tracking, and command (TT&C) stations (DG ENTR website, http://ec.europa.eu/enterprise/policies/satnav/galileo/programme/index_en.htm).

Among the new technologies required by the Galileo program and developed for the first time in Europe, it is worth mentioning those related to very accurate time and position measurement. European industries[39] developed two cutting-edge

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[36] The GSA was established as a Community Agency on 12 July 2004, by Council Regulation (EC) 1321/2004, status amended in 2006 by Council Regulation (EC) No 1942/2006 and by Regulation (EU) No. 912/2010, which entered into force on 9 November 2010, See EGA website, Accessed 16 Aug 2012. For a full overview of the GSA tasks, please refer to http://www.gsa.europa.eu/gsa/overview, GSA website, Accessed 16 Aug 2012.

[37] Main documents include Regulation 912/2010 "setting up the European GNSS Agency, repealing Council Regulation (EC) No 1321/2004 on the establishment of structures for the management of the European satellite radio navigation programs and amending Regulation (EC) No 683/2008 of the European Parliament and of the Council"; COM (2011d) and COM (2013b).

[38] EGNOS (European Geostationary Navigation Overlay System) is an overall system that increases GPS and Glonass systems by improving the services (some services are already available in Europe since 2009). EGNOS is a joint project of ESA, the European Commission and Eurocontrol, the European Organisation for the Safety of Air Navigation. Galileo will be part of the EGNOS too. See ESA website: http://www.esa.int/esaNA/egnos.html. Accessed 21 Aug 2012.

[39] Namely the Observatoire de Neuchatel, Officine Galileo of Italy, Temex Neuchâtel Time and Astrium Germany.

atomic clocks: a Rubidium Atomic Frequency Standard and a Passive Hydrogen Maser. Each satellite of the constellation will carry both clocks, which will contribute to determining positions very accurately (within 45 cm) (Galileo Technologies development, ESA 2012).

ESA, through its Radio Navigation Laboratory based at the European Space Research and Technology Centre (ESTEC) in the Netherlands, routinely monitors signal-in-space health and performance for satellite navigation systems. Galileo program is also supported by this test and simulation facility.

### Industrial Issues

Initially, the EC hoped to fund the Galileo program through a public-private partnership (PPP) that is, with the financial support of the private sector, which would benefit in the end from the commercial revenues of the program. Miscalculations about the business model, subsequent costs overruns, delays, and misunderstandings between the public and private sector and within the latter led to the impossibility of finding an agreement between players and eventually led to the failure of the model. The EC decided then to fully finance Galileo with public funding, and following some inquiries the program will be re-started on a fresh and solid basis with a new administrative and management structure centralized at EC level and with clear roles for ESA and industries.

Today the private sector remains involved in the program through procurement contracts signed by the EC or ESA on behalf of the EC. The first 22 satellites of the "Full Operational Capability" phase are being built by OHB (Germany) and Surrey Satellite Technology Ltd (UK), which is producing the payloads. The first four Galileo IOV satellites, instead, were built by a consortium led by EADS Astrium, Germany (with Astrium FR and Astrium UK).[40]

The contract for the system support services, which is a requirement for the integration and validation of the Galileo system, was awarded to Thales Alenia Space.

The contract for launching satellites was awarded to Arianespace and covers the launch of two satellites onboard of each of the five Soyuz launched from Kourou. The contract for the operations, instead, was signed with SpaceOpal GmbH (an Italian-German joint venture) and the European Space Agency acting on behalf of the European Commission.[41]

### Applications, Users, and Relevance for Security

As far as the services are concerned, Galileo will provide the following services worldwide and independently:

- The *Open Service (OS)*: It provides the "classic" positioning and navigation performance, is free of user charge, and is open to anyone.

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[40] About Galileo contracts, see industries' websites and DG ENTR website, http://ec.europa.eu/enterprise/policies/satnav/galileo/programme/index_en.htm. Accessed 16 Aug 2012.

[41] *Ibidem.*

- The *Safety-of-Life Service (SoL)*: It provides the user with timely warning if the integrity of the signal is not guaranteed. This improvement is of particular interest to safety critical transport communities (like aviation). A service guarantee will be provided for this service.
- The *Commercial Service (CS)*: It is an improved service which is more accurate by providing access to two additional signals (a service guarantee will be provided for this service too). Customers may be mostly private users.
- The *Public Regulated Service (PRS)*: It is a service for specific users (public authorities) requiring a high continuity of service and controlled access. PRS navigation signals will use encrypted codes and data. This service is supposed to be the core service for security and defense authorities, which will be in the end the main end user.
- Galileo also supports the *search and rescue service* which is the European contribution to the international COSPAS-SARSAT cooperative effort on humanitarian search and rescue activities.

Users are defined as persons in physical possession of Galileo signal receiver. People in distress will benefit highly from the Galileo services, and the same can be said for S&R forces, security forces, civil protection, road-maritime and air transport agents, and agriculture-related employees, just to name the main ones.

### International Dimension

Navigation and positioning are functions with global outreach, and since Galileo will not be the only system operating in this sector, an open dialogue with other nations was necessary. As already said, Galileo is already interoperable with GPS, thanks to transatlantic dialogue carried on since the beginning of the program. Moreover, in 2003 the EC concluded a cooperation agreement with China regarding, among other issues, market development and industrial cooperation, in exchange of financial participation in the program that was experiencing heavy run costs. The agreement was abandoned in 2006 because of the fear surrounding the possibility of Galileo advanced technologies falling into Chinese hands. The EC entered again in negotiations with this country to settle, this time, the controversy over frequency overlap with the Chinese program Compass.[42]

Recalling again the wider cooperation framework with Africa in the space domain, the regional organization African Union (AU) and the EU are working to extend the European Geostationary Navigation Overlay System (EGNOS) to the African continent to improve air and maritime transport safety. With regard to Russia, part of the space cooperation concerns the interoperability of Galileo and GLONASS navigation program but also the commercialization of Soyuz rockets through Arianespace. Launched from the Guyana Space Centre, Soyuz brought the

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[42] According to the International Telecommunication Union policies, the first country to start using a specific frequency band is granted priority status, and subsequent users (the EC in this case) need to ask permission to the band first user to use that frequency, which is unacceptable for PRS service and the quest of European autonomy for navigations services.

first two Galileo satellites into orbit in 2011 (Marta, dossier Fondation pour la Recherche Stratégique).

Moreover, the Galileo Information Centre for Latin America prepares the ground for Latin American countries to integrate and exploit Galileo signals on the continent, through contacts with end users, stakeholders, authorities, and identifying applications and business opportunities.

#### 46.3.4.3 SST Program: A Proposal from the EU

The 7th Space Council (2010) confirmed the importance attached also by the EU to security for space and invited the European Commission and the EU Council to propose a governance scheme and data policy of an SSA program,[43] taking into account civil and military user needs (under definition) and the ESA preparatory program. The EC, on its side, supports this program through a number of R&D projects on space weather and the security of space assets from on-orbit collisions in the framework of the FP7 R&D program (DG ENTR website, http://ec.europa.eu/enterprise/policies/space/esp/security/assets/index_en.htm).

The last initiative undertaken by the EC in the field of SSA consists in a proposal for a European Decision on the establishment of a European Space Surveillance and Tracking (SST) program (COM 2013a). On the basis of its new competences in the space sector (Lisbon Treaty, art. 4 and 189), the EC proposes to support the development of an SST program with a contribution of 700M€ for the period 2014–2020. The sensitivity of the program is taken into account: in fact, it is suggested that MS keep ownership and control of assets and data. The EU would play the role of coordinating access to the case-by-case declassified information and providing services, likely through the European Union Satellite Centre (EUSC).[44]

This proposal, to be discussed by the Council and the Parliament, marks the beginning of a new approach of the EU to its space programs with military applications, in order to satisfy MS security concerns.

## 46.4 Conclusions

The following table sums up the current European institutional space missions and programs in support to security and defense policies (Table 46.1):

Security and defense policies are progressively and gradually being supported by European institutions and organizations' space programs. For the time being, space

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[43] For an overview of ESA-EDA initiative, see for instance EDA, Issue 1 May-July 2012. *Euroepan Defense matters*. See also 7th Space Council, 2010, paragraphs 22–24, http://www.eda.europa.eu/libraries/documents/space_policy_resolution.sflb.ashx. Accessed 23 Aug 2012.

[44] The European Union Satellite Centre (EUSC) contributes, in a way, to the European security by providing to MS and EU institutions support to ESDP missions and policies through the exploitation of space-based system. Nevertheless, this institutional actor is not considered here as it does not own satellites nor develops new programs. In fact, EUSC activity is based on the exploitation of national and commercial space-based data which are purchased with EU budget.

**Table 46.1** Existing European institutional security programs

| | Program | Fund | Overall management | R&D resp. | Main security mission | Nature | Status |
|---|---|---|---|---|---|---|---|
| European Union | Copernicus | EC+ESA and EUMETSAT financing +GCM | EC | ESA | Earth observation for security and emergency response | Civil with dual-use appl.s | Preoperational |
| | Galileo | EC+ESA | EC (GSA) | ESA | Navigation and positioning | Civil with Dual-use appl.s | Preoperational |
| | SST *(proposal)* | EU support – existing assets funded by MS | EU | – | Space surveillance and tracking to avoid collisions and damages | Civil with dual-use potential appl.s | Preliminary studies/EC proposal |
| EUMETSAT | Meteosat, Metop, Jason | EUMETSAT+ESA | EUMETSAT | ESA | Meteorology, atmosphere, ocean, and climate monitoring | Civil with dual-use appl.s | Operational |
| ESA | SSA | ESA | – | ESA | Space Situational Awareness (mainly NEO and SW segments) | Civil with dual-use potential appl.s | Preparatory activities |

programs with high-end military features and performances are granted by few space-faring nations in Europe and at a national level.

However, three main European institutional actors are getting more and more involved in satellite programs for security purposes, following a dual-use approach and taking advantage also of the enlarged meaning of security, which applies also to transport policies or environmental policies, for instance.

Dual-use programs' applications are multiple and involve a very wide range of different users: public and private and civil and military, at local, national, European and international level. Overall, applications ensure a qualitative and independent service to security forces in meteorology, Earth observation (intelligence, surveillance, etc.), navigation, and positioning domains. Likely soon, European and international operators will also benefit from space surveillance tracking service provided by the EU, as a key tool to support security *in* space.

European institutional involvement in security and defense space programs is recent and scattered. This is also because, in contrast to the USA, for instance, the nascent European space programs could not lean on a common and consolidated European military strategy, which still remains a national prerogative. Additionally, despite the European integration process, when security and defense realms are concerned, the success of cooperative intra-European efforts is not at all given for granted.

Existing dual-use European institutional programs have been so far the only possible way for supranational organizations to develop and manage security-oriented space capabilities. This is certainly already a success given the history of European countries in the last 60 years.

It is interesting to observe that the three main institutional actors developing dual-use programs (ESA, EU, and EUMETSAT) are quite different in nature and purpose. They are interacting increasingly to coordinate themselves and ensure that each one exploits its own competences without unnecessary duplications. The EU is ensuring the political direction, end user engagement, part of the funding, and the overall management of its two flagship programs. ESA is involved in the R&D phases in all mentioned programs, while EUMETSAT operates its own infrastructures and may be involved in the operation of other similar missions (Sentinels 4 and 5). Work-sharing along competences in the different phases of a satellite program, rather than along thematic competences (civil vs. military, for instance), seems to be the preferred approach to ensure the development of supranational capabilities.

The challenge ahead still remains the capacity to effectively bring all those programs under a unique European "space for security" strategy in order to ensure that they all contribute to a single European space capability for security and defense purposes. Funding, operations, governance, and data policy of the European space programs for security are some of the most complicated issues that in some cases still need to be solved. They are particularly touchy when it comes to national defense realms. The process may be long and is very much linked to the MSs' political will and the maturity of a common European defense strategy. However, the satellite program overview demonstrates that progress has been made in the last 40 years, that it is still ongoing, and that in the end, although with some limits, Europe seems to have found its own approach to the couple “space and security.”

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# European Member States Satellite Programs

# 47

Martin Hellmann and Wolfgang Rathgeber

## Contents

**Abstract**

This chapter provides an overview of European Member States' satellite programs. It covers the different types of sensors that can be used in satellites. Earth-observation satellite missions are introduced. The countries presented are Germany, France, Italy, United Kingdom, and Spain.

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The views presented in this chapter are the personal views of the authors and do not (necessarily) reflect the views of their respective institutions.

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## 47.1 Introduction

Since the 1970s, when the space race between the United States and the Soviet Union started cooling down, some European nations have established themselves as space players. The activities of European nations traditionally have focused on the civil and commercial uses of space. Over the past years, this focus has been changing. European nations have come to recognize the value of an independent Earth-observation infrastructure, which can supply various authorities with up-to-date information in order to better protect the environment, identify and monitor regions of latent crisis at an early stage, improve the management of humanitarian crises, and safeguard the national security. Additionally, European nations understand the importance of avoiding unilateral dependencies in reconnaissance and achieving European non-dependence in remote sensing (EUSC 2012).

More than 30 European remote-sensing satellites are currently operating or are planned for launch by individual nations, by coalitions, and/or by European nations collectively. Some of these satellites are dedicated military assets, like the German military reconnaissance satellite constellation SAR-Lupe or the French Helios satellites. Apart from dedicated military satellites, there are some which are dual use, including Italy’s radar satellite constellation, COSMO-SkyMed, and others, like the German TerraSAR and TanDEM-X satellites, which are civilian/commercial satellites capable of providing data for security or military applications upon request.

### 47.1.1 Sensor Types

Satellites carry different types of sensors (Richards and Jia 2006). They can have radar sensors (e.g., Synthetic Aperture Radar (SAR) like SAR-Lupe and COSMO-SkyMed), electro-optical sensors (Helios) or hyperspectral sensors (EnMAP). Remote-sensing systems, based on the energy source, can be grouped into two types: passive and active systems (Campbell 2002). Passive sensors detect natural radiation (usually reflected sunlight) which is emitted or reflected by the object or from the surrounding areas. These sensors are mainly optical, infrared, and hyperspectral sensors or radiometers. Passive remote-sensing systems detect energy in the visible, infrared, and thermal infrared regions of the electromagnetic spectrum. Active sensors emit energy in order to scan or illuminate objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target. Radar and Lidar are typical examples of active sensors. The different sensors operate in different wavelengths which are sensitive to different scattering mechanisms. Microwave sensors use wavelengths in the centimeter or decimeter range. These differences in the sensors and censoring techniques have advantages and disadvantages.

Radar systems, unlike optical ones, can provide high-contrast topographic data, even during the night and cloud cover. They are, depending on the wavelength, able to penetrate through foliage and can therefore detect objects beneath a forest canopy. However, data analysis of these systems is more complex. Data from optical systems, on the other hand, is easier to interpret for the untrained user.

Hyperspectral data provides the possibility of obtaining information regarding the chemical composition of the observed objects but also suffers from complexity in the data analysis for less advanced users. Infrared sensors are able to detect heat and can therefore typically used to detect forest fires from space. Often, if available, a combination of different sensors and satellites is used in order to combine the different types of information and to reduce the response time.

In other words, the type of sensor will define "what you see," i.e., the type of information that can be detected and measured and under which conditions (e.g., SAR for day, night, and through clouds versus electro-optic, which can be used only when the area is illuminated by the sun and cloud free, versus infrared for fire detection). The quality of remote-sensing data – or "how good or how much you can see" – on the other hand depends heavily on the resolution. There are four main resolution categories: spatial resolution, spectral resolution, temporal resolution, and radiometric resolution.

**Spatial resolution** is a measure of the smallest object that can be resolved by the sensor or the linear dimension on the ground represented by each pixel or grid cell in the image.

**Spectral resolution** describes the specific wavelengths that the sensor can record within the electromagnetic spectrum. For example, the "photographic infrared" band covers the wavelength range 0.7–1.0 μm.

**Temporal resolution** is a description of how often a sensor can obtain imagery of a particular area of interest. For example, the Landsat satellite revisits an area every 16 days as it orbits Earth, while the SPOT satellite can take an image of an area every 1–4 days.

**Radiometric resolution** refers to the number of possible brightness values in each band of data and is determined by the sensor and by the number of bits into which the recorded energy is divided. In 8-bit data, the brightness values can range from 0 to 255 for each pixel (256 total possible values). In 7-bit data, the values range from 0 to 127 or half as many possible values.

In summary, the choice of sensor and sensor performance is crucial element for any given mission. The number of satellites is also important for the system response time and, therefore, for the information age. In the case of multiple satellites, the decision between formation or constellation flight, the number of satellites, and the choice of orbits will define the capability of the system. Last but not least, the most limiting factor is the budget. These parameters define the framework for all national defense and security-related satellite missions. These will be outlined for the European countries in the following sections.

## 47.2 National Satellite Missions

In the following sections the European national satellite missions of security relevance will be shortly introduced country by country. As explained before, remote sensing is particularly relevant and prevailing within the security domain; thus, only Earth-observation missions are considered.

### 47.2.1 Germany

Germany operates one of the two dedicated military Earth-observation satellite programs in Europe called *SAR-Lupe*. SAR is an abbreviation for Synthetic Aperture Radar and "Lupe" means magnifying glass in German. Due to the SAR sensor, SAR-Lupe can acquire remote-sensing data day or night through all weather conditions. The SAR-Lupe program consists of five identical (770 kg with a size of approx. 4 × 3 × 2 m) satellites. The five satellites operate in three 500-km orbits in planes roughly 60° apart (OHB 2012a). Operating in X-band, the radar satellites have two modes. The first mode ("stripmap," in which the satellite maintains a fixed orientation with regard to Earth) provides extended time imaging with a fixed direction of the antenna. The second one ("spotlight," in which the satellite or the sensor direction rotate to keep pointing at a specific target area, increasing integration time) is used for high-resolution imagery. The actual resolution values of SAR-Lupe are classified. The only official statement is that the spatial resolution is much better than 1 m (OHB 2012b). The response time for imaging of a given area is 10 h or less. The satellites were developed by Orbitale Hochtechnologie Bremen (OHB) System AG (OHB 2014) as the prime contractor, and the SAR-Lupe system is owned and operated by the Federal Ministry of Defense (BMVg). The first satellite was launched from Plesetsk in Russia on 19 December 2006 (DLR 2006) while the launch of the other four satellites followed at roughly 6-month intervals. The entire system achieved full operational readiness on 22 July 2008. The planned lifetime of the system is 10 years, and the work for the follow-up system called SARah has already started (Bischoff 2014).

The ground segments of SAR-Lupe and the French optical reconnaissance system Helios 2 are to be used jointly as the core element of European-wide strategic reconnaissance operations (OHB 2012b; ReportInvestor 2010). France and Germany have an agreement to share data from Helios 2 and SAR-Lupe, providing receivers of one system with data from the other one. In addition, Belgium and Spain will receive Helios 2 data under a shared cost agreement (MOD France 2009).

Following the footsteps of European radar satellites ERS-1, ERS-2, and Envisat, as well as the joint US-German-Italian Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) that flew on the US Shuttle Radar Topography Mission, the German civil SAR satellite missions TerraSAR-X and TanDEM-X seek to support scientific and commercial applications of radar-based Earth observation. Demonstrating Germany's expertise in satellite-based radar technology, the mission is the result of a long-term focus in Germany's national space program. Unlike the SAR-Lupe mission, TerraSAR-X and TanDEM-X are civil/commercial missions but feature a strong potential of security applications (like space-based disaster mitigation) and also exhibit some potential for military applications based on their high-resolution 3D modeling capabilities.

*TerraSAR-X (TSX)* is Germany's first national remote-sensing satellite that has been implemented under what is known as a public-private partnership (PPP) between the German Federal Ministry of Education and Research

(Bundesministerium für Bildung und Forschung (BMBF)), the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt (DLR)), and the Astrium GmbH (Astrium 2009). It is an Earth-observation SAR satellite mission for scientific and commercial applications. The 4.88-m long and 2.4-m wide satellite with a hexagonal cross section and a launch mass of 1,230 kg (DLR 2011) was launched from the Baikonur Cosmodrome in Kazakhstan on 15 June 2007 into a near-polar Sun-synchronous orbit around Earth, at an altitude of 514 km (Flugrevue 2007). The active antenna operates in X-band, allowing different imaging modes to be used. In the Spotlight mode the radar image records an area of 5–10 by 10 km with a resolution of up to one meter. In the stripmap mode, it records strips of 30-km width and up to a length of 1,500 km with a 3-m resolution. In the ScanSAR mode a strip of 100 km in width and up to a maximum of 1,500 km in length can be scanned with a resolution of 18 m. The data is used for a wide spectrum of applications in fields such as hydrology, geology, climatology, oceanography, environmental and disaster monitoring, and cartography (DEM generation), making use of interferometry and stereometry. The satellite has a designed life span of at least 5 years.

In June 2010 the nearly identical *TanDEM-X* satellite (TDX) was launched (Bergin 2010). TDX and TSX together form the first configurable SAR interferometer in space, the TanDEM-X mission (TerraSAR-X add-on for Digital Elevation Measurement) (Astrium 2010). Flying in close formation only a few 100 m apart, the two satellites are imaging the terrain below them simultaneously, from different angles. These images are processed into accurate elevation maps with a 12-m resolution and a vertical accuracy better than 2 m. The amount of data generated by the satellites will grow to 1.5 petabytes within 3 years. Like the TerraSAR-X mission, TanDEM-X is a project developed under a public-private partnership between the German Aerospace Center (DLR) and Astrium GmbH in Friedrichshafen, Germany. The TanDEM-X satellite has been designed for a nominal lifetime of 5 years.

*EnMAP* (Environmental Mapping and Analysis Program) is a German hyperspectral satellite mission providing high-quality hyperspectral image data on a timely and frequent basis (ENMAP 2013). The main objective is to investigate a wide range of ecosystem parameters encompassing agriculture, forestry, soil and geological environments, coastal zones, and inland waters.

The project management for the EnMAP mission is under the responsibility of the Space Administration of the German Aerospace Center (DLR). The German Research Center (DLR) for Geosciences (Deutsches GeoForschungsZentrum (GFZ)) (GFZ 2014) in Potsdam has the scientific lead for the project. The Kayser-Threde GmbH is responsible for the development, production, and launch of the satellite. The satellite's hyperspectral imager is provided by Kayser-Threde GmbH and the satellite's bus by OHB System AG (OHB). The establishment and 5-year operation of the ground segment (data reception, data processing including quality control, data archiving, calibration, as well as providing a web interface to the EnMAP user) is performed by the DLR entities: the Earth Observation Center (EOC) and the German Space Operations Center (GSOC). The Satellite will be equipped with a dedicated imaging push-broom hyperspectral sensor mainly based on modified existing or pre-developed technology. It will cover a broad spectral range from 420 nm to 1,000 nm (VNIR) and from 900 nm to 2,450 nm (SWIR) with high radiometric resolution and stability in both spectral ranges. It will image swaths with a width of 30 km up to 1,000 km length per orbit at high spatial resolution of 30 m × 30 m. The envisaged launch of the EnMAP satellite is in 2015.

The *RapidEye* mission is a commercial remote-sensing mission by the German Company RapidEye AG (RapidEye/Blackbridge 2014). It was supported by German Aerospace Center (DLR) with funds from the Ministry of Economics and the Brandenburg state government. The total sum invested in the project amounts to around 160 million Euro, of which about 10 % is funded by DLR. The RapidEye business concept was initiated in 1996 by Kayser-Threde GmbH of Munich with support from the German Aerospace Center (DLR). Eight years later the funding was secured for the RapidEye satellite constellation and ground segment with the help of the European Union, the State of Brandenburg (Germany), a banking consortium consisting of Commerzbank, Export Development Canada (EDC), and KfW Banking Group. MacDonald Dettwiler (MDA) was awarded the contract as the prime contractor to build RapidEye's satellite system. The satellite bus was built by Surrey Satellite Technology Ltd. (SSTL) in England. Each satellite is based on an evolution of the flight-proven MicroSat-100 bus. Each satellite measures less than one cubic meter and weighs 150 kg (bus + payload). The push-broom sensor carried on each satellite is the Jena Spaceborne Scanner JSS 56. Each of those five sensors is capable of collecting image data in five distinct bands of the electromagnetic spectrum: blue, green, red, red edge, and near infrared. RapidEye's satellites are the first commercial satellites to include the red-edge band, which is sensitive to changes in chlorophyll content.

The RapidEye's complete constellation of five satellites was successfully launched with a single DNEPR-1 rocket (a refurbished ICBM missile) on 29 August 2008 from the Baikonur Cosmodrome in Kazakhstan and became commercially operational in February 2009. The mission consists of a constellation of five identical small satellites (named TACHYS, (rapid); MATI, (eye); CHOMA, (Earth); CHOROS, (space); TROCHIA, (orbit)) and a ground infrastructure based on proven systems. The five satellites are placed in a single Sun-synchronous orbit of approximately 620 km, with the satellites equally spaced over the orbit. Each satellite carries a 5-band multispectral optical imager with a ground sampling distance of 6.5 m at nadir and a swath width of 80 km. The constellation has the ability to acquire images of any area on Earth once per day and can also provide a large area coverage within 5 days.

Although being built primarily for the commercial market in agricultural imaging and mapping, the RapidEye constellation will also be used by the German military. Even though the satellites have a relative coarse spatial resolution compared to other military systems, the temporal resolution of the five-satellite constellation is high. In May 2011, RapidEye filed for bankruptcy protection and in August 2012 RapidEye Canada Ltd. of Lethbridge, Alberta, Canada, acquired RapidEye AG. In November 2013 RapidEye has officially changed its name to

BlackBridge. This change is the result of a 2-year process of uniting all BlackBridge owned companies as one presence in the marketplace (RapidEye/ Blackbridge 2014).

The *BIRD* mission (Bi-spectral Infrared Detection) was a small satellite mission funded by DLR. The BIRD satellite was launched with the Indian PSLV-C3 on 22 October 2001 into a 572 km circular Sun-synchronous low Earth orbit.

The microsatellite mission BIRD successfully demonstrated in 6 years of operations (2001–2007) the technical and programmatic feasibility to combine ambitious science and innovative, but not necessarily space proven, components under "design to costs" constraints. BIRD was designed for spaceborne remote detection and sensing of hot spot events like vegetation fires, active volcanoes, burning oil wells, and coal seams using push-broom sensors on board of a microsatellite. The 3-axis-stabilized BIRD satellite has a total mass of 94 kg. The size of the box-shaped main body is 620 × 620 × 550 $\text{mm}^3$. The satellite assures a peak power consumption of 200 W for the duty cycle. The duty time of the payload is 10 min in one orbit. The data of one duty cycle can be stored in the 1Gbit mass memory and is transmitted to a German ground station during the next pass.

One of the main goals of BIRD was to demonstrate both the advantages as well as the limits of a variety of new technology experiments. In 2008, after 6 years of flight during which BIRD delivered highly valuable infrared sensor data allowing the detection of hot spots in a sub-pixel range with a spatial resolution down to 2 square meters, the spacecraft-routine-operation-phase was officially terminated. Despite the damage of three reaction wheels and the gyroscope, BIRD is still fully functional with the whole payload and in all other subsystems. The pointing accuracy now depends on the still working attitude sensors (magnetometer, Sun-sensor) and actuators (magnetorquer) but with a smaller precision than before.

Two satellite projects with similar on-board instruments are following the BIRD mission. *TET-1* was launched in 2012 (SpaceDaily 2012) and *BIROS* which is slated for launch in 2014 (EOPortal 2012). Both projects feature fire detection technology. The tandem of satellites will provide a significant improvement in the space-based detection of forest fires and the monitoring of their propagation. Furthermore, DLR is currently discussing with international partners regarding further components of a multi-satellite system. Putting in place such a constellation would be a further improvement of space-based fire monitoring. A positive effect would be the valuable contribution that the instruments could make to climate research – such as mapping of urban microclimates.

The *TET-1* (Technologieerprobungsträger-1, Technology Testbed-1) weighs 120 kg and has a payload capacity of 50 kg. The 70-kg satellite bus is built by Astro- und Feinwerktechnik Adlershof GmbH (Astro 2014a). The DLR Space Administration appointed the space systems engineering company Kayser-Threde GmbH as prime contractor for the development of the satellite (Astro 2014b).

TET-1 will be operated as part of the OOV program for 14 months under contract of the German space agency and will be handed over then to DLR Research and Development department to be used as one part of the FIREBIRD constellation, together with BIROS.

The 11 experiments selected by DLR for this mission include solar cells, navigation equipment, a camera that can be used to detect forest fires, telecommunications technologies, spacecraft propulsion systems, and computer hardware. For a 1-year period, TET-1 will operate in low Earth orbit, at an altitude of 520 km. After that, it will slowly reenter Earth's atmosphere, where it will burn up.

### 47.2.2 France

*SPOT* (Satellite Probatoire de l'Observation de la Terre) is a family of optical satellites that have been launched since 1986. SPOT 4 was launched on 24 March 1998 from Kourou. It features two imaging instruments offering panchromatic and multispectral acquisition mode. Stereoscopic operation for the creation of digital terrain models is possible as well. SPOT 5 has been launched on 4 May 2002 from Kourou. It has a mass of 3 metric tons and flies two advanced imaging instruments that allow a resolution of 2.5–5 m in panchromatic mode and 10 m in multispectral mode. SPOT 4 and 5 have been followed by SPOT 6 (launched in December 2012) and SPOT 7 (to be launched in 2014), agile satellites with a resolution of 2 m, sharing orbits with the Pleiades which is described below (SPOT 2012).

*Helios* is a French optical satellite imaging constellation for military reconnaissance. Helios is funded by France, Italy, and Spain. The first-generation Helios satellites, Helios 1A and 1B, were launched in 1995 and 1999. Featuring daily revisit capability, they had a resolution of about one meter. However, due to their lack of infrared capability, they were incapable of obtaining images at night or in cloudy weather conditions.

The second generation of the program began with the launch of Helios 2A on 18 December 2004. Helios 2B was launched exactly five years later, on 18 December 2012. Built by EADS Astrium and featuring electro-optical sensors, the satellites have a mass of 4 metric tons each and occupy a Sun-synchronous polar orbit. Their resolution capability is classified but estimated to be around 0.5 m. The Helios 2B program is managed by the French procurement agency DGA, which has delegated the responsibility for the space segment to CNES (Bergin 2009).

*Pleiades* will be a dual-use successor to France's SPOT optical Earth-observation satellite constellation. Access to data from the two Pleiades satellites will be prioritized to military users. Weighing around one metric ton each and designed for a lifetime of 5 years (Pleiades 2013), the Pleiades satellites are on a Sun-synchronous, almost circular orbit of 694-km altitude. Their stereoscopic acquisition capacity supports mapping of urban environments, as a complement to aerial photography. The first Pleiades satellite was launched 17 December 2011 on a Europeanized Soyuz rocket from Kourou. The second one was launched on 2 December 2012. The satellites collect panchromatic data of 0.7-m resolution and multispectral data (blue, green, red, and infrared) of 2.8-m resolution. Austria, Belgium, Spain, and Sweden are participating to the costs of the system in exchange for access to data. The Pleiades configuration is also meant to be the French supplied optical contribution to Optical and Radar Federated Earth Observation (ORFEO).

The *Essaim* (French for "swarm") configuration is a family of four small satellites for electronic intelligence. They were commissioned by DGA, and they were launched on 18 December 2004 (together with, among others, Helios 2A) from Kourou. The satellites draw upon the Myriade platform from EADS Astrium, who was also the prime contractor. Weighing 120 kg each, the spacecraft were designed for a lifetime of 3 years (CNES 2012).

The 17 December 2011 launch from Kourou mentioned before also brought the four small satellites of the *ELISA* configuration to space. ELISA stands for Electronic Intelligence Satellites and is a demonstration project for spotting radar and other transmitter positions. Featuring an exploitation phase of 3 years, the project is run by DGA and CNES, who tasked EADS Astrium as a prime contractor with developing the space segment. Following up on the ESSAIM project, ELISA could lead to an operational program (Renseignement d'Origine EélectroMagnétique (ROEM), translated to SIGINT in English) of space-based electronic intelligence. Like Essaim, the ELISA satellites are using the Myriade platform and have a mass of roughly 130 kg each. They occupy a Sun-synchronous orbit of around 700 km altitude (ELISA 2012).

### 47.2.3 Italy

*COSMO-SkyMed* is an Earth-observation satellite configuration specifically designed as an integrated dual-use system, i.e., serving both military and civilian purposes. It is run by the Italian Space Agency (ASI), the Italian Ministry of Defense, and the Italian Ministry of Education, Universities, and Scientific Research. The system consists of four satellites of 1,900 kg each, launched between 7 June 2007 and 6 November 2010 from Vandenberg Force Base, California, into a Sun-synchronous orbit of around 620-km altitude. The satellites have been developed by Finmeccanica subsidiary Alenia Spazio as a prime contractor. They are based on a Prima bus and they are equipped with X-band SAR instruments.

The system has been set up to allow a large amount of images to be taken each day, to feature all weather and 24-h acquisition capability, and to deliver high image quality in terms of spatial and radiometric resolution. It provides worldwide coverage with a special focus on the Mediterranean area (ASI 2010). COSMO-SkyMed is also the Italian supplied radar contribution to ORFEO (see Sect. 47.2.2).

### 47.2.4 United Kingdom

The United Kingdom has not put much emphasis on developing its own Earth-observation satellites, because it has been relying on privileged access to relevant US assets. *TopSat* is a technology demonstration project initiated by the British National Space Centre (BNSC) and the UK Ministry of Defense as part of the Microsatellite Applications in Collaboration (MOSAIC) program. In the meantime, the BNSC part has been taken over by the newly created UK Space

Agency. TopSat aims at showing how relatively small and cheap satellites can be used to obtain impressive results.

The TopSat satellite was launched on 27 October 2005 from Plesetsk into an orbit of 686 km altitude. It only weighs 190 kg and offers a resolution of 2.8 m in black and white and 5 m in color. To enable a compact construction of the satellite, no expandable solar arrays or other moving parts have been employed. QinetiQ was the prime contractor, owns the satellite, and runs its operation. The platform, built by Surrey Satellite Technology (SSTL), allows for controlled spacecraft maneuvers to increase the integration time of acquisitions, ensuring highly resolved images even in low-light conditions (UKSPACE 2010).

### 47.2.5 Spain

The Spanish National Earth-Observation Programme (PNOTS) will be a complete system, based on two spacecrafts: *SEOSat-INGENIO* and *PAZ* (PAZ 2012). With the PNOTS Spain tries to acquire a fully independent operational satellite remote-sensing capability.

PNOTS is funded and owned by the government of Spain. INTA (Instituto Nacional de Técnica Aeroespacial), the Space Agency of Spain, is managing the common ground segment of the two missions. Hisdesat, together with INTA, will be responsible for the in-orbit operation and the commercial operation of both satellites. EADS CASA Espacio is the prime contractor leading the industrial consortia of both missions.

A major objective of PNOTS is to maximize the common developments and services and to share the infrastructure between both missions (whenever possible). Both missions will also contribute to the European Copernicus program. According to the contract, the ESA SEOSat/Ingenio project team must ensure that the European ground segment will allow the SEOSat/Ingenio system to become a candidate national mission contributing to Copernicus and to participate to the ESA third party mission scheme within the EO multi-mission environment – and therefore to support HMA (Heterogeneous Mission Access) services (SEOSAT 2012).

SEOSat-INGENIO is the first Spanish Earth-observation satellite financed by the Spanish Ministry of Industry and built by a consortium of industries of the Spanish space sector with Astrium España as the prime contractor. It is a satellite system with a planned 7-year lifetime mission, equipped with an image optical instrument with 2.5 m resolution in black and white and 10-m resolution in color. It will generate an average of 230 images (60 × 60 km) per day and provide more than four coverages of the Spanish territory in 1 year.

The mission will provide high-definition panchromatic and multispectral ground imaging for various applications that can be used in mapping, monitoring borders land changes, urban planning, agriculture, water management, environmental monitoring, and risk and safety management. The launch of the INGENIO satellite is planned for 2015. The satellite will be operated from a Sun-synchronous polar orbit.

The second satellite in this program is PAZ (Spanish for “peace”). PAZ is the first Spanish radar satellite developed and implemented by the Spanish Ministry of Defense and the Ministry of Industry, Trade and Tourism in the frame of the National Earth-Observation Program. PAZ shall be launched into the same orbit as TerraSAR-X and TanDEM-X (see Sect. 47.2.1) in 2014 (CEOS 2014). PAZ is designed as a dual-use mission. The focus of the mission is to provide tactical information from space that meets the Spanish government’s defense and security needs but will also contribute to high-resolution civil applications.

The satellite structure is based on the TerraSAR-X satellite and was integrated by Astrium’s Friedrichshafen site in Germany. The radar instrument was developed and integrated at the company’s Barajas facility. PAZ will be owned and operated by Hisdesat. The Spanish Aerospace Technology Institute (INTA) has been commissioned to develop and operate the satellites’ ground segment.

## 47.3 Conclusions

European states dispose of a wide range of space-based Earth-observation missions that are relevant to security purposes. Traditionally these systems are owned and run on a purely national basis and serve the interests of one specific state. However, new routes like cooperation between two or more states and new acquisition schemes like public-private-partnerships (PPP) are being explored. It remains to be seen whether truly European, i.e., supranational, approaches will follow as a next step.

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# European Multinational Satellite Programs

# 48

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## Contents

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**Abstract**

Multilateral cooperation is an established approach for European countries to develop and acquire high-quality space systems, based on collective needs, pooling of resources, and cost sharing. This applies equally to the defense and security domain, where comprehensive earth observation competences are operationally required. In this context, the cooperation under MUSIS will be detailed as a characteristic paradigm. The acronym stands for "**Mu**ltinational **S**pace-based **I**magery **S**ystem" and represents the initiative of 7 + 1 defense ministers of European Union members (Belgium, France, Germany, Greece, Italy, Poland, Spain, and Sweden in the joining) to produce surveillance, reconnaissance, and observation capabilities, as required in the time horizon of 2015–2030. MUSIS started out ambitiously as an idea for a European Earth Observation System for defense and security, with multinational-produced space components and a commonly defined and developed user ground segment. However, from conception to deployment, MUSIS has been proven a complicated endeavor and time-consuming process so far. MUSIS has received skepticism for not being able to evolve into a tangible space program yet, with finalized and validated framework for its operational deliverables, participation requirements, and resource allocation. The reasons are nested in the requirements for multinational coordination among its participants, the formalities of national and collective decision making, and the individual political, operational, and industrial imperatives at national level. MUSIS remains an open intergovernmental project with a certain political guidance, but the lack of legally binding programmatic provisions so far plus the ongoing financial crisis leaves room for ambiguity in participants' intentions and further commitments regarding MUSIS. This chapter addresses the background upon which MUSIS is based, the satellite program description and its development, the space components architecture, and the MUSIS foreseen operation and reaches some conclusions regarding the program and its future prospects.

## 48.1 Introduction: MUSIS and Its Relevance to Space Security

### 48.1.1 Description

The main purpose of MUSIS is to succeed and extend the presently existing earth observation military capabilities within the particular group of European countries. These countries are already cooperating efficiently in the operational use of the contemporary Helios 2, Pléiades, COSMO-SkyMed, and SAR-Lupe remote sensing satellites. Accordingly, partners seek to ensure a future continuation of both, the cooperation established and the capabilities shared. With this experience and need, France, Germany, Italy, Spain, Belgium, and Greece, after signing – in this order from 2001 to 2003 – a document of common operational requirements, launched in 2006 the preparatory technical studies for the definition of MUSIS as the next-generation system in the field of earth observation. Since 2010, Poland has joined MUSIS, while Sweden also declared its intention to join the cooperation.

The initial aspirations for MUSIS suggested an inclusive and dedicated European, multinational space program, with an all-accessing generic *user ground segment* (UGS) under common design and development. In spite of the operational sense of such concept and the more than 10 years of consultations and activities, the participants could not come to terms with one encompassing and distinct MUSIS program, where all partners would be committed to its ends. MUSIS, in its present form, is definitely not a satellite system program of any kind, at least not in the conventional way of practice for such programs. This is made particularly clear by the individual space component programs that are developed separately, under national authority and control. Even though these national capabilities are still offered as the contributing space components of MUSIS, up to now there is no legally binding obligation, whatsoever, to participate in MUSIS.

However, this idiosyncratic situation in MUSIS is reflective of the degree of consolidation and cooperation that can be accomplished today in both the European defense and security and space domains and therefore bears merit to be further detailed. More so, the basic idea of MUSIS is not yet forfeited, and the cooperation is kept active under a new, more loosely federated approach and with the initiatives of some of the partners. Efforts now focus in producing nationally the satellites and their associated ground infrastructure while at the same time investigating suitable interoperability solutions, in order to achieve the required by MUSIS crossover imaging functionality.

MUSIS as a system shall provide improved earth observation capabilities, appropriate and with priority, to the defense and security institutional users of the involved countries. Yet the system is conceived to be of *dual use*, allowing for the exploitation of specific imaging and data services, by civilian users, for other governmental, scientific, or commercial purposes. With the defense user in focus, the space components of MUSIS are detailed to perform operational imaging missions – worldwide, in all light/weather conditions – and to deliver timely and applicable image data to their tethered ground infrastructure, in a reliable way and within a secure environment. The capacity of MUSIS is intended to directly support defense and security activities and applications such as surveillance, reconnaissance, monitoring, and particularly geospatial intelligence, including planning, preparation, and conduct of operations and the subsequent assessment of their impacts.

### 48.1.2 Relevance to Space Security

Space assets constitute an essential part of the capabilities needed in the defense and security domain. Since information minimizes uncertainty and increases the chances for prudent political and strategic decisions, space-based capabilities for collecting data and acquiring intelligence are integral to any nation’s operational doctrines and competences.

Reliable and worldwide applicable capabilities such as timely and appropriate reconnaissance, dependable and secure communications, and consistent and precision navigation have been proven in the field to be of instrumental advantage, in terms of situational awareness, perceptive planning, clarity of intentions and command, and the ability to conduct dynamically operations. A consistent flexibility and accuracy toolbox can be applied in parallel, both against the fog of uncertainty and for the synchronization of own actions with changes in the operational environment. By fully integrating space competences into all kinds of operations, decision makers are better able to tailor their planning, employ more effectively available forces, and achieve objectives at the least risk and cost.

Earth observation is a key area in military activities, providing integral input into *intelligence, surveillance, target acquisition, and reconnaissance* (ISTAR) applications and *command, control, communications, and information systems* ($C^3$IS). There, data is registered, processed, and transformed into information, making it available, in a timely and consisted way, to a wide range of authorized users. Space-based sensors are specific imaging devices, in orbit around the Earth, and as such have the benefit of unrestricted access over any given area of strategic or operational interest. Moreover, and notwithstanding the fact that in the majority of cases they remain simply the most cost- and risk-effective way to image any given area of interest, they provide almost exclusively the only tangible access to areas that are otherwise problematic to gain physical admission to, for political or military reasons altogether.

## 48.2 Background

The EU collectively, as well as several of its individual members, has identified and expressed the need for acquiring autonomous European space capabilities and, in particular, earth observation competences (Kolovos 2009). The special operational requirements, prescribed for defense and security purposes, result in technologically challenging and high-cost development and procurement of a suitable system. Therefore, the EU has recognized, as early as 2003, the necessity to cooperate closely on this subject and employ the virtues of synergy, in order to distribute the burdens of effort and cost, mitigate individual risks, and share capacity among themselves in a complementary way.

Presently, seven European Union countries (BE, DE, EL, ES, FR, IT, and PL) subscribe, through a common operational requirements document known as the BOC (Besoin Opérationnel Commun), to the concept of a European benefit, global-reaching, space-based, Earth Observation System for defense and security purposes.

The first generation of such a system is recognized to be comprised of the nationally developed and multinationally exploited space components that the signatory countries are operating at present. It is in this framework where the real European defense space observation capabilities are created, based on the national or multinational initiatives that produced the existing Helios 2, SAR-Lupe, COSMO-SkyMed, and Pléiades programs.

However, beyond the individual space components and their related ground infrastructure, there is no physical system setup. These space components have been developed and remain actually under national command and control for their vital functions and basic operation. The BOC is a multinational cooperation scheme, among its signatories, that takes form at the operational level of image tasking and subsequent data reception.

Essentially, the partners of BOC apply a pooling and sharing concept, where France, Germany, and Italy act as space component providers for the whole group and where participants may enter, at their own discretion and upon conditions, into direct cooperation with one or more of the countries that offer part of their observation capabilities. Considering that the idea of BOC is applied, in retrospect, to national programs that have been already up there and running, the establishment of the first generation of a European Earth Observation System is a milestone achievement, even if it refers more to a virtual system at this stage.

Taking note that the nominal end of life of today's Helios 2, COSMO-SkyMed, and SAR-Lupe satellites is scaled somewhere between 2014 and 2017 and considering the time required for the design and development of a space system, especially under synergy, activities have already been initiated, as early as 2005, to prepare the next generation of the European Earth Observation System for the defense and security community.

MUSIS, as such, aspires to meet all these challenges effectively, becoming a reliable and competent successor, for the present distinct capabilities in the optical, infrared (IR), and microwave (radar) spectrum, as well as pushing forward the technological and operational envelope of Europe, in terms of collective capacity for earth observation missions and image data for defense and security purposes.

With space exploitation typically incurring high costs and countries facing the reality of severe budget constraints, various cooperation and system utilization approaches are explored for the implementation of MUSIS. The basis lies in the proven benefits of dual opportunities and complementing space assets as well as in the anticipation of significant advantages from prospective synergies in the political, operational, and industrial levels for each of the participants.

### 48.2.1 Security Considerations and Operational Requirements

Space is widely acknowledged to be a critical dimension of the EU security considerations, particularly able to follow Europe's evolving agenda (Pasco 2009). In fact, the qualities of space assets have been proven, to deliver both universal and specific applications, for almost all operational requirements that formulate out of the diverse spectrum of security concerns, defense strategies, and foreign affairs policies. Inherently, earth observation, as a situational awareness and decision support tool, has become a key capability for the EU member states, collectively – but also individually – indispensable.

France and Germany already had experience from their own national competences and undertook the initiative to lay out in a document, known as BOC (*Besoin Opérationnel Commun; pour un système global européen par satellites à des fins de défense et de sécurité*), the principal operational requirements for the establishment of a European Earth Observation System (Pasco 2009).

This is the first concrete action, at EU members' level, to register respective common operational requirements and further on to prescribe the development and use of a European Earth Observation System for defense and security purposes. Today, seven European Union countries (DE, ES, FR, IT: 2001- BE: 2002, EL: 2003 and PL: 2010) have cosigned the BOC, while it remains still open to other members (with SE considering joining in).

It must be noted that agreement with the BOC principles is a prerequisite for the entry and involvement in any one of the first-generation space components, namely, the French Helios 2 and Pléiades satellites, with remote sensing devices in the optical and IR spectrum, and the Italian COSMO-SkyMed and the German SAR-Lupe satellites, with radar imaging payloads.

More importantly, BOC is the main operational requirement behind MUSIS. As such, BOC is the first practical step for any EU member, aspiring to access earth observation capabilities, tailored for defense and security applications.

At the operational level, everything distils to a single – but universal – imagery requirement, stated economically in the condition of "the right image at the right time." This seemingly simple demand tends to strain the design of observation systems, since the acquisition of a factual and timely image depends both on the quantitative and qualitative aspects of the global capacity at hand. This is particularly true with the complementary qualities of optical-IR and radar images, where earth observation users seek to establish parallel access to different imaging capabilities in order to respond to any operational requirement in a more definitive, comprehensive, and consistent way.

Proof of the above is found in the individual agreements that started the cooperation among the three major space component providers (DE, FR, IT) and allowed them to mutual exchange data, derived from their electrooptical (Helios 2, Pléiades) and radar (COSMO-SkyMed, SAR-Lupe) imaging systems (France–Italy, "*Torino* Agreement," 2001 and Germany–France, "*Schwerin* summit," 2002).

In this framework, BOC was used as a stepping stone to update and explicate its generic requirements into a comprehensive and conclusive set of operational conditions that have to be met by the characteristics of the future Earth Observation System. This produced the formally approved Operational Requirements Document (ORD) and Functional Requirement Document (FRD), tethered both to the realization of MUSIS (BE et al. 2006). The result of this collaborative procedure was a distinct line-out of the perimeter of the system – including the *user ground segment* functions – and the thorough definition of the content of MUSIS by the actual group of prime users of the system.

The concept of a second-generation system takes tangible form in the MUSIS project, in 2006, when the partners agree to conduct preparatory studies that would define and realize such a space-based system for surveillance, reconnaissance, and observation.

The scope of these studies has been to recommend candidate architectures for MUSIS and an associated *user ground segment* that could deliver the prescribed earth observation capabilities in the visible, infrared, and radar part of the spectrum. The ORD and FRD parameters delimit a given reference environment for those industrial studies.

The assessment, of the results and options identified in the industrial studies, concluded that the architecture of MUSIS shall include one optical space component, contributed by France; two radar space components, contributed by Germany and Italy, respectively; and a generic UGS for accessing all capabilities in unison. In addition, Spain offered a wide swath optical satellite to be included in the system. Originally MUSIS contained also a hyper-spectral imaging capacity requirement that was left out at the end.

The validated structure of MUSIS is anticipated to provide a set of operational imaging instruments that reflect effectively on national and collective security considerations. The European security agenda dictates foremost the mission continuity of the current earth observation capabilities and calls for improved operational and functional performances for those major competences. Furthermore, MUSIS shall be adequately equipped to address almost all corresponding military applications and an expanded array of “soft security” threats. The particular focus on complementary capacity, in the domains of environmental awareness and geography, is indicative of the comprehensive interests.

Since the operational requirements of MUSIS are recorded in classified documents (ORD and FRD), its prescribed abilities and performances are not known in detail. In general – and from what little is known publicly – there is an agreement that MUSIS will provide, in theory, access to all components and for all its participants, with multisensor, high-yield, reactive imaging competences and the advantages of data sharing from a common archive.

Likewise, the main features of MUSIS, deducted from its architecture, are for a global, all weather, any light conditions system, which shall cover all the areas of interest with imaging agility (increased image output – particularly in crisis zones – and expedient multiuser dissemination), reaching levels of high- and very-high-resolution images (permitting identification and localization of smaller targets) (DGA 2010a).

An insight, of the order of magnitude of the system’s expected performances, can be attained by extrapolating the imaging characteristics of today’s European earth observation missions that will be succeeded by the respective space components of MUSIS. In the electrooptical capacity, it is indicative to mention a published figure for the Helios 2 spatial resolution, i.e., 35 cm (Wikipedia.org 2012), and the output of Pléiades, estimated to be 900 images/day (Svitak 2011). On the radar imaging elements side, a ground sampling distance of less than 80 cm is achieved today with SAR-Lupe (Lange 2007), while the four COSMO-SkyMed satellites are capable of a nominal 1,800 images/day (eoPortal.org 2012). One can rightfully expect significant improvements and technological maturing of the imaging qualities for the future CSO (DGA 2010a), CSG, and SARah in MUSIS.

### 48.2.2 Timeline and Important Milestones

The history of European multinational satellite programs, in the domain of earth observation for defense and security purposes, traces back to the first studies of the Helios 1 optical system that started in 1978 and produced the first launch in 1986. This program has inaugurated a partnership, with concrete operational results in the fields of space applications and imagery intelligence, between France, Italy, and Spain. In perspective, this cooperation might be considered the working example that opened an integrated approach to field space assets for defense and security at European level.

It was in 2000, at the Mainz Summit, where Germany and France declared their intention to build up jointly an independent European satellite-based reconnaissance capacity. The start-up idea for such a multinational European system attracted the immediate interest of Italy, while later on, the partnership has been extended through the BOC framework towards Spain, Belgium, and Greece (2001–2003), lately Poland (2010) and possibly Sweden.

The above framework produced also the first collaborations among the three owners of relevant space assets (DE, FR, IT) that allowed mutual exchange of their image data. The convergence of views led the governments of France and Italy to initiate (France-Italy, 2014), in March 2000, a study for cooperation between their two national earth observation programs. This subsequently led to the signing of the "*Torino* Agreement," in January 2001.

The Franco-Italian bilateral agreement defines the scope of the cooperation, being the development of their respective *dual-use* systems, Pléiades and COSMO-SkyMed, together with the ground segment ORFEO (Optical and Radar Federated Earth Observation System) and including the sharing of the COSMO-SkyMed and Helios 2 capacities.

Another bilateral agreement was signed, this time between Germany and France at the *Schwerin* summit, in July 2002, which facilitated the sharing of the radar SAR-Lupe and electrooptical Helios 2 capacities at operational level. It is noteworthy that the exchange of operational image data started only in 2010 for both the *Torino* and *Schwerin* arrangements, after suitable UGS infrastructure modifications were put in place (DGA 2010b).

The operational value of complementary imaging capabilities was acknowledged in 2007 when France ordered the PHAROS (*Portail d'Accès au Renseignement de l'Observation Spatiale*) application. A virtual federation of the military Helios 2, SAR-Lupe, and *dual-use* COSMO-SkyMed and Pléiades systems is achieved through an access portal for imagery intelligence, equally in stationary and deployable configurations. Each individual cell will provide direct access to both optical/IR and radar imagery, with multiple satellite systems programming capabilities and online image request and catalog retrieval functions (DIC 2011).

However, the first proof of actual multinational cooperation in European imaging capabilities comes when six ministers of defense (BE, DE, EL, ES, FR, and IT) sign, in 2006, the *Technical Arrangement to the European Research Grouping Arrangement No 1* (TA1), "…related to the Preparatory Studies for the Definition and the Realization of a MUSIS for Surveillance, Reconnaissance and Observation" (BE et al. 2006).

In November 2008, after the results of the preparatory industrial studies have been appropriately evaluated, the same ministers of defense (Italy signed later in March 2009) agreed on a politically binding *letter of intent* (LoI) that defined the scope, the perimeter, and the containing elements of a MUSIS. Additionally, the LoI guidance called also for the institutional involvement of the *European Defense Agency* (EDA) and the *Organisation Conjointe de Coopération en matière d'ARmement* (OCCAR) in MUSIS.

Accordingly in 2009, the partners established a MUSIS mandate for EDA and classified MUSIS as an EDA ad hoc Category B program. EDA links MUSIS with the EU, in the context of the *Common Security and Defense Policy* (CSDP), and will add value by capitalizing on its expertise with multinational programs; focusing any potential further interest by other EU members for MUSIS; mediating with possibly interesting research and technology projects, like those included in the *EU Commission Framework Programme 7*, the *Copernicus (former Global Monitoring for Environment and Security*, GMES), and the *European Data Relay Satellite* (EDRS); and finally reconnoitering routes of synergy between civil and military EU space capabilities (EDA 2009).

The OCCAR *Integration Decision* for MUSIS was approved by the *Board of Supervisors*, in London, later in the summer 2009. The *Organisation for Joint Armament Cooperation* was to manage the administrative procedures and the technological activities related to the common part of the MUSIS program, starting from the definition phase of a common UGS.

In the summer of 2010, EDA announced the expressed intention of PL and SE to join the MUSIS project. The accession of PL to MUSIS followed with the competent signature of the BOC and LoI at the end of 2010.

The most recent institutional step forward concerns the signature by France and Italy, in May 2011, of an OCCAR *program decision* for the MUSIS federating activities:

> The scope of this Programme Decision consists of the preliminary definition of a "Common Interoperability Layer" (CIL) to be developed to federate the MUSIS space components CSO (Composante Spatiale Optique) and CSG (COSMO Second Generation). It consists of two consecutive sets of activities called MUSIS Phase B1 and MUSIS Phase B2. (OCCAR 2011)

OCCAR announced, in August 2012, the successful completion of MUSIS federating activities, phase B1, and the subsequent launch of phase B2, where CIL is described as:

> …an advanced bridge which will be placed on the ground between the two space systems. The CIL will enable operators from one nation to order image products from the partner's system, task the satellites of the other nation, receive the image products and store them in a secure way. (OCCAR 2012)

### 48.2.3 Operational and Technological Origins

The operational and technological origins of the programs that are intended to be associated with MUSIS are interwoven with the corresponding individual programs and their own respective internal validation at national level. The current synthesis of MUSIS foresees capacity contribution from the satellites, national, programs described in Table 48.1.

As a general approach, MUSIS space component providers draw upon their own operational and technological base to design and develop imaging satellite systems under national requirements. In this context, each consultation process is individual, but as a practice converges upon the involvement of the intended users, for operational advice and evaluation; the support of national space institutions, for technological expertise and scientific validation; and the contracting of competent national and European space industries, for development and application.

It must be reminded that those national programs remain classified programs for their most part, and their respective details are not releasable to a comprehensive extend. Nevertheless, they are designed to succeed the respective current space imaging capabilities for defense and security purposes and consequently present strong operational and technical ties with their lineages.

Notwithstanding the above, at the conceptual level of a federation of imaging capabilities, with an interoperable user ground infrastructure, the *Technical Arrangement No 1* acknowledges the operational guidance of the BOC and the “ESDP and Space” (2004) documents and places the related industrial studies activities in previously established technological framework agreements like the *memorandum of understanding* (MoU) concerning the *European Understandings for Research Organisation Programmes and Activities* (EUROPA MoU 2001) and the *European Research Grouping Arrangement No 1* concerning *Co-Operative Defence Research and Technology Projects* (ERG-1 2002).

## 48.3 Satellite Program Description

The only true common activities that yielded industrial contracts so far were the MUSIS architecture and UGS preparatory studies awarded with the *Technical Arrangement No 1*. The scope of work of this arrangement was “the identification of optimized architectures for the MUSIS system” and “the definition of a generic and open architecture for a *user ground segment* compatible with various space segments” (BE et al. 2006).

TA1 established an administrative and contracting procedure and organized the dedicated management structure for its own MUSIS objectives. However, the contributing members used this administrative and management frame as the general platform for MUSIS group work and consultation, well beyond the completion and delivery of the corresponding studies by the industry. In fact the TA1 advisory mechanism survived even the official duration of the arrangement (expired by 2010) and remained in use until recently.

**Table 48.1** European space component programs contributing to MUSIS

| Space component | Provider | Mission continuity | Utilization | Imaging capabilities | Cooperation status | Development status | Federating activities | Remarks |
|---|---|---|---|---|---|---|---|---|
| **Composante Spatiale Optique (CSO)** | France | Helios 2 Pléiades | Defense and security | Electrooptical | Open for cooperation to other MUSIS participants | Contracts awarded to industries under national authority | TA1 (system architecture studies) | |
| | | | | | No other participant committed yet | Satellite development in progress | Common Interoperability Layer (CIL) | |
| | | | | | | User ground segment (UGS) under definition | | |
| **COSMO second generation (CSG)** | Italy | COSMO-SkyMed | *Dual use* | Microwave (radar) | Open for cooperation to other MUSIS participants | Contracts awarded to industries under national authority | TA1 (system architecture studies) | |
| | | | | | No other participant committed yet | Satellite development in progress | TA1 (system architecture studies) | |
| | | | | | | User ground segment under definition | | |
| **SARah** | Germany | SAR-Lupe | Defense and security | Microwave (radar) | National development | The program is not yet at a materialization phase | TA1 | |
| **Ingenio (formerly SEOSAT) satellite** | Spain | Ingenio-Paz will be a new mission | Dual use | Electrooptical | Open for cooperation to other MUSIS participants | Contracts awarded to industries under national authority | | Ingenio is coupled with Paz (radar satellite, not partaking in MUSIS) into a dual-capability and dual-use system |
| | | | | | No other participant committed yet | Satellite and UGS development in progress | | |

The discontinuity of TA1 (a *Technical Arrangement No 2* was drafted but never succeeded to be finalized and signed) and the absence of a MUSIS general framework agreement (its establishment was one of the key principles in the defense ministers *letter of intent* but up to now could not be promoted) created a new reality for the MUSIS participants.

MUSIS remains an open intergovernmental project with a certain political guidance (LoI), but the total lack of legally binding programmatic provisions so far leaves room for ambiguity and flexibility in participants' intentions and further commitments regarding MUSIS. Today, this situation is not synchronized with the development tempo of space components within their national programs and can only maintain a basic consultation structure among the MUSIS partners.

The uncertainty to produce a definite MUSIS program led France and Italy to set up the bilateral CIL initiative in OCCAR. The *Common Interoperability Layer* comes to bridge, at the UGS level, the two concerned space components, namely, CSO and CSG, in order to provide ways of mutual access to both optical and SAR capabilities while respecting confidentiality requirements and remaining consistent and compatible with the national programs in general. The appointment of OCCAR, as the competent contracting and administrative authority, indicates that the CIL is pursued still under the broader MUSIS concept, and it remains open to other partners and space components of the cooperation.

### 48.3.1 Administrative Structure

MUSIS is an intergovernmental cooperation of 7 + 1 EU member states at the level of *Ministry of Defense* (MoD). There is no distinct single governing authority, but instead this function is performed from the participants' MoD, both from the capitals and at the occasion of a head of defense convention, where, among others issues, MUSIS could be discussed.

At the political level, decision making and budgeting responsibilities rest upon the defense ministers, who have delegated their respective national armaments agencies to steer, report, and recommend actions in all matters that regard the collaboration of MUSIS. Armaments agencies utilize their procurement experience, research and technology know-how, and defense industry cooperation base to respond to MUSIS.

The *National Armaments Directors* (NADs) exercise administration and coordinate MUSIS-related work at the strategic level. They are supported with policy advice from appropriate national defense offices, and moreover the armed forces provide their own validated operational considerations and technical conditions for MUSIS.

Equally, each contributing member is politically and legally accountable, both at national- and cooperation-wide level for its commitment and compliance to the objectives and requirements of MUSIS. The intergovernmental character of MUSIS implies the signature, by state entities, of multinational cooperation agreements with political, operational, and financial effects. Therefore, parliament institutional approval is sometimes a suitable way to acquire the required national authorization for the ratification of MUSIS arrangements.

### 48.3.2 Management Structure

The management and organization scheme for MUSIS is along the lines of the one applied in the existing first-generation programs, almost identical in all six European countries that started the sharing of imaging space assets. As the primary end user, in all countries, is normally the Ministry of Defense, its associated management structure is assigned with the executive command and control of the project.

At national level, usually four main elements are actively involved in the management of space-based imaging capabilities: the defense headquarters, who exercises program implementation and operational command of ground infrastructure; the national armaments unit that handles resource management and investment; the industrial contractor for technical supervision and maintenance; and usually the national aerospace agency for scientific expertise and functional control of the space segment.

In terms of financial parameters, project funding, budget planning, and resource allocation, oversight is ensured at defense HQ level, under the responsibility of the program implementation office that also issues associated expenditure justification and authorization. Payments and financial protocol are followed usually by the department of the MoD with accountant duties.

At the level of multinational cooperation, the first executive management organization was established in the form of a participant's working group, namely, the MUSIS *Main Group* (MG). The mandate of the MG was later officially endorsed by the signature of the TA1, where the group was renamed to the *Technical Arrangement Management Group* (TAMG) and given "the overall responsibility for the cooperation" (BE et al. 2006).

The MUSIS partners enjoyed equal status within TAMG and decisions required unanimity. TAMG was tasked to direct and manage the MUSIS cooperation, "on behalf of the contributing members," and assigned with the implementation of the *Technical Arrangement No 1* for the preparatory industrial studies. This included analysis of technical options for space system and UGS, preparation of follow-up arrangements, security aspects, contract approval, resource sharing, and allocation and establishment of other subordinate working groups (BE et al. 2006).

Consequently, TAMG mandated, monitored, and endorsed the work of the *Operational Working Group* (OWG) and is in charge of the operational issues of the studies, including user input and evaluation of results and the *Technical Working Group* (TWG), which was tasked to monitor the technical features of the contracts awarded through the TA1. In fact TWG defined the perimeter of the technical studies and the contract specifications.

Regarding the role of *Contracting Administrative Authorities* (CAA), it was agreed to employ the expertise and resources of both France and Italy to manage the system architecture and user ground segment studies respectively. All partners were involved in the process through respective national *Points of Contact* (PoC), who were assisted – where needed – by MoD legal advisors, in order to put in place the suitable legal frame and formulate the MoU in contracting terms.

Nowadays, the above management organization is obsolete since the mandate of the Technical Arrangement No 1 has expired, and there are no other distinctive MUSIS-related contracts active but for the FR-IT initiative, to define a *Common Interoperability Layer*, between their respective CSO and CSG systems, as a bare functional way to ensure mutual access to optical/IR and radar images. Conforming to the MUSIS *letter of intent* guidance, to employ the Organization for Joint Armament Cooperation as CAA, France and Italy signed in 2011 a contract with OCCAR-EA that authorizes the *executive administration* of the industrial studies for the definition of the CIL.

Finally TAMG, with participants' representatives acting as national PoC, served effectively as the principal meeting forum for MUSIS, well beyond the expiration of TA1 and regardless of the absence of federating common activities, until 2011. From 2012 on, TAMG was re-branded to MUSIS LoI *Steering Group* (SG) in order to reflect better the current status of the cooperation. The LoI SG inherited the same representatives, protocols, and functions from the TAMG, but its mandate is to be updated under new consultation.

### 48.3.3 Operational and Mission Objectives

MUSIS was envisaged to be the next system to hold the baton – in the relay race of the individual space component programs – and enhance drastically the collective European earth observation capabilities for defense and security. The next-generation system is targeted for the 2015–2030 time horizon and is expected to muster capacity from national and multinational space components, some with *dual-use* applications.

The 7 + 1 European partners' dedicated cooperation has the primary objective to design and realize MUSIS as a multinational space-based imaging system for surveillance, reconnaissance, and observation, aimed to fulfill the corresponding common operational requirements and to ensure the succession of their present Helios 2, Pléiades, SAR-Lupe, and COSMO-SkyMed systems.

The key operational parameters of MUSIS, as prescribed in the ORD and FRD and reiterated in principle by the LoI, dictate for quantitative and qualitative improvements at system level, together with a guarantee of access to all imaging capabilities, by all partners and with multisensor, high imaging, high reactivity, and data sharing characteristics. In this regard, the role of the *user ground segment* becomes most crucial for the overall added value and operational effectiveness of such a system that must cater for interoperable and harmonized access of many actors to all available capacities.

However, in the course of action, it was decided that the second-generation Earth Observation System will follow a loosely federated approach, where the imaging capabilities will be realized independently, through national space programs and far from the concept of an associated user ground infrastructure of common definition and design.

Under the present situation, it is assumed that the primary objective is still valid, at least at the individual space component level, but the factor of satisfaction for significant operational parameters will depend largely on the feasibility and the extent of integration of analogous functions in the Common Interoperability Layer, notwithstanding the prerequisite of linking all contributing space components through CIL and having equally all MUSIS partners involved in such federating activities.

### 48.3.4 Technical Specifications

For reasons analyzed previously, any detailed technical specification information, of both individual space component programs and UGS studies, including the TA1 results, is restricted to the community of MUSIS partners, their CAA, and the involved industries. Only general technical characteristics can be derived from the juxtaposition of operational and functional features with corresponding technological solutions and applications.

Broadly, specifications will order the improvement of performances in imaging sensors (spatial, spectral, temporal resolution, radiometry quality, localization accuracy), the optimization of system features (platform agility, data management efficiency, image product dissemination continuity), and the ability to formulate exportable imagery data products, compatible with the realization of advanced geospatial applications (comprehensive geography, precision height and elevation information, urban battle environment) (DGA 2011).

### 48.3.5 Industrial Policy

In the context of the TA1 studies, the MUSIS CAAs, to be exact the French General Directorate for Armament (*Direction Générale de l'Armement* – DGA) and the Italian TELEDIFE (*Direzione Informatica, Telematica e Tecnologie Avanzate*), were put in charge of the contractual process for the MUSIS architecture and its associated UGS studies respectively (BE et al. 2006).

The CAAs applied an industrial policy where companies had to meet certain criteria (like proof of technological aptitude and previous involvement in earth observation space programs and personnel and facilities security clearance) to submit a valid candidacy for MUSIS-related work. This focused policy steered the space technology able companies to organize their proposals along two industrial consortia, under the leadership of EADS Astrium and Thales Alenia Space as competitive prime contractors. Each prime contractors organized their own industrial consortium with the inclusion of specific space applications companies, chosen as fit, from a nationally suggested defense and space industry pool, across all MUSIS partners and for the purposes of the TA1 studies.

The equivalent contractual executive authorities are now vested with OCCAR-EA, after its appointment as MUSIS CAA, for the federating activities of the cooperation. OCCAR-EA was entrusted with the contract management of the CIL, in which the same industrial prime contractors from France and Italy are taking part, this time as one consortium.

### 48.3.6 Governance and Development Structure Rationale

MUSIS started out ambitiously as an idea for a European Earth Observation System for defense and security, with multinational-produced space components and a commonly defined and developed UGS. This basic idea was adequately conceptualized in the letter of the TA1 and the spirit of the minister's LoI: a federation of national and collaborative space components, some with *dual-use* applications, functioning in a multiuser, complementary imaging environment, all at the level of a generic common UGS.

Aside from admitting the operational value of such an arrangement, the partners seemed to grow divergent lines along issues of national policies, resource sharing, industrial concerns, and administrative procedures. The need to detail and define a concrete way ahead for MUSIS was entangled with those matters long enough to create uncertainty and discomfort in the group, with partners even investigating other possible approaches to fulfill their operational requirements for a next-generation imaging system.

MUSIS-lagged consultations were endangering the timely realization of some space component programs, as important system features could not be finalized, since they depended on the specific user ground infrastructure that could not be agreed how exactly to be implemented. Despite the efforts of participants and significant group work achievements, France and Italy, under the risk of setting their respective CSO and CSG programs out of sync, took the decision to move ahead with the materialization of their satellite systems, including proprietary solutions for the associated UGS. The resort to separate national development practices, for MUSIS space components and their user ground segments, was imperative in order to avoid a gap, in individual and collective imaging capabilities, from one system generation to the other.

## 48.4 Satellite Program Development

### 48.4.1 Research and Development Coordination Authority

Since MUSIS was perceived always as a collaborative project, all partners are nominally involved in research and development (R&D) management of activities related with MUSIS. Participants to MUSIS follow-up R&D work at the administrative level with their competent national armaments agencies and in the technological area with the involvement of national space agencies and defense science institutions. This model was effectively applied for the R&D activities of TA1.

Expectedly, space component providers are the ones more practically involved in the context of their national programs for their space and ground segments. Outside this national frame, only France and Italy sustain the single ongoing, at MUSIS level, R&D coordination activity for their CIL effort. In this case the French DGA with CNES (*Centre National d'Études Spatiales*) and the Italian SEGREDIFESA/DNA (*Segretariato generale della difesa/Direzione nazionale degli armamenti*) with ASI (*Agenzia Spaziale Italiana*) are jointly responsible for coordinating CIL-related R&D work.

### 48.4.2 Technological Aspects

Generally, MUSIS will cover earth observation technologies in the space-based electrooptical and microwave imaging (radar) capabilities domain. The main scientific fields involved are those associated with the development of applications in low earth orbit (LEO) satellite platforms; imaging satellite instruments; sensors payload configuration; mission control infrastructure; onboard and onground volume data management; imagery dissemination; and the plan, receive, register, archive, process, and export functions at the UGS level.

However, since MUSIS is mainly intended for the defense and security user, its future requirements, for reconnaissance from space, project a demanding set of operational conditions and advanced functional capabilities to be realized from these technologies. Moreover, defense and security infrastructure imposes austere access, utilization, confidentiality, reliability, and availability protocols for their systems.

As such, it is expected to enhance significantly imaging competences and improve drastically system performances. Whatever new technologies will be dedicated to the development of the future CSO, CSG, and SARah satellites, they will be based on the working examples of Helios 2 and Pléiades, COSMO-SkyMed, and SAR-Lupe systems, respectively.

The concept of a constellation of complementary imaging satellite systems, federated under operational mandate and with an associated multifunctional UGS, is a rational European practice to muster, organize, and share investment, risk, capabilities, and resources. MUSIS already contains *dual-use* elements, in which technology and applications are regulated also for civilian uses, including commercial products.

This becomes apparent when appraising the extensive and numerous R&D projects associated with the pilot services and infrastructure of Copernicus, with an active example being G-MOSAIC (Copernicus *services for Management of Operations, Situation Awareness and Intelligence for regional Crises*). Its applications (nuclear and treaties monitoring, natural resources and conflicts, migration and border monitoring, critical assets, crisis management and assessment) all fall, by nature and definition, in the situational awareness interests of defense users alike (gmes.info 2012).

Additionally, it can be safely assumed that the CIL initiative will find suitable foundation work in the previous efforts of France and Italy to federate and share capacity among their present Helios 2, COSMO-SkyMed, and Pléiades systems. In this context the ORFEO and PHAROS programs could provide ample room for common technological proficiencies with MUSIS user ground functions.

### 48.4.3 Synergies and Technological Cooperation

The European and collaborative character of MUSIS is reflected in the involvement of EDA and OCCAR respectively. The involvement of EDA in MUSIS clearly asks for the identification of possible synergies in other European space programs. Such synergies are awaited to be found understandably in Copernicus, in which Italy's CSG will be a *Copernicus Contributing Mission*, but also in the space telecommunication project called EDRS (*European Data Relay System*). One of the very purposes of EDRS will be the reduction of image delivery time, by shortening transmission delays of large volume data, as a dedicated service for Earth Observation Systems like Copernicus and possibly MUSIS (ESA 2012).

The range of potential synergies spreads across a wide spectrum of space applications as almost the same partners are involved, more or less, in both defense and security, *dual-use*, and purely civilian Earth Observation System development. It is reasonable and beneficial, from all aspects, to instigate vigorous interaction among the key R&D institutions that take part in the respective national and collaborative parts of such programs.

Remarkably enough, participants in MUSIS seem to accept that there would not be any imaging technology transfusion between partners that master separately capabilities in electrooptical or SAR earth observation. MUSIS, as a virtual federation of nationally developed and operated space programs, allows component providers to preserve their very own individual imaging advantages and avoid the transfer of critical technology to possible industrial competitors from other nations.

Nevertheless, the common studies of CIL are example of an established R&D cooperation, at times only between France and Italy, but still in those technology areas that remain of mutual benefit for all MUSIS partners.

## 48.5 Space Components Architecture

With the TA1 studies' results and the consolidated recommendations of its working groups, the ministers of defense validated the MUSIS synthesis that is described in Table 48.2.

More analytic description of the contributing space components and their associated ground infrastructure along, as well as related technical and operational information, may be found in other relevant parts of this handbook.

**Table 48.2** MUSIS architecture

| Space component | Nr. of satellites | First launch | Orbit | Imaging payload type | Resolution class | User ground segment | Remarks |
|---|---|---|---|---|---|---|---|
| **Composante Spatiale Optique (CSO)** | 2 + 1 (3rd satellite realization is conditional upon adequate participation of other partners) | 2016 | Low earth orbit (LEO) | Electrooptical (panchromatic, multispectral, and infrared) | Very high resolution (VHR) and high resolution (HR) | Particular to CSO, but interoperable through CIL with CSG | Although CSO and CSG will develop their own associated user ground segment, France and Italy seek to bridge the two space components through a Common Interoperability Layer in the ground |
| **COSMO Second Generation (CSG)** | 2 | 2014 | (LEO) | Radar (X-band SAR) | VHR and HR | Particular to CSG, but interoperable through CIL with CSO | id. |
| **SARah** | Germany has not yet defined the number and configuration of satellites that will replace the five SAR-Lupe satellites | 2017 | | Radar (SAR) | VHR and HR | Particular | Linking of SARah UGS is nominally possible by joining the open cooperation in CIL |
| **Ingenio (formerly SEOSAT) satellite** | 1 | 2014 | (LEO) | Wide swath (WS) electrooptical | Medium resolution | Ingenio UGS was not originally included in the concept | Ingenio is coupled with Paz (radar satellite, not partaking in MUSIS) into a dual-capability and dual-use system |

## 48.6 MUSIS Operation

### 48.6.1 System Users

The composition of MUSIS, with defense and security and *dual-use* space segments, is suitable to accommodate the needs of various users with individual imagery objectives. Even though MUSIS is designed for the governmental user, at each participant's national level, its capacity is estimated able enough to deliver alike to EU institutions, to regional and international organizations, and to commercial applications, in a competent and competitive way.

At this time, the following main categories of MUSIS users are distinguishable:

- *Defense and security user*. In terms of priority, advanced imaging configurations availability, and frequency and volume of image services, they discern as the primary user. The majority of this group is the military user from the intelligence, geospatial, and operational domains. Other national security actors (e.g., national intelligence services, crisis management agencies) might be served equally.
- *National user*. In the wider sphere of national interests and public service, MUSIS might be capable to cater to other governmental and state institutions in need of image data. This data would be provided by the military capacity with quality, confidentiality, and application conditions or downgraded as appropriate for civilian use, *institutional user*. The European aspect and multinational cooperation character of MUSIS accommodates capacity possibility for EU institutions (e.g., SatCen) and other regional or international organizations (e.g., UN, NATO). MUSIS military quality imagery could be made available, under specific utilization agreement, as an established service or ad hoc to missions and situations of concern.
- *Civilian user*. Private, business, and academic users will be offered commercial license imagery services and products from the *dual-use* MUSIS capacity surplus.

The multinational environment of MUSIS, where defense and security users coexist with other national and institutional operators and civilian users alike, is specifically demanding in applying suitable technical solutions and operational rules that can guarantee functionality for all and the segregation of military from civilian domains.

### 48.6.2 Operational Command and Control

Because of the national space components and the multinational, multiuser, and multitask environment of MUSIS, it is presumed that the satellites will remain under strict national authority for mission control and operational command. Generally, UGS level operators stay focused on image acquisition planning and imagery generation procedures. Like in the current systems, multinational satellite exploitation and image quotas will be regulated by explicit operational agreements, specific to each space component.

At this stage, the operational command and control structure of MUSIS is not known. Obviously, participating countries will integrate experience from the exploitation of their current systems, and reasonably they will try to assimilate legacy infrastructure for mission control and UGS functions. If the current distribution of command and control responsibilities will be applied, it is expected to have mission control responsibility with the national space agencies (ASI, CNES, DLR, INTA) and satellite operational command authority at the respective UGS national main station.

In a similar way, it is likely to incorporate command and control structures and operational protocols from the current agreements between the space components providers that have already installed conditions for crossover imaging capabilities. Particularly, CIL could benefit from the heritage of the ORFEO and PHAROS arrangements and interfaces.

### 48.6.3 Advantages and Disadvantages

MUSIS is based on the perceived advantages of political, operational, and industrial value of such a cooperation. In the EU context, the MUSIS partners share the same principal political expectations towards the objectives of the *Common Foreign and Security Policy* (CFSP), specifically its CSDP element. Improvement and expansion of European industrial cooperation, in the defense and space applications domains, is institutionally (commission, EEAS, EDA, ESA, OCCAR) promoted in every aspect (capabilities pooling, resource sharing, risk distribution, and technology transfer).

Considering the operational and functional dimensions, MUSIS was intended to solve some of the capability access and interoperability problems of existing European governmental Earth Observation Systems that are mostly operating as stand-alone competences, with incompatible user ground segments and no built-in crossover interaction. This induces additional operational cost and critical delays when users need access to different imaging capabilities. MUSIS was conceived to ameliorate the shortcomings of stand-alone space imaging capabilities with concrete operational advantages that are about to yield:

- Access to complementary imaging competences
- Decrease of system response time
- Increase of overall image capacity
- Focusing imagery output at area of interest level
- Improving imaging qualities
- Advanced imagery products
- Image data archive and catalog benefits
- Coordinated and optimized system use
- Safeguarding confidentiality and reliability parameters

However, from conception to deployment, MUSIS has been proven a complicated endeavor and time-consuming process so far. The reasons are nested in the requirements for multinational coordination among 7 + 1 participants, the formalities of national and collective decision making, and the individual political, operational, and industrial imperatives at national level.

Some of the lessons learned from the TA1 work involved the coordination shortcomings between national initiatives, a lack of consistency between the different architectures proposed by the prime contractors, and the absence of established standards or design rules, accepted both by industry and participants' MoDs.

## 48.7 Conclusions

Today, Space – and particular its defense and security use – is institutionally endorsed, operationally required, and technologically feasible, within the EU capacities and in parallel with its spacefaring members' policies, practices, and resources. Space assets offer innate panopticon viewing qualities that become critical enablers of defense and security applications, in all operational domains (land, sea, air) and for almost all types of missions and objectives.

The extensive experience, systematic know-how, and application maturity achieved in space-based imaging systems by individual member states, most notably France, Germany, Italy, and Spain, are justified and continuously fueled by the consistent effectiveness and exclusive merits of earth observation instruments. The particulars of system architecture, imaging competences, and UGS functions that yield reliable and comprehensive earth observation for defense and security have been adequately researched, applied, and tested under operational conditions for at least one generation of systems.

However, the inherent constraints, associated with separate development of observation capabilities, through individual national space programs, have been clearly identified to affect the range, the response and completeness of operational choices, and equally the level, quality, and availability of the cooperation options for the interested countries. A system conceived from design, to development and fielding, towards collaborative usage, is expected to address more successfully, both individual and collective operational requirements along with shared political objectives and industrial incentives.

This understanding, shared under BOC among seven EU members, forms a substantial driver for the future European earth observation architecture in the form of the MUSIS. The prospect of federating the next-generation space components promises improved performances and significant multiplying factors at system level.

On the other hand, MUSIS has received skepticism for not being able to evolve into a tangible space program yet, with finalized and validated framework for its operational deliverables, participation requirements, and resource allocation. A decade has passed since the acknowledgment of the BOC, but the materialization of a comprehensive next-generation Earth Observation System is not yet fully ensured.

MUSIS continues to draw on the sound collaborative basis that forged today's working examples of European synergy in earth observation for defense and security, i.e., the Helios 2, Pléiades, COSMO-SkyMed, and SAR-Lupe satellites and the ORFEO and PHAROS *user ground segment* amendments. Although partners are convinced of the operational value of their collective arrangements – and therefore support the maintenance of MUSIS consultations – they are in parallel determined to continue, in lieu of a capability gap risk, their imaging missions through national development of the successor space components: CSO, CSG, and SARah. Yet, the call for collaboration at the space components level is still valid, generally for CSO and CSG, although cooperation options are now pursued bilaterally, on a case-by-case basis, and restricted mostly to the operational usage of the system and its capabilities.

Still, the assignment of CIL studies to OCCAR remains a French and Italian program, under the frame of MUSIS federating activities, and is an open invitation to the other participants, especially the ones with contributing capabilities. Ideally, CIL will accommodate also the German SARah space component and the Ingenio satellite.

At present, the initial results of the CIL preliminary definition studies, with their feasibility proof and architecture recommendation, provide a description of a practical solution. In fact, this success ensures the continuation of MUSIS federating activities in 2013 (phase B2 contract) and promises the subsequent development and production (C and D phases) of CIL, in synchronization with the related space components' satellites entry-into-service planning (OCCAR 2012).

Moreover, MUSIS has a prominent role to defend the cooperative nature of Europe and address the realistic needs of members to apply sharing and pooling principles in space asset development, procurement, and exploitation. EDA and OCCAR are the European cooperation safeguards of MUSIS, and they appear to be instrumental in channeling further participation interest, like in the cases of Poland and Sweden, and managing the executive level of common activities, as the ones prescribed with the CIL industrial contracts.

Notwithstanding the above, MUSIS – as more or less all other European space endeavors – comes today under the pressures and scrutiny of the economic and financial crisis in the EU. As some partners are affected more severely than others, their aspirations towards MUSIS might be curtailed to the effect of significant budgetary constraints that are trimming down their initial expectations for space-based operational capabilities. Indicative, of the high costs incurred by such systems, is the fact that only a single contract, for the two CSO satellites, amounts to 795 million € (DGA 2010a). A rough estimation of the global cost for MUSIS could be substantiated to exceed the 2 billion € mark.

The way ahead for MUSIS might not be unencumbered, but at least the CIL bilateral initiative broke the previous consultation deadlock and provided an acceptable reconciliation between the space components and *user ground segment* development plans. In this regard, the re-initiation of tangible federating activities in OCCAR, together with the group's enlargement and the prospective benefits of EU-wide synergies under the patronage of EDA, provides reassurance that MUSIS will overcome previous shortcomings and eventually culminate to establish the second-generation space-based system for surveillance, reconnaissance, and observation.

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# The Chinese Space Launch Program

# 49

Lehao Long and Dan Li

## Contents

## Abstract

China's development of launch vehicles is sticking to the "self-reliance and independent innovation" path. With more than 40 years experience, China has successfully developed more than 10 models of launch vehicles and experienced the transition from research test to flight application, and from flight application to the industrialization. This chapter provides an overview of China's space

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launch plan. This chapter mainly presents the development history of China's launch vehicles, launch vehicles in service, and the new generation of launch vehicles under development and describes the efforts made by China in the field of space security.

## 49.1 Introduction

With enhancing capacity of access to space at the core, and driven by launch missions, China's development of launch vehicles is sticking to the "self-reliance and independent innovation" path. With more than 40 years experience, China has successfully developed more than 10 models of launch vehicles and experienced the transition from research test to flight application and from flight application to the industrialization. It promoted the development of satellites and satellite application technology and manned space technology and strongly supported the successful implementation of major projects in China with the "manned space project" and "lunar exploration project" as the representative.

To ensure safe, reliable, fast, economic, environment-friendly access to space, promote space exploration technology development and enhance the progress of human civilization was the development goal of China's launch vehicles in the past, is the goal at present, and will be the goal in the future.

This chapter mainly presents the development history of China's launch vehicles, launch vehicles in service, and the new generation of launch vehicles under development and describes the efforts made by China in the field of space security.

## 49.2 Development Background of China's Launch Vehicles

China is the cradle of rockets. As early as the Song Dynasty (in the eleventh century), China invented black powder rocket, which was in line with the principle of rocket propulsion. It spread to the Arab World and the West in the thirteenth century.

The development of China's present launch vehicles began in the mid-1960s. With hard exploration and painstaking efforts, China has now successfully developed the Long March I (LM-1) series, the Long March II (LM-2) series, the Long March (LM-3) series, and the Long March IV (LM-4) series of launch vehicles and is developing a new generation of launch vehicles. It formed a family of Long March launch vehicles of more than 10 kinds of models. With 40 years development, China's space launch technology has made remarkable achievements. The LM launch vehicles experienced many technological leaps, such as from using conventional propellants to cryogenic propellants, from one-time start of the last stage to multi-start, from structure being in series to being in parallel, from one vehicle launching one satellite to launching multi-satellites, and from launching cargos to launching human beings. Now, they can launch different kinds of satellites and manned spacecrafts to different types of low, medium, and high Earth orbits. The launch capacity for low Earth orbit (LEO), sun-synchronous orbit (SSO), and geosynchronous transfer orbit (GTO) is 12 t, 6 t, and 5.5 t, respectively. The orbit injection precision reaches leading international level. It can meet the diverse needs of different users. The existing LM launch vehicles have the ability to launch spacecrafts to the moon and the deep space in the solar system.

On April 24, 1970, China's LM-1 rocket successfully launched the Dongfanghong-1 satellite into low Earth orbit, making China the fifth country in the world that successfully launched its own satellite with its homemade rocket.

In 1999, LM-2F launch vehicle successfully launched the experimental Shenzhou spacecraft and laid a solid foundation for the realization of the strategic goals of China's manned space flight, making China the world's third country of independently developing manned space technology, and further enhanced China aerospace industry's status in the international arena. In October 2003, China's first manned space mission was a success. In June 2012, China successfully accomplished the first manned rendezvous and docking.

In October 2007, LM-3A launch vehicle successfully sent China's first lunar probe satellite "Chang'e-1" into preset orbit, marking China's space industry successfully entered the new field of deep space exploration, Chinese nation's thousands of years' dream of flying to the moon started to become a reality.

Launching artificial Earth satellite, manned spacecraft, and lunar probe are three milestones in the development of China's space industry.

## 49.3 Launching Plan and Development of China's Launch Vehicles

Up to June 30, 2012, LM launch vehicles carried out 165 launches, sending 190 spacecrafts into orbit and its launch success rate reaches 95 %. China's launch vehicles finished the first 50 launches in 28 years. In recent years, with the drive of launch demand from home and abroad, the subsequent 115 launches only take 12 years. With one single model, the LM-3A series have realized more than 50 launches, which fully verify the reliability of launch vehicles and promote the industrialization of China's launch vehicles.

The launch plan of China's launch vehicles will continue to maintain a high density. It is said that during the "12th Five-Year" period, China will complete 100 launches with an annual average about 20 times.

## 49.4 International Commercial Launch of LM Launch Vehicles

Since the Chinese government officially announced that the LM launch vehicles entered the international commercial launch market in 1985, they have successfully sent various foreign-made satellites into orbit and occupied a place in the international market of commercial satellite launch services.

As of June 30, 2012, LM launch vehicles accomplished 34 commercial launches, including 40 international commercial satellites launches, six piggyback launch services, and four domestic satellite in-orbit deliveries. China's rising aerospace industry attracts international counterparts' attention with its good market reputation and first-class brand image. In the future, China's aerospace industry will greatly expand international exchanges; will make comprehensive and multilevel cooperation with many foreign clients in the fields of product development, system construction, satellite application, resource sharing, personnel exchanges, and manned space flight; and will actively realize the goal of using space technology to benefit human beings.

See Table 49.1 International commercial launch record of LM launch vehicles.

## 49.5 Launch Vehicles in Service

### 49.5.1 LM-2

The LM-2 series developed in 1970 are mainly used for LEO missions. Currently, the LM-2 series consist of seven kinds of launch vehicles (see Fig. 49.1), i.e., LM-2, LM-2C series, LM-2D, LM-2E, and LM-2F. Among them, LM-2 and LM-2E are no longer in use.

#### 49.5.1.1 LM-2C/CTS-1/CTS-2

The LM-2C series have two-stage state and three-stage state, mainly used for launching satellites into LEO, SSO, extremely elliptical orbit (EEO), and GTO. It possesses the capability of launching multi-satellites with one vehicle.

#### LM-2C in Two-Stage State

With total length of 43 m, diameter of 3.35 m, LM-2C launch vehicle is mainly used for launching LEO and SSO satellites. Its launch capacity for 200 km LEO and 600 km SSO is 4.1 t and 1.5 t respectively.

In August 1987, the LM-2C successfully provided piggyback launch of microgravity test instrument for French Matra Marconi Company, marking the beginning of China's international cooperation in aerospace industry. Since the first flight on November 26, 1975, the model have launched 26 times, among which 25 times are successful.

#### LM-2C in Three-Stage State

LM-2C in three-stage state, namely, LM-2C/CTS is formed by adding a solid upper stage to the LM-2C. It includes LM-2C/CTS-1 and LM-2C/CTS-2. Its total length is 43 m, and the diameter is 3.35 m. LM-2C/CTS-1 mainly used for launching multi-satellites, and SSO satellites, with 1.9 t launch capacity for 600 km SSO. LM-2C/CTS-2 mainly used for launching EEO satellites and GTO satellites. The GTO launch capacity (inclination of 28°) is 1.25 t. Since 1997, LM-2C/CTS has completed a total of 10 launches with all success.

**Table 49.1** International commercial launch record of LM launch vehicles

| No. | Payload/SC | Launch vehicle | Customer | Launch date | Remarks |
|---|---|---|---|---|---|
| 1[a] | Microgravity test instrument | LM-2C F09 | Matra Marconi, France | 1987/08/05 | Piggyback |
| 2[a] | Microgravity test instrument | LM-2C F11 | Intospace Germany | 1988/08/05 | Piggyback |
| 3 | AsiaSat-1 | LM-3F07 | AsiaSat, HK | 1990/04/07 | Dedicated |
| 4[a] | BADR-A/Aussat dummy payload | LM-2E F01 | SUPARCO, Pakistan | 1990/07/16 | Piggyback |
| 5 | Aussat-B1 | LM-2E F02 | Aussat, Australia | 1992/08/14 | Dedicated |
| 6[a] | Freja | LM-2C F13 | SSC, Sweden | 1992/10/06 | Piggyback |
| 7 | Optus-B2 | LM-2E F03 | Aussat, Australia | 1992/12/21 | Dedicated |
| 8 | APSTAR-1 | LM-3F09 | APT, HK | 1994/07/21 | Dedicated |
| 9 | Optus-B3 | LM-2E F04 | Optus, Australia | 1994/08/28 | Dedicated |
| 10 | APSTAR-II | LM-2E F05 | APT, HK | 1995/01/26 | Dedicated |
| 11 | AsiaSat-2 | LM-2E F06(EPKM) | AsiaSat, HK | 1995/11/28 | Dedicated |
| 12 | Echo Star-1 | LM-2E F07(EPKM) | EchoStar, USA | 1995/12/28 | Dedicated |
| 13 | INTELSAT-7A | LM-3B F01 | INTELSAT | 1996/02/15 | Dedicated |
| 14 | APSTAR-1A | LM-3F10 | APT, HK | 1996/07/03 | Dedicated |
| 15 | ChinaSat-7 | LM-3F11 | ChinaSat, China | 1996/08/18 | Dedicated |
| 16[a] | Microgravity test instrument | LM-2D F03 | Marubeni Corp., Japan | 1996/10/20 | Piggyback |
| 17 | Mabuhay sat | LM-3B F02 | Mabuhay, Philippines | 1997/08/20 | Dedicated |
| 18 | APSTAR-IIR | LM-3B F03 | APT, HK | 1997/10/17 | Dedicated |
| 19 | Iridium | LM-2C/SD F02 | Motorola, USA | 1997/12/08 | Dual |
| 20 | Iridium | LM-2C/SD F03 | Motorola, USA | 1998/03/26 | Dual |
| 21 | Iridium | LM-2C/SD F04 | Motorola, USA | 1998/05/02 | Dual |
| 22 | ChinaStar-1 | LM-3B F04 | China Orient, China | 1998/05/30 | Dedicated |
| 23 | SinoSat-1 | LM-3B F05 | SinoSat, China | 1998/07/18 | Dedicated |
| 24 | Iridium | LM-2C/SD F05 | Motorola, USA | 1998/08/20 | Dual |
| 25 | Iridium | LM-2C/SD F06 | Motorola, USA | 1998/12/19 | Dual |
| 26 | Iridium | LM-2C/SD F07 | Motorola, USA | 1999/06/12 | Dual |
| 27 | CBERS-01 | LM-4F04 | INPE, Brazil | 1999/10/14 | Dedicated |
| 28[a] | SACI | LM-4F04 | INPE, Brazil | 1999/10/14 | Piggyback |
| 28 | CBERS-02 | LM-4F08 | INPE, Brazil | 2003/10/21 | Dual |
| 30 | APSTAR-VI | LM-3B F06 | APT, HK | 2005/04/12 | Dedicated |
| 31 | NigComSat-1 | LM-3B F07 | NSRDA, Nigeria | 2007/05/14 | Dedicated |
| 32 | ChinaSat-6B | LM-3B F08 | ChinaSat, China | 2007/07/05 | Dedicated |
| 33 | CBERS-02B | LM-3B F09 | INPE, Brazil | 2007/09/19 | Dedicated |
| 34 | ChinaSat-9 | LM-3B F10 | China Sat, China | 2008/06/09 | Dedicated |
| 35 | VeneSat-1 | LM-3B F11 | Venezuelan ministry of science and technology | 2008/10/30 | Dedicated |
| 36 | PALAPA-D | LM-3B F12 | PT Indonesia Tbk | 2009/08/31 | Dedicated |

(*continued*)

**Table 49.1** (continued)

| No. | Payload/SC | Launch vehicle | Customer | Launch date | Remarks |
|---|---|---|---|---|---|
| 37 | Paksat-1R | LM-3B F15 | SUPARCO | 2011/08/12 | Dedicated |
| 38 | W3C | LM-3B F17 | Eutelsat | 2011/10/07 | Dedicated |
| 39 | NigComSat-1R | LM-3B F18 | NSRDA, Nigeria | 2011/12/20 | Dedicated |
| 40 | APSTAR-VII | LM-3B F19 | APT, HK | 2012/03/31 | Dedicated |

Note: In the “Launch Vehicle” column, FXX indicates the flight number of the launch vehicle
[a]6 piggyback services are noted with

**Fig. 49.1** LM-2 series

Between 1997 and 1999, LM-2C/CTS-1 successfully completed “one vehicle two satellites” launch for seven times, sending 14 Iridium satellites (two dummy satellites and 12 communications satellites) into orbit. Till April 2012, LM-2C/CTS successfully launched TC-1, TC-2, and HJ-1 A/B satellite, respectively.

Specifications of LM-2C series

| | | First stage | Second stage | Third stage CTS-1/CTS-2 |
|---|---|---|---|---|
| Maximum diameter of core stage (m) | | 3.35 | 3.35 | / |
| Propellant mass (t) | | 172 | 54.6 | 2.62/0.125 |
| Propellant | | UDMH/$N_2O_4$ | UDMH/$N_2O_4$ | Solid |
| Engine | | YF-21C | YF-24E | Solid |
| Engine thrust (kN) | | 2961.6 | 741.4 (main)<br>11.8 × 4 (vernier) | 107 |
| Engine-specific impulse (N·s/kg) | | 2556.6 | 2922.37 (main)<br>2834.11 (vernier)<br>(vacuum) | 10.78 |
| Booster number | | / | | |
| Booster diameter (m) | | / | | |
| Lift-off mass (t) | | 242 | | |
| Total length (m) | | 43.027 | | |
| Fairing diameter (m) | | 3.35 | | |
| Launch capacity (kg) | LEO | 4100(two stages) | | |
| | SSO | 1,500 (two stages), 1,900(600 km SSO) | | |
| | GTO | 1,250 | | |
| Current main mission (orbit) | | SSO satellite | | |
| Main launch site | | Jiuquan, Taiyuan, Xichang satellite launch center | | |
| Research and development entity | | China aerospace science and technology corporation | | |

### 49.5.1.2 LM-2D

LM-2D is a two-stage conventional liquid launch vehicle, mainly used for LEO and SSO missions. It has the capabilities of launching two satellites in parallel and launching multi-satellite with one vehicle.

With total length of 41.056 m and diameter of 3.35 m, LM-2D launch vehicle is mainly used for launching satellites to LEO and SSO. Its launch capacity for 260 km LEO and 600 km SSO is 3.6 t and 1.5 t respectively.

Since the first flight on August 9, 1992, LM-2D has conducted 16 launches with complete success, altogether sending 21 satellites into orbit.

Specifications of LM-2D series

| | First stage | Second stage |
|---|---|---|
| Maximum diameter of core stage (m) | 3.35 | 3.35 |
| Propellant mass (t) | 124 | 59 |

(*continued*)

Specifications of LM-2D series

| | | First stage | Second stage |
|---|---|---|---|
| Propellant | | UDMH/$N_2O_4$ | UDMH/$N_2O_4$ |
| Engine | | YF-21C | YF-24C |
| Engine thrust (kN) | | 2961.6 | 742.04 (main)47.1 (vernier) |
| Engine-specific impulse (N·s/kg) | | 2556.6 | 2,942(main)2,834 (vernier)(vacuum) |
| Booster number | | / | |
| Booster diameter (m) | | / | |
| Lift-off mass (t) | | 250 | |
| Total length (m) | | 41.056 | |
| Fairing diameter (m) | | 3.35 | |
| Launch capacity (kg) | LEO | 3,600 (260 km LEO) | |
| | SSO | 1,500 (600 km SSO) | |
| Current main mission (orbit) | | SSO satellite | |
| Main launch site | | Jiuquan satellite launch center | |
| Research and development entity | | China aerospace science and technology corporation | |

### 49.5.1.3 LM-2F

LM-2F is a highly reliable and safe launch vehicle developed to meet the demands of China's manned space special project. LM-2F has two variants of launching Shenzhou spacecraft and target spacecrafts. As for launching Shenzhou spacecraft, its diameter is 3.35 m, total length is 58.3 m. It consists of four liquid boosters, first stage, second stage, fairing, and the escape tower. Its launch capacity for LEO is 8.1 t.

October 15, 2003, LM-2F successfully sent China's astronaut Yang Liwei into space, making China the third country in the world having manned space capability and also marking China's Manned Space Project entering into a substantive application stage. Till June 16, 2012, LM-2F has completed 10 successful launches, including five unmanned spacecrafts, four manned spacecrafts (i.e., "Shenzhou V," "Shenzhou VI," "Shenzhou VII," and "Shenzhou IV"), and one target spacecraft.

Specifications of LM-2F

| | First stage | Second stage | Booster |
|---|---|---|---|
| Maximum diameter of core stage (m) | 3.35 | 3.35 | 2.25 |
| Propellant mass (t) | 184 | 83.727 | 45.277 |
| Propellant | UDMH/N2O4 | UDMH/N2O4 | UDMH/N2O4 |
| Engine | YF-20 K | YF-24 K | YF-25 K |
| Engine thrust (kN) | 2961.6 | 741.4 (main)<br>11.8 × 4(vernier) | 740.4 |
| Engine-specific impulse (N·s/kg) | 2556.6 | 2922.37(main)<br>2834.11(vernier)(vacuum) | 2550 |
| Booster number | 4 | | |
| Booster diameter (m) | 2.25 | | |

(*continued*)

| Specifications of LM-2F | | | | |
|---|---|---|---|---|
| | | First stage | Second stage | Booster |
| Lift-off mass (t) | | 493 | | |
| Total length (m) | | 58.3 | | |
| Fairing diameter (m) | | 3.35 | | |
| Launch capacity (kg) | LEO | 8,100 | | |
| Current main mission (orbit) | | LEO | | |
| Main launch site | | Jiuquan satellite launch center | | |
| Research and development entity | | China aerospace science and technology corporation | | |

## 49.5.2 LM-3

The LM-3 series are made up of four launch vehicles (see Fig. 49.2), i.e., LM-3, LM-3A, LM-3B, and LM-3C. As LM-3 has been retired, the rest of the three kinds of rockets are known as the LM-3A series of launch vehicles.

### 49.5.2.1 LM-3A

LM-3A is a three-stage liquid launch vehicle, consisting of the first stage, second stage, third stage, and fairing. Its total length is 52.52 m, the diameter of the first stage and the second stage is 3.35 m, and the diameter of the third stage is 3 m. Its standard launch capacity to GTO is 2.6 t. From its maiden flight in 1994 to June 2012, the vehicle consecutively launched 23 times, with launch success rate of 100 %.

| Specifications of LM-3A | | | | |
|---|---|---|---|---|
| | | First stage | Second stage | Third stage |
| Maximum diameter of core stage (m) | | 3.35 | 3.35 | 3 |
| Propellant mass (t) | | 171.843 | 33.207 | 18.518 |
| Propellant | | UDMH/$N_2O_4$ | UDMH/$N_2O_4$ | $LH_2$/LOX |
| Engine | | YF-21C | YF-24E | YF-75 |
| Engine thrust (kN) | | 2961.6 | 741.4 (main)11.8 × 4(vernier) | 82.76 |
| Engine-specific impulse (N·s/kg) | | 2556.6 | 2922.37(main)2834.11(vernier) (vacuum) | 4,300 |
| Booster number | | 0 | | |
| Booster diameter | | – | | |
| Lift-off mass (t) | | 243 | | |
| Total length (m) | | 52.52 | | |
| Fairing diameter (m) | | 3.35 | | |
| Launch capacity (kg) | LEO | – | | |
| | SSO | – | | |
| | GTO | 2,600 | | |
| Current main mission (orbit) | | GTO | | |

(*continued*)

Specifications of LM-3A

| | First stage | Second stage | Third stage |
|---|---|---|---|
| Main launch site | Xichang satellite launch center | | |
| Research and development entity | China aerospace science and technology corporation | | |

LM-3 LM-3A LM-3B LM-3C

**Fig. 49.2** LM-3 series of launch vehicles

### 49.5.2.2 LM-3B

LM-3B is a three-stage liquid launch vehicle employing enhanced LM-3A as the core stage and strapped with four liquid boosters. Its total length is 54.84 m. The diameter of booster is 2.25 m. The diameter of the first stage and the second stage is 3.35 m, and the diameter of the third stage is 3.0 m. At present, LM-3B rocket consists of three variants. Its standard launch capacity to GTO is between 5.1 and 5.5 t, which is the strongest one among China's launch vehicles. From the first flight in 1996 to June 2012, it completed a total of 21 launches, and 20 launches were successful.

LM-3B is the main launch vehicle to undertake the high orbit international commercial satellite launching services. In the next few years, LM-3B launch vehicle will perform the second phase of lunar exploration project, and launch the "Chang'e III" and "Chang'e IV" satellites.

Specifications of LM-3B standard

| | First stage | Second stage | Third stage | Booster |
|---|---|---|---|---|
| Maximum diameter of core stage (m) | 3.35 | 3.35 | 3 | 2.25 |
| Propellant mass (t) | 171.935 | 49.876 | 18.324 | 37.756 |
| Propellant | UDMH/$N_2O_4$ | UDMH/$N_2O_4$ | $LH_2$/LOX | UDMH/$N_2O_4$ |
| Engine | YF-21C | YF-24E | YF-75 | YF-25 |
| Engine thrust (kN) | 2961.6 | 741.4 (main)<br>11.8 × 4(vernier) | 82.76 | 740.4 |
| Engine-specific impulse (N·s/kg) | 2556.6 | 2922.37(main)<br>2834.11(vernier)<br>(vacuum) | 4,300 | 2556.6 |
| Booster number | 4 | | | |
| Booster diameter (m) | 2.25 | | | |
| Lift-off mass (t) | 427 | | | |
| Total length (m) | 54.84 | | | |
| Fairing diameter (m) | 4 | | | |
| Launch capacity (kg) LEO | – | | | |
| SSO | – | | | |
| GTO | 5,100 ~ 5,500 | | | |
| Current main mission (orbit) | GTO | | | |
| Main launch site | Xichang satellite launch center | | | |
| Research and development entity | China aerospace science and technology corporation | | | |

### 49.5.2.3 LM-3C

LM-3C takes LM-3A as the core stage and is strapped with two liquid boosters at the first stage. Its total length is 54.84 m. The diameter of the booster is 2.25 m, the diameter of the first stage and second stage is 3.35 m, and the diameter of the third stage is 3.0 m. The GTO launch capacity of LM-3C reaches 3.8 t.

On April 25, 2008, the first flight of LM-3C was a complete success. In 2012, LM-3C will launch Chang’e II satellite. Till June 2012, it successively launched eight times with a success rate of 100 %.

Specifications of LM-3C standard

| | | First stage | Second stage | Third Stage | Booster |
|---|---|---|---|---|---|
| Maximum diameter of core stage (m) | | 3.35 | 3.35 | 3 | 2.25 |
| Propellant mass (t) | | 171.946 | 49.815 | 18.448 | 37.69 |
| Propellant | | UDMH/$N_2O_4$ | UDMH/$N_2O_4$ | $LH_2$/LOX | UDMH/$N_2O_4$ |
| Engine | | YF-21C | YF-24E | YF-75 | YF-25 |
| Engine thrust (kN) | | 2961.6 | 741.4 (main)<br>11.8 × 4(vernier) | 82.76 | 740.4 |
| Engine-specific impulse (N·s/kg) | | 2556.6 | 2922.37(main)<br>2834.11(vernier)<br>(vacuum) | 4,300 | 2556.6 |
| Booster number | | 2 | | | |
| Booster diameter (m) | | 2.25 | | | |
| Lift-off mass (t) | | 343 | | | |
| Total length (m) | | 54.84 | | | |
| Fairing diameter (m) | | 4 | | | |
| Launch Capacity (kg) | LEO | – | | | |
| | SSO | – | | | |
| | GTO | 3,800 | | | |
| Current main mission (orbit) | | GTO | | | |
| Main launch site | | Xichang satellite launch center | | | |
| Entity of research and development | | China aerospace science and technology corporation | | | |

### 49.5.3 LM-4

The LM-4 series are made up of three launch vehicles (see Fig. 49.3), i.e., LM-4A, LM-4B, and LM-4C. As LM-4A has been retired, the rest of the two kinds of rockets are known as the LM-4 series.

#### 49.5.3.1 LM-4B

LM-4B is a three-stage launch vehicle using room-temperature liquid propellants. It is made up of the first stage, second stage, third stage, and fairing. It consists of the vehicle structure, engine, pressurized feeding system, control, telemetry, and external measuring safety subsystems. Its total length is 45.776 m, the diameter of the first and second stage is 3.35 m, and the diameter of the third stage is 2.9 m. LM-4B can implement a variety of orbit missions (SSO, LEO, GTO) and different types of satellite launches. Its launch capacity for 200 km 60° inclination circular orbit is about 4.6 t and for 400 km sun-synchronous orbit is about 3.2 t. LM-4B is mainly

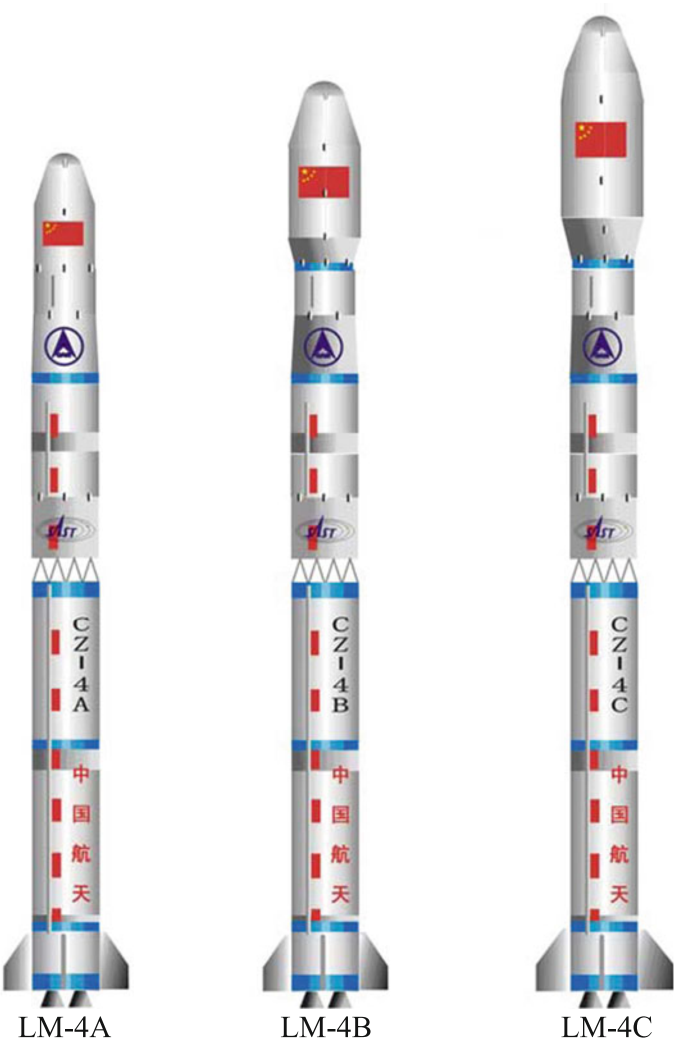

**Fig. 49.3** LM-4 series of launch vehicles

used to send satellites to SSO. Up to June 2012, it had 18 consecutive launches with a success rate of 100 % since its first flight is in 1999.

Specifications of LM-4B

| | First stage | Second stage | Third stage |
|---|---|---|---|
| Maximum diameter of core stage (m) | 3.35 | 3.35 | 2.9 |
| Propellant mass (t) | 181.89 | 35.408 | 14.34 |

(*continued*)

| Specifications of LM-4B | | | | |
|---|---|---|---|---|
| | | First stage | Second stage | Third stage |
| Propellant | | UDMH/$N_2O_4$ | UDMH/$N_2O_4$ | UDMH/$N_2O_4$ |
| Engine | | YF-21C | YF-24H | YF-40B |
| Engine thrust (kN) | | 2961.6 | 742.04(main)46.09(vernier) | 100.848 |
| Engine-specific impulse (N · s/kg) | | 2556.6 | 2942.4(main) 2761.6(vernier)(vacuum) | 2,971 |
| Lift-off mass (t) | | 250 | | |
| Total length (m) | | 45.776 | | |
| Fairing diameter (m) | | 3.35 | | |
| Launch capacity (kg) | LEO | 4,600 | | |
| | SSO/400 km | 3,200 | | |
| | GTO | / | | |
| Current main mission (orbit) | | SSO | | |
| Main launch site | | Taiyuan satellite launch center | | |
| Research and development entity | | China aerospace science and technology corporation | | |

### 49.5.3.2 LM-4C

LM-4C is an enhanced three-stage liquid launch vehicle by adding new technologies such as restart of the third-stage engine to LM-4B. Its total length is 45.776 m, the diameter of the first and second stage is 3.35 m, and the diameter of the third stage is 2.9 m. Its launch capacity for 600 km trajectory tilted by 60° degree to the equator is about 3.7 t, for 800 km SSO is 2.7 t, and for GTO is about 1.3 t. LM-4C is mainly used to send satellites to SSO. From 2006 to June 2012, it launched eight times, with a success rate of 100 %.

| Specifications of LM-4C standard | | | | |
|---|---|---|---|---|
| | | First stage | Second stage | Third stage |
| Maximum diameter of core stage (m) | | 3.35 | 3.35 | 2.9 |
| Propellant mass (t) | | 189.841 | 34.449 | 13.971 |
| Propellant | | UDMH/$N_2O_4$ | UDMH/$N_2O_4$ | UDMH/$N_2O_4$ |
| Engine | | YF-21C | YF-24H | YF-40A |
| Engine thrust (kN) | | 2961.6 | 742.04(main)46.09(vernier) | 100.848 |
| Engine-specific impulse (N·s/kg) | | 2556.6 | 2942.4(main) 2761.6(vernier)(vacuum) | 2,971 |
| Lift-off mass (t) | | 250 | | |
| Total length (m) | | 47.977 | | |
| Fairing diameter (m) | | 3.8 | | |
| Launch capacity (kg) | LEO | / | | |
| | SSO/800 | 2,700 | | |
| | GTO | 1,300 | | |
| Current main mission (orbit) | | SSO | | |

(*continued*)

| Specifications of LM-4C standard | | | |
|---|---|---|---|
| | First stage | Second stage | Third stage |
| Main launch site | Taiyuan satellite launch center | | |
| Research and development entity | China aerospace science and technology corporation | | |

## 49.6 Future Launch Vehicles

China is continuously strengthening the construction of space transportation systems, further perfecting the completeness of LM launch vehicles, enhancing the ability of access to space, and developing a new generation of launch vehicles and upper stages with the LM-5, LM-6, and LM-7 as the representatives. LM-5 uses nontoxic environment-friendly propellants with LEO launch capacity of 25 t and GTO capability of 4 t. LM-6 is a new and fast responsive rocket, with launch capacity for 700 km SSO not less than 1 t. Launch capacity of LM-7 for LEO and 700 km SSO is 13.5 t and 5.5 t respectively.

### 49.6.1 LM-5

LM-5 is a new large rocket developed under the guideline of “one series, two engines, and three modules.” The “three modules” refers to the 5 m diameter module using liquid hydrogen and liquid oxygen as propellants, the 3.35 m diameter and 2.25 m diameter modules using liquid oxygen and kerosene propellants. The “two engines” refers to the newly developed liquid oxygen and liquid hydrogen engine of 50 t class thrust and the liquid oxygen and kerosene engine of 120 t class thrust. Based on the design concept of “generalization, serialization, and combination,” six configurations with 5 m-diameter core stage will be formed based on the three newly developed modules. Its GTO launch capacity covers from 6 t to 14 t, and LEO launch capacity from 10 t to 25 t. LM-5 configuration for the first flight is the one strapped with four 3.35 m-diameter boosters.

LM-5 uses brand new power system, large vehicle structural design and manufacturing technology, advanced control and digital technology, which significantly improve the overall level of China’s launch vehicles and the capacity of utilizing space resources. Its total length is 57 m. The diameter of the first stage and second stage is 5 m. The diameter of four strap-on booster is 3.35 m. Its maximum GTO launch capacity is 14 t.

### 49.6.2 LM-6

As a member of the new generation rockets, LM-6 is a light and fast responsive liquid launch vehicle. To meet easy and quick launch requirements, it is transported to the simple launch pad (without tower) as the integrated by the vertical car to be erected, filled up, and launched. It is 29.9 m long and 3.35 m in diameter. Its lift-off mass is about 102 t, and lift-off thrust reaches about 1200 kN. It adopts three-stage configuration and uses nontoxic propellants such as liquid oxygen and kerosene. With monitoring and control limits, its launch capacity for 700 km SSO is approximately 500 kg. Without limit of monitoring and control conditions, by the glide and restart of the third stage, its launch capacity for 700 km SSO is about 1,000 kg.

### 49.6.3 LM-7

LM-7 is a new medium-sized launch vehicle, mainly used for launching cargo ship to the space station. Its total length is 53.1 m. Lift-off mass is about 595 t. Lift-off thrust is 735 t. The diameter of the core stage is 3.35 m, and the diameter of the four strap-on boosters is 2.25 m. The maximum launch capacity for LEO with 200 km × 400 km, 42 is 13.5 t.

## 49.7 Prospect of Security Policy

### 49.7.1 China's Space Security Policy

Outer space is the common wealth of human being, and the exploration of outer space is the unremitting pursuit of mankind. At present, the world space activities are booming. Major space nations successively develop or adjust the space development strategy, development plan and development objectives, status and role of the aerospace industry in the country's overall development strategy have become increasingly important. The impact of space activities on human civilization and social progress has been enhanced.

China puts the development of space industry as an important part of the country's overall development strategy and always adheres to the policy of exploring and using outer space for peaceful purposes. In recent years, China's space industry develops rapidly with some important technology areas having reached the world's leading level. Space activities play an increasingly important role in China's economic construction and social development.

In the future, China will focus on the national strategic goals, strengthen independent innovation, expand opening up and cooperation, and promote sound and rapid development of space industry. Meanwhile, China is willing to work together with the international community to jointly safeguard a peaceful and clean outer space and make new contributions to promote the human peace and development.

China's aims of developing space activities are as follows: to explore the outer space and enhance the understanding of the Earth and the universe; to peacefully use the outer space and promote human civilization and social progress for the benefit of all human beings; to meet the needs of economic construction, scientific and technological development, national security, and social progress; to improve the scientific and cultural quality of human beings; to safeguard national interests; and to enhance overall national strength.

The principle of China's space security policy is subordinate to and serves the overall national development strategy and adheres to the scientific planning, self-development, the peaceful use and open cooperation principles.

Scientific planning is defined as respecting science and law, and comprehensively balancing and scientifically developing space technology, space application, space science, and other space activities based on the development reality of the aerospace industry, to maintain the comprehensive, coordinated, and sustainable development of aerospace industry.

The meaning of self-development always adheres to the independent and self-reliant path of development, mainly relies on our own power to self-develop the space industry according to national conditions and national strength, to meet the basic needs of the country's modernization drive.

Peaceful use means always adhere to the peaceful use of outer space, opposes weaponization of outer space and arms race in outer space, rationally develops and utilizes space resources, and effectively protects the space environment, letting space activities bring benefits to the people.

Open cooperation refers to adhere to the combination of being independent and cooperating openly, on the basis of equality and mutual benefit, peaceful utilization and common development, actively carry out international exchanges and cooperation in the space industry, and committed to the common progress of human space industry. International cooperation in the space field should follow the basic principles of United Nations' *Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries*.

In the next 5 years, China will strengthen the basic capacity building of aerospace industry, advance the deployment of cutting-edge research, and continue to implement major scientific and technological projects and priority projects in key areas, such as the manned spaceflight, lunar exploration, high-resolution Earth observation system, satellite navigation and positioning system, and the new generation of launch vehicles. It will comprehensively improve space infrastructure, promote the development of satellite industry and its application industry, conduct space science research in depth, and enhance the comprehensive, coordinated, and sustainable development of the aerospace industry.

### 49.7.2 Space Debris Mitigation of LM Launch Vehicles

Established in 1993, the Inter-Agency Space Debris Coordination Committee (IADC) aims to strengthen the research and coordination of member states in the field of space debris. China is also a member of the committee. As a space power, China actively participates in the related anti-space debris activities and conscientiously fulfills the duties and obligations that it commits to IADC, in order to protect the image and status of China's aerospace industry in the international arena.

China organizes experts in the fields of aerospace and space policy to study the feasibility of the design and management of space debris mitigation and formulated the *Guideline for Orbital Debris Mitigation* in 2006. From technical aspects, the standard puts forward basic requirements on the design of orbital debris in each step of space activities. Those basic requirements are consistent with IADC's guidelines for space debris mitigation. Based on the *Guideline for Orbital Debris Mitigation*, China is gradually setting design and management standards for space debris mitigation.

In accordance with international conventions, China will greatly promote the space debris mitigation design of Long March launch vehicles. For LEO missions, life of the last stage in orbit is less than 25 years, and passivation measures are generally adopted; for SSO missions, active de-orbit measures or passivation measures are taken.

In the future, China will continue to strengthen the space debris monitoring, mitigation and spacecraft protection in the field of space debris. It will develop space debris monitoring and collision warning technology and carry out the monitoring and collision warning of space debris and small near-Earth celestial bodies. It will establish evaluation system of space debris mitigation design and actively take space debris mitigation measures on the after-mission spacecrafts and launch vehicles. It will test digital simulation technology of space debris impact and promote the construction of space debris protection system.

## 49.8 Conclusion

Free exploration, development and utilization of outer space and celestial bodies, is the equal right shared by countries in the world. Each country's outer space activities should contribute to its national economic development and social progress and should benefit human security, survival, and development. China's launch vehicle technology development will contribute to the technological progress of world's space exploration. China advocates strengthening international exchange and cooperation and promoting inclusive development in the space industry on the basis of equality and mutual benefit, peaceful use, and common development.

# Chinese Satellite Programs: An Internal View

# 50

Shenyuan Hou and Hao Liu

## Contents

### Abstract

Over more than half a century, China's space industry has created a unique program tailored to China's conditions, achieved successful human spaceflight and lunar exploration projects, established a complete and necessary system for research, design, production, and testing, substantially upgraded its overall level of space technology, enhanced the economic and social benefits of space applications, and obtained numerous innovative results in space science. This chapter briefly introduces the development of China's satellite programs. It covers the beginning and evolution of Chinese satellite programs and provides an overview of the different satellite programs: Earth observation, communication and broadcasting, navigation and positioning, and scientific and technological test

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satellites. The chapter also addresses the future of the Chinese satellite programs and China's international space exchanges and cooperation.

## 50.1 Introduction: Origins of the Chinese Satellite Programs

China is a developing country with vast territory and large population and it experiences frequent natural disasters. The purposes of China's satellite programs include expanding the understanding of the Earth and the universe; promoting human civilization and social progress; meeting the demand of economic construction, technological development, and national security; raising scientific and cultural standards; safeguarding national interests; and enhancing comprehensive national strength. China has always sought to explore and utilize outer space for peaceful purposes.

China's satellite engineering was developed on the basis of weak infrastructure industries, relatively backward scientific and technological capabilities, and limited national funding. Satellite development in China can be divided into three phases:

- Technology preparation phase (1958–1970). China's satellite development began in the late 1950s. In February 1968, the China Academy of Space Technology (CAST) was established. In April 1970, China launched the first man-made satellite, DFH-1, making China the world's fifth country to independently develop and launch a man-made satellite.
- Technology test phase (1971–1984). In 1975, China successfully launched and recovered a remote-sensing satellite for the first time. In 1984, China launched the first geosynchronous Earth orbit (GEO) communications satellite, DFH-2.
- Satellite application phase (1985–present). On the basis of several successful tests, recoverable satellites and communications satellites began to be put into practical application. Subsequently, China successfully developed and launched meteorological satellites, communications and broadcasting satellites, navigation and positioning satellites, resources satellites, ocean observation satellites, and scientific and technological test satellites.

By the end of 2011, China has successfully developed and launched 144 man-made satellites (not including export satellites). Through continuous efforts, China gradually formed a full range of satellite series, including Earth observation, communications and broadcasting, navigation and positioning, and scientific and technological testing. Satellite programs have been transformed from a technology test to an operational service. Various satellites have been widely used in many fields, including social construction, business, science and technology, culture, and education.

## 50.2 Satellite Program Development

### 50.2.1 Earth Observation Satellites

To date, China has developed the Fengyun (wind and cloud), Haiyang (ocean), Ziyuan (resource), Yaogan (remote sensing), and Tianhui (space mapping) satellite

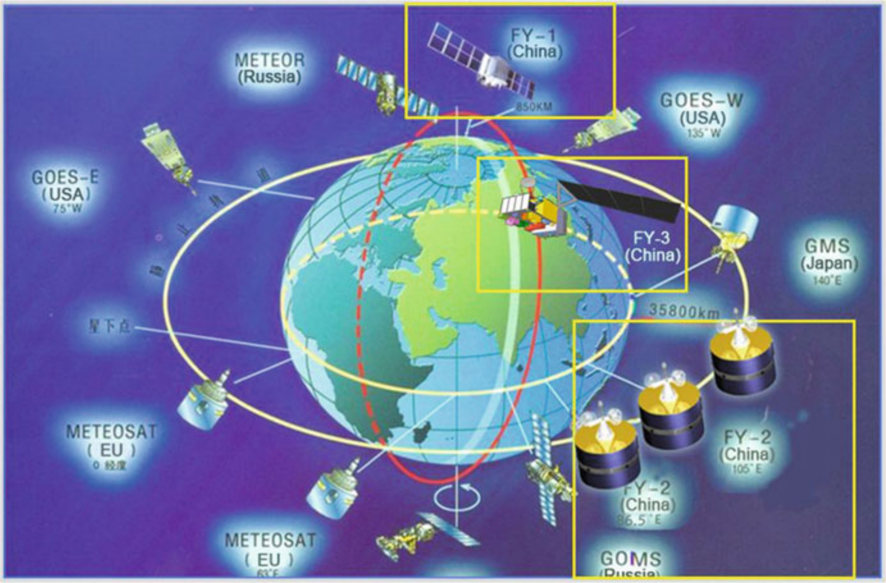

**Fig. 50.1** Fengyun series satellites listed among the WMO satellites

series, plus a small satellite constellation for environmental and disaster monitoring and forecasting.

Fengyun satellites are now capable of providing global, three-dimensional, and multispectral quantitative observation. The Fengyun-2 GEO meteorological satellite succeeded in double satellite observation and in-orbit backup; while the Fengyun-3 polar orbit meteorological satellite succeeded in networking observation of morning and afternoon satellites. Fengyun series satellites have been listed among the World Meteorological Organization (WMO) operational satellites (Fig. 50.1).

According to China's oceanic administration, China aims to establish ocean water color satellites, ocean dynamics environmental satellites, and ocean monitoring satellites, namely Haiyang-1, Haiyang-2, and Haiyang-3 satellite series. China successfully launched two ocean water color satellites (Haiyang-1 A and B) in 2002 and 2007, respectively, establishing a complete ocean remote sensing ground application system. The first Haiyang dynamics environmental satellite, launched in August 2011, is capable of all-weather and full-time microwave observation.

In 1999, the first China-Brazil Earth Resources Satellite (also known as Ziyuan-1), jointly developed by China and Brazil, was successfully launched. Previously, China had developed and launched eight resources satellites with much better spatial resolution and image quality (Fig. 50.2). On 9 January 2012, the Ziyuan-3 stereo survey satellite was successfully launched.

China has also developed recoverable and data transmission-type mapping satellites. Between 1975 and 2006, China launched and recovered 23 recoverable

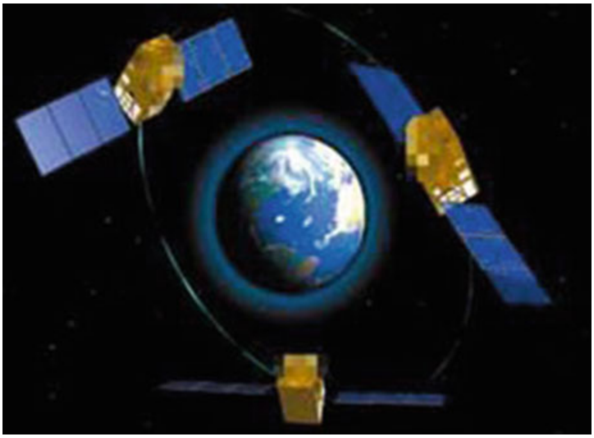

**Fig. 50.2** Three Ziyuan-2 satellites networking

**Fig. 50.3** Huanjing A/B satellites are undergoing testing

satellites. All mapping satellites now being used are data transmission-type satellites. More than 10 satellites in the Yaogan and Tianhui series have been launched.

The small satellites constellation for environmental and disaster monitoring and forecasting is now capable of disaster monitoring with medium resolution, wide coverage, and high revisit rate. It is comprised of two optical satellites and one SAR (synthetic-aperture radar) satellite, providing dynamic monitoring of disasters, ecological damage, and environmental pollution. Huanjing-1 A/B satellites were launched in 2008 (Fig. 50.3).

China is building a high-resolution Earth observation system based on satellite, stratospheric airship, and aircraft, perfecting the corresponding ground system to establish a data and application center. Combined with other observation means, this system will provide all-weather and all-time global Earth observation capability. By 2020, China will have established its advanced land-atmosphere-ocean Earth observation system to provide services and decision-making support for such areas as modern agriculture, disaster mitigation, resources and environment, and public security.

The application fields and scope of Earth observation satellites have been constantly expanding, and business services capabilities have also been growing. An Earth observation satellite application system has taken its initial shape. China has built four new satellite ground stations, enhancing its ability to receive data from meteorological, ocean, and land observation satellites. Based on comprehensive planning, China has also established the ground data processing system for Earth observation satellites, extending its ability in centralized data processing, data archiving, data distribution, and services provision. China has established centers for environmental satellite application, satellite disaster-relief application, satellite mapping application, and other application institutes for Earth observation satellites, promoting the spread and utility of Earth observation satellite data. China has improved calibration services of remote-sensing satellite radiation calibration fields, enhancing the quantitative application level of Earth observation satellites.

Today, Earth observation satellite data has been widely used in various fields for economic and social development. Fengyun satellites have effectively monitored typhoons, floods, forest and grassland fires, droughts, sandstorms, and other natural disasters; their weather forecasting and climate change monitoring capabilities have also been enhanced remarkably. The ocean satellite series has monitored China's maritime territory and the world's key ocean areas. Their forecasting accuracy for sea ice, ocean temperatures, and wind fields has increased greatly, and their time efficiency in monitoring dangerous sea conditions has also been notably enhanced. The resource satellite series has played an important role in efforts to investigate, monitor, and manage the resources of land, minerals, agriculture, forestry, and water, as well as geological disasters and city planning. Remote-sensing and Tianhui satellites have played an important role in scientific experiments, land censuses, mapping, and other fields. The small satellites constellation for environmental and disaster monitoring and forecasting has provided critical technical support for surface water quality and atmospheric environmental monitoring, major pollution events disposal, and major natural disaster monitoring, assessment, and relief.

### 50.2.2 Communications and Broadcasting Satellites

China has developed three generations of DFH series communications satellite platforms, namely DFH-2, DFH-3, and DHF-4. The first three-axis-stabilized DHF-3 communications satellite with medium capacity was launched in 1997,

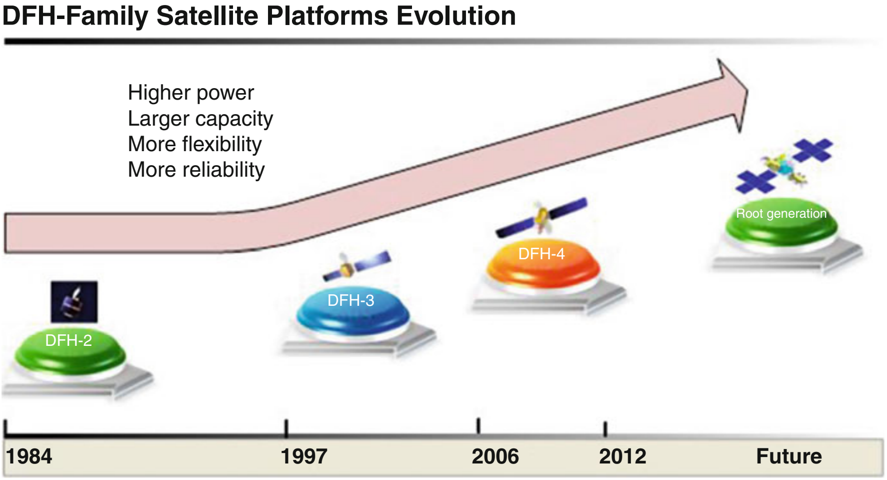

**Fig. 50.4** The evolution of DFH satellite platforms

and the first DHF-4 communications satellite, Sinosat-2, with high capacity was launched in 2006.

By the end of 2011, China had successfully launched more than 30 GEO communications satellites, including

- 9 DFH-2/2A satellites;
- 20 DFH-3 satellites, 5 of which have exceeded 8 years of design life and are now still in operation; and
- 8 DFH-4 satellites.

In the coming years, China will launch another 20 GEO communications satellites (Fig. 50.4).

China has made breakthroughs in the key technologies of high-capacity GEO satellite common platform, space-based data relays, and tracking, telemetry, and command (TT&C), showing remarkable improvement in the technical performance of its satellites and in the application level of voice, data, radio, and television communications. The successful launching and stable operation of the Zhongxing-10 (Chinasat) satellite indicates a significant increase in the power and capacity of China's communications and broadcasting satellites. The successful launch and stable operation of the Tianlian-1 (Space Chain) data relay satellite shows that China has preliminary capability of both space-based data relays and space-based TT&C.

China has steadily promoted the applications of communications and broadcasting satellites and cultivated a certain scale market. It has improved its satellite radio and TV network, and in 2008 China established a satellite service platform to provide every village with access to direct broadcast and live telecasts. It also implemented satellite broadcasting and transmissions of China National Radio and China Central Television programs and one channel program of provincial radio and TV stations, thus greatly increasing the radio and TV program coverage.

China has strengthened development of its satellite tele-education broadband network and tele-medicine network, mitigating the shortage of education and medical resources in remote and border areas. China has also strengthened its satellite capacity in emergency communications, providing important support for rescue and relief work and for major disaster management.

Commercial communications satellites developed by China have successfully entered the international market with increasing competitiveness of the associated satellite products. China has exported complete satellites and provided in-orbit delivery of communications satellites to Nigeria, Venezuela, and Pakistan and has signed commercial satellite and ground system export contracts with Bolivia, Laos, Belarus, and other countries.

### 50.2.3 Navigation and Positioning Satellites

In the early 1980s, China began to actively study the navigation satellite systems in line with China's conditions. In 2000, the BeiDou Navigation Demonstration System was established, making China the third nation to possess an independent navigation satellite system, following the United States and Russia. China has been steadily accelerating the construction of the BeiDou Navigation Satellite System and had successfully launched 13 satellites by the end of April 2012.

The BeiDou system is comprised of three major components: space constellation, a ground control segment, and user terminals. The space constellation consists of five GEO satellites and 30 non-GEO satellites. The GEO satellites are positioned at 58.75°E, 80°E, 110.5°E, 140°E, and 160°E, respectively. The non-GEO satellites include 27 MEO satellites and three IGSO satellites. The MEO satellites operate in an orbit with an altitude of 21,500 km and an inclination of 55° and are evenly distributed in three orbital planes. The IGSO satellites are operating in an orbit with an altitude of 36,000 km and an inclination of 55°, which are evenly distributed in three inclined geo-synchronous orbital planes. The subsatellite tracks for the three IGSO satellites coincide, while the longitude of the intersection point is at 118°E, with a phase difference of 120°.

Upon the full system completion, the BeiDou Navigation Satellite System can provide positioning, velocity measurement, and timing services to worldwide users. It can also provide wide area differential services with the accuracy better than 1 m and short messages services with the capacity of 120 Chinese characters each time. The functionality and performance parameters are as follows:

- Main functions: positioning, velocity measurement, one-way and two-way timing, short messages
- Service area: global
- Positioning accuracy: better than 10 m
- Velocity accuracy: better than 0.2 m/s
- Timing accuracy: 20 ns (Fig. 50.5)

Along with the construction of the BeiDou Navigation Satellite System and the development of the RNSS services, the BeiDou System has been widely used in

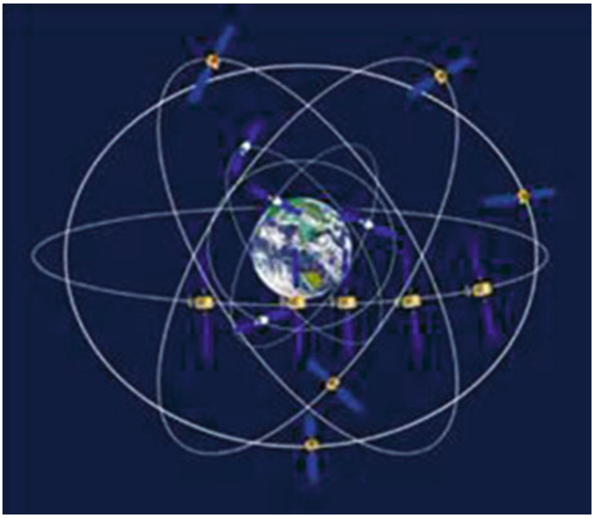

**Fig. 50.5** China's BeiDou Navigation Satellite System

transportation, marine fisheries, hydrological monitoring, weather forecasting, forest fire prevention, timing for communication systems, power distribution, disaster mitigation, national security, and many other fields, resulting in significant social and economic benefits. Particularly, the system has played an important role in the South China frozen disaster; earthquake relief in Wenchuan, Sichuan Province, and Yushu, Qinghai Province; the Beijing Olympic Games; and the Shanghai World Expo.

China's international exchange and cooperation in the field of satellite navigation began in the 1990s. Over the last 20 years, various activities have been carried out with extensive outcomes. The BeiDou Navigation Satellite System adheres to open and friendly international relations and carried out extensive exchanges and consultation with countries possessing navigation satellite systems to promote compatibility and interoperability between global navigation satellite systems (GNSS). Extensive exchange and cooperation with countries that do not have navigation satellite systems has also taken place in order to share the benefits of navigation satellites with them.

### 50.2.4 Scientific and Technological Test Satellites

China has developed and launched a series of scientific and technological test satellites, conducted numerous new technology validation tests and space environment exploration missions, and acquired valuable data on space environment, solar activity, and the Earth's magnetic field. China is steadily advancing its work on space debris mitigation, enhancing monitoring and early warning of space debris, and studying space debris mitigation technology.

**Fig. 50.6** The Tance-1 satellite, part of the Double-Star Program

### 50.2.4.1 "Shijian" (Practice) Series Satellites

China has developed and launched "Shijian" series satellites to explore the space environment's major parameters and effects. China has also carried out space experiments in life science, materials science, fluid mechanics, and other fields under conditions of microgravity and strong radiation, as well as new space technology demonstration. On 15 June 2010, the Shijian-12 satellite was successfully launched.

### 50.2.4.2 Double-Star Program

China has implemented the Double-Star Program to explore the Earth's magnetosphere in concert with the Cluster Program of the European Space Agency (ESA), obtaining much new scientific data and making important progress in space physics (Fig. 50.6).

## 50.3 Future Prospects

In the coming years, China will strengthen its basic capacities in the space industry, accelerate research on cutting-edge technologies, and continue to implement important space scientific and technological projects, including human spaceflight, lunar exploration, a high-resolution Earth observation system, a satellite navigation and positioning system, and other projects with high priority in the key fields. China will develop a comprehensive plan for construction of space infrastructure, promote its satellite and satellite applications industry, conduct further space science research, and push forward the comprehensive, coordinated, and sustainable development of China's space industry.

China will build a space infrastructure frame composed of Earth observation satellites, communications and broadcasting satellites, and navigation and positioning satellites, and will develop a preliminary capability of long-term, sustained, and stable service. China will develop new types of scientific satellites and technological test satellites.

### 50.3.1 Earth Observation Satellites

China will improve its existing meteorological, oceanic, and resource satellite series and its small satellite constellation for environmental and disaster monitoring and forecasting. It aims to develop and launch new-generation GEO meteorological satellites, stereo mapping satellites, radar satellites for environment and disaster monitoring, electromagnetic monitoring test satellites, and other new-type Earth observation satellites. It will make breakthroughs in key technologies for interferometric synthetic-aperture radar and gravitational field measurement satellites. It will initiate a high-resolution Earth observation system as an important scientific and technological project and establish a stable all-weather, 24-h, multi-spectral, various-resolution Earth observation system.

China will continue to expand cooperation with other countries regarding its resource survey satellites, so as to maintain the continuity of remote sensing data with medium resolution. China will also develop new GEO optical and microwave remote sensing satellites, as well as Earth resource remote sensing satellites with higher spatial resolution.

China will develop high-performance stereo mapping satellites, improve global geographic information access capabilities, and establish an independent and complete mapping satellite system step-by-step.

China will construct a meteorological satellite fleet based on HEO satellite FY-4 and LEO satellite FY-3, improve observation accuracy, frequency, and flexibility and further improve the accuracy of short-time and short-term weather forecasting, as well as dynamic monitoring capability of global environmental change.

China will develop HY-1 morning and afternoon satellites, HY-3 ocean monitoring satellites, and follow-up satellites, in order to enhance monitoring capability, shorten revisit period, form a complete ocean remote-sensing satellite fleet, and achieve stable operation.

China will launch an S-band SAR satellite Huanjing-1 C, along with Huanjing-1 A and B satellites, to establish the first all-weather, multi-means environment and disaster monitoring system. China will further increase the number of satellites and expand the scale of the constellation, in order to provide dynamic monitoring of the environment and disasters for China and its neighboring countries.

China will improve its ground facilities for receiving, processing, distributing, and applying satellite data and will strengthen the development of calibration fields

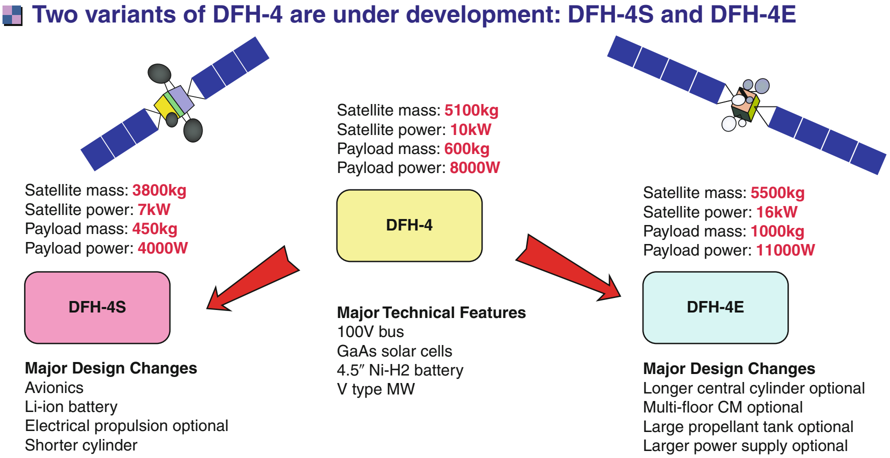

**Fig. 50.7** DFH-4 family

and other facilities. It will improve the observation data sharing and comprehensive applications, make more self-providing space data, and guide social resources to actively develop market-oriented data application services. It will implement application demonstration projects and promote the wide utilization and industrialization of Earth observation satellites.

### 50.3.2 Communications and Broadcasting Satellites

China will further develop fixed communications satellites, television broadcasting satellites, data relay satellites, mobile communications satellites, and the next-generation GEO communications and broadcasting satellite platform with higher capacity and power. The DFH-4 enhanced version (DFH-4E) and more powerful DFH-5 will be put onto the market in the next few years (Fig. 50.7).

China will further strengthen the application of communications and broadcasting satellites in the field of public services and key industries of the national economy, while expanding the value-added services in satellite communication areas, so as to promote the commercialization process of satellite communication and expand the industrial scale of communications and broadcasting satellite applications.

### 50.3.3 Navigation and Positioning Satellites

Based on a three-step development plan, from an experimental system to a regional system and then to a global system, China will continue building its BeiDou Satellite Navigation System, implementing a regional BeiDou Satellite Navigation

System before 2012, whose navigation and positioning, timing, and short-message services will cover the Asia-Pacific region. China aims to complete the global BeiDou Satellite Navigation System by 2020, and it will comprise five GEO satellites and 30 non-GEO satellites.

China will build and improve ground TT&C segments; develop a system for monitoring and assessing the performance of the global satellite navigation system; strengthen technology research, product development, and the standardization system of navigation and positioning satellites; enhance application level; promote position-based services; expand the industrial scope; and focus on promoting further use of the BeiDou Satellite Navigation System in various fields of China's national economy.

### 50.3.4 Scientific and Technological Test Satellites

In the next few years, China will further develop scientific and technological test satellites, strengthen the development of its space science research system, upgrade the quality of space science research, and enhance the popularity of space science knowledge in the whole nation.

China will develop and launch a hard X-ray modulation telescope satellite, Shijian-9, a test of new technology and recoverable satellites. It will begin to implement projects with a quantum science test satellite and dark matter probing satellite.

Using scientific satellites and deep-space probes, China will study the properties of black holes and physical laws under the extreme conditions, explore the properties of dark matter particles, and test basic theories of quantum mechanics. It will also conduct scientific experiments on microgravity and space life science explore and forecast the space environment, and study its effects.

## 50.4 International Exchanges and Cooperation

China will adhere to the fundamental principles stated in the "Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries." China maintains that international exchanges and cooperation should be strengthened to promote inclusive space development on the basis of equality and mutual benefit, peaceful utilization, and common development.

In recent years, China has implemented international space exchanges and cooperation in various ways. It has signed a number of cooperation agreements and memoranda on the peaceful utilization of outer space with many countries, space agencies, and international organizations. China has taken part in relevant activities sponsored by the United Nations and other international organizations and has supported international space commercial cooperation. These measures have yielded positive results. China has taken part in activities organized by the United

Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) and its Scientific and Technical Sub-committee and Legal Sub-committee. China has cooperated with the space institutes of various countries through the mechanism of the "International Charter on Space and Major Disasters." China participates in activities organized by the International Committee on Global Navigation Satellite Systems, International Space Exploration Coordination Group, Inter-Agency Space Debris Coordination Committee, Group on Earth Observations, World Meteorological Organization, and other intergovernmental international organizations. China has also developed multilateral exchanges and cooperation in satellite navigation, Earth observation, Earth science and research, disaster prevention and mitigation, deep-space exploration, space debris, and other areas. The nation's independently developed space debris protective design system has been incorporated into the satellite protection manual of the Inter-Agency Space Debris Coordination Committee.

## 50.5 Conclusions

China is stepping into space with more confidence. Through independent development efforts in developing application satellites and satellite applications, China has made positive contributions to space exploration.

China is also strengthening innovation capability in space science and technology. It focuses on implementing important space projects to realize leapfrog development in space science and technology by way of new breakthroughs in core technologies and resource integration. China is actively building an innovative space technology system featuring integration of the space industry, the academia and the research community, and space science and technology enterprises and research institutions as the main participants. It has strengthened basic research in the space field and multiple advanced frontier technologies to increase sustainable innovative capacity in space science and technology.

China advocates the peaceful use of space around the world and cooperation with other countries to develop satellite programs based on the principals of mutual respect, mutual benefit, and equality.

**Acknowledgments** The author acknowledges the contributions of experts from the China Aerospace Science and Technology Corporation (CASC) and the China Academy of Space Technology (CAST).

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# The Japanese Space Launch Program

# 51

Mamoru Endo

## Contents

**Abstract**

This chapter provides the fundamental information of Japanese launch program. The Japanese solid and liquid launch systems have been developed step by step and attained the world class in technology and reliability. These several years, the Basic Space Law was enacted and the Basic Plan for Space Policy was

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established at a policy level, placing greater importance on national security and industrial promotion. This is drastically changing the situation around the development and operation of space transportation systems in Japan including determination of developing the next-generation flagship launch vehicle by the 2020s in order to ensure autonomous access to space in the future. This chapter provides, firstly, the historical overview of solid and liquid launch vehicles as background. Secondly, the administrative and management structures of launch program are described referring to some political documents and technology management processes. Thirdly, launch program development, which has been promoted by the government, JAXA, academia and industry, is described. Fourthly, the outline, performance, and vehicle configuration of current launch vehicles are described in detail. In addition, authors present the privatization through technology transfer and the support subprogram as launch vehicle exploitation. Finally, the future prospects are discussed.

## 51.1 Introduction: Historical Overview of Launch Vehicles in Japan

Over 50 years period, Japanese space launch program has progressed mainly for space science and space utilization. It is unique in the world in that the program had been promoted only for peaceful purposes.

Japan’s national space programs were being conducted under the leading management role of two organizations: for the space science area, the Ministry of Education’s Institute of Space and Astronautical Science (ISAS) which was originally founded at the University of Tokyo in 1964, and for the space applications area, the National Space Development Agency of Japan (NASDA) which was established under the Science and Technology Agency in 1964.

These two organizations, together with the National Aerospace Laboratory of Japan (NAL), were merged into on October 1, 2003, creating a core space agency, the Japan Aerospace Exploration Agency (JAXA). JAXA promotes space related activities from basic research to development and utilization in a comprehensive manner.

Against the above-mentioned background, Japan’s launch vehicles have been developed step by step on two characteristic flows: solid and liquid propellants.

### 51.1.1 Solid Launch Vehicle

In ISAS, the research on solid propellant rockets of Japan started with a horizontal launch experiment of tiny pencil-size rockets more than 50 years ago, conducted by Professor Itokawa’s research group. From the very beginning, Japan’s research and development of solid propellant launchers was conducted independent of foreign technologies and aimed only at space science missions. Such endeavor was finally rewarded in 1970 when Japan's first artificial satellite "Ohsumi" was launched by a four-stage Lamda-4S rocket. Japan's third-generation solid rocket launcher, M-3SII, lifted Japan's first planetary spacecraft "Sakigake" in 1985.

In the mid-1990s, the M-V rocket became available to meet the strong demands for 2-ton class full-scale scientific missions planned in the late 1990s and early 2000s and contributed to Japan's space science in almost all its fields from space astronomy to even planetary missions. After lifting its first payload, the world's first radio-astronomy satellite "HALCA", in 1997, the vehicle launched the world's first asteroid sample-return spacecraft "HAYABUSA" in 2003 directly into its interplanetary trajectory. The spaceship carried back samples of the asteroid "Itokawa" to the Earth. The asteroid is named after Japan's pioneer of rocket development. This epoch making achievement was the result of a combination of the highest-performance M-V and the high-performance HAYABUSA. In February 2006, when it put the sun-synchronous satellite, the vehicle demonstrated the world's best performance and became the only solid rocket launcher that can be utilized for both interplanetary and sun-synchronous missions "AKARI" into orbit. The operation of the M-V rocket was terminated in September 2006 mainly due to its relatively high operational cost after launching Japan's second solar observation satellite "HINODE" into a solar synchronous transfer orbit (Morita et al. 2009). The history of solid launch vehicle is shown in Fig. 51.1.

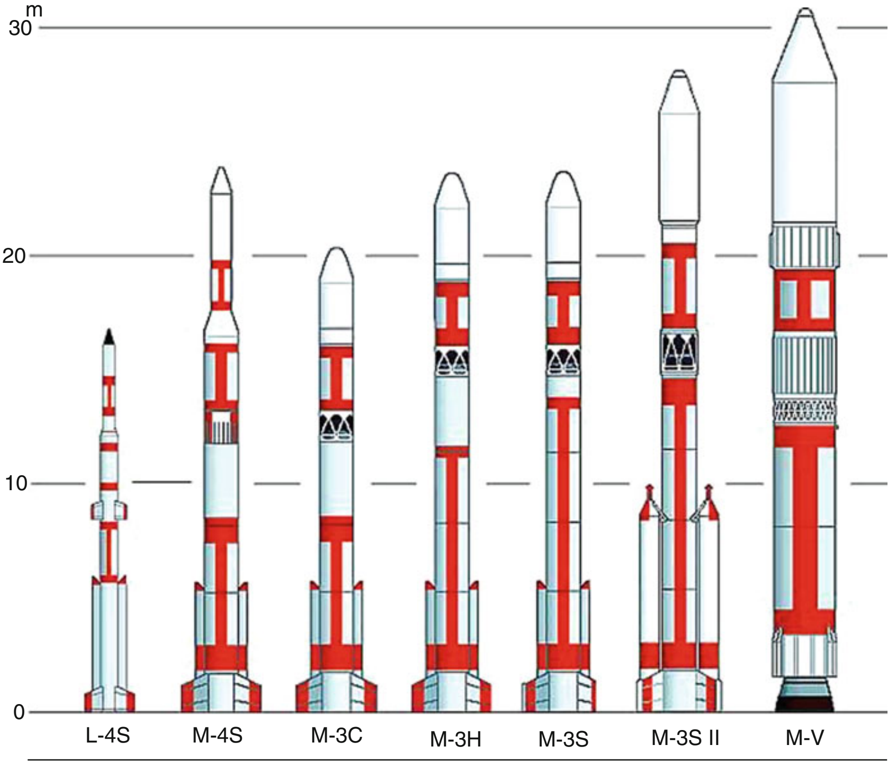
### 51.1.2 Liquid Launch Vehicle

Since 1969, NASDA developed and operated launch vehicles to support domestic missions including those for communications, broadcasting, and Earth observation. The N-series rocket (N-I and N-II), Japan's first liquid rocket booster, and the H-I rocket were developed based on the US Delta rocket technology transferred through intergovernmental agreements. Specifically, major components of the N-series rocket and the first stage of the H-I rocket are direct derivatives from the US Delta rocket technology.

From 1975 through 1987, the N-series rockets launched 15 medium-sized domestic application satellites. The missions launched by the N-I and N-II were mostly successful. It is noteworthy that the technology was established to the degree where satellites were able to be placed into Geostationary Earth Orbit (GEO) through the N-series rocket program.

The H-I launch vehicle was a three-stage vehicle capable of launching a 550-kg payload into GEO and developed based on both the US and Japanese technology. The development efforts were concentrated on high-performance upper stages while its first stage, including strap-on boosters, uses the same license-produced components as the N-II.

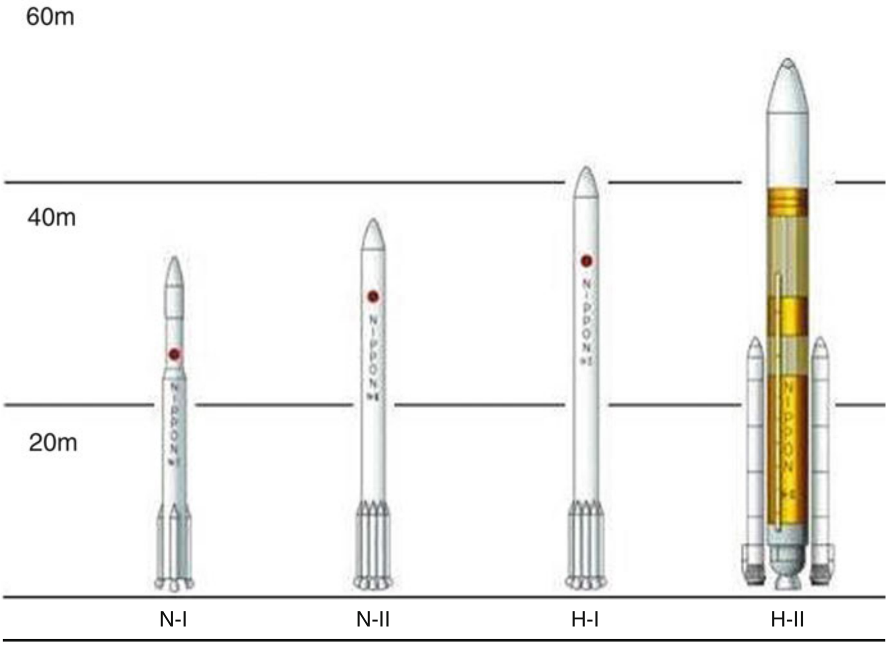
The domestically developed upper-stage technology contributed to the new H-II rocket development program. To meet the demands of Japan's satellite users for



| | L-4S | M-4S | M-3C | M-3H | M-3S | M-3SII | M-5 |
|---|---|---|---|---|---|---|---|
| Stages | 4 | 4 | 4 | 4 | 4 | 4 | 3 |
| Length (m) | 16.5 | 23.6 | 20.2 | 23.8 | 23.8 | 27.8 | 30.8 |
| Diameter (m) | 0.77 | 1.41 | 1.41 | 1.41 | 1.41 | 1.65 | 2.5 |
| Capacity to 185 km (kg) | 26 | 180 | 195 | 290 | 290 | 780 | 1,800 |
| First Flight | 1966 | 1970 | 1974 | 1977 | 1980 | 1985 | 1997 |

**Fig. 51.1** History of solid launch vehicle

placing large-capacity application satellites into orbit in the 1990s, NASDA developed the H-II launch vehicle based on domestic technology. It was a two-stage vehicle augmented by a pair of large solid rocket boosters and capable of placing a 2-ton payload into GEO. H-II launch vehicle was successfully developed and launched in 1994 (Shibato and Kuroda 2005). The evolution of liquid launch vehicle is shown in Fig. 51.2. The technologies acquired through the development and operations of the H-II launch vehicle were carried on to the successor, H-IIA.



| | N-I | N-II | H-I | H-II |
|---|---|---|---|---|
| Stages | 3 | 3 | 3 | 2 |
| Length (m) | 32.6 | 35.4 | 40.3 | 50 |
| Diameter (m) | 2.4 | 2.4 | 2.44 | 4.0 |
| Capability to GTO (ton) | 0.25 | 0.7 | 1.1 | 4.0 |
| First Flight | 1975 | 1981 | 1986 | 1994 |

**Fig. 51.2** Evolution of liquid launch vehicle

## 51.2 Launch Program Description

In Japan, national access to space capability is defined in the Basic Space Law which was enacted in May 2008, as “Article15: The State shall take measures to promote the research and development of necessary equipment (including parts thereof) and technologies and to establish the facilities and installations, to ensure the availability of radio frequencies with regard to Space Development and Use as well as to take other necessary measures, in consideration of the fact that it is important for the State to have the capability to independently develop, launch, track and operate artificial satellites, etc.”

Based on the Basic Space Law, the Basic Plan for Space Policy was established as the national comprehensive strategy by the Strategic Headquarters for Space

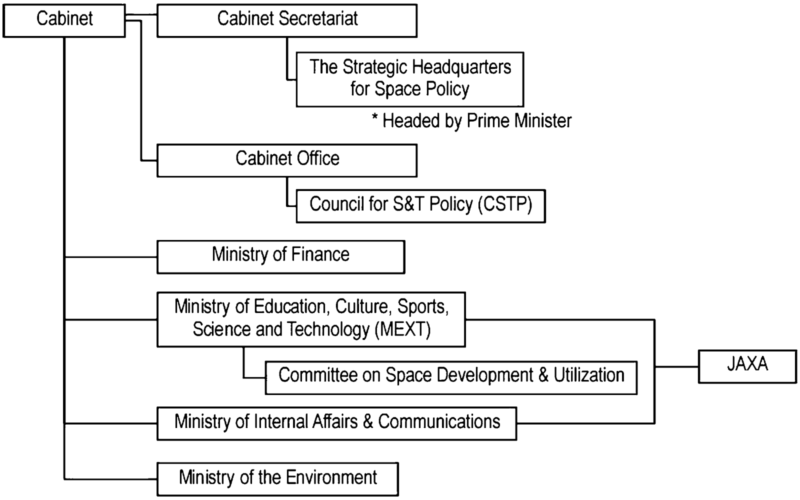


**Fig. 51.3** The administrative structure of Japanese space development

Policy. It describes the basic policy and the measures which the government should take as a 5-year program foreseeing the next 10 years saying that "the space transportation system is an essential technology to allow Japan to launch satellites to space independently as needed" (Strategic Headquarters for Space Policy 2009).

Moreover, industrial policy is also described as "to maintain independent space activities and reinforce international competitiveness toward increase of sales in the space equipment industries such as satellites and rockets, it is necessary to maintain and reinforce a basis for competitive power such as base technologies and facilities usable for industries in consideration of international market competitiveness" and "to maintain the ability to launch necessary satellites to space independently, domestically-developed rockets will be used basically when launching government-affiliated satellites like other countries. Also, Government will encourage the use of domestically -developed rockets when Japanese private companies launch their satellites" (Strategic Headquarters for Space Policy 2009).

The specific measures are as follows:

- Establishment of transportation system associated with the development and utilization plan of satellites
- Maintenance and development of base technologies
- Research and development of future transportation system
- Promotion of maintenance and development of launch sites

Under the policy above mentioned, the government, related agencies, and industries fulfill each role. The administrative structure of Japanese space development is shown in Fig. 51.3.

The Strategic Headquarters for Space Development, headed by the Prime Minister, is established in the Cabinet Office and promotes measures with regard to Space Development and Use comprehensively and systematically.

JAXA is an independent administrative agency which is administrated by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and another couple of Ministries. JAXA has been positioned as the core organization that provides technical support for the governmental development and utilization of space.

JAXA has a number of objectives: facilitating the academic research, enhancing the level of space science and technology and promoting the space development and utilization. These aims are pursued by conducting in collaboration with universities, relevant organizations and industries.

Concerning the launch program, JAXA conducts the launch, tracking, and operation of satellites as well as the development of methods, facilities, and equipment necessary for this purpose. This is mentioned in the related law concerning JAXA.

JAXA's budget is allocated through MEXT after deliberation and approval by the National Diet. JAXA's activity is supervised and reviewed including technical issues by MEXT and Ministry of Internal Affairs and Communications(MIC).

## 51.3 Launch Program Development

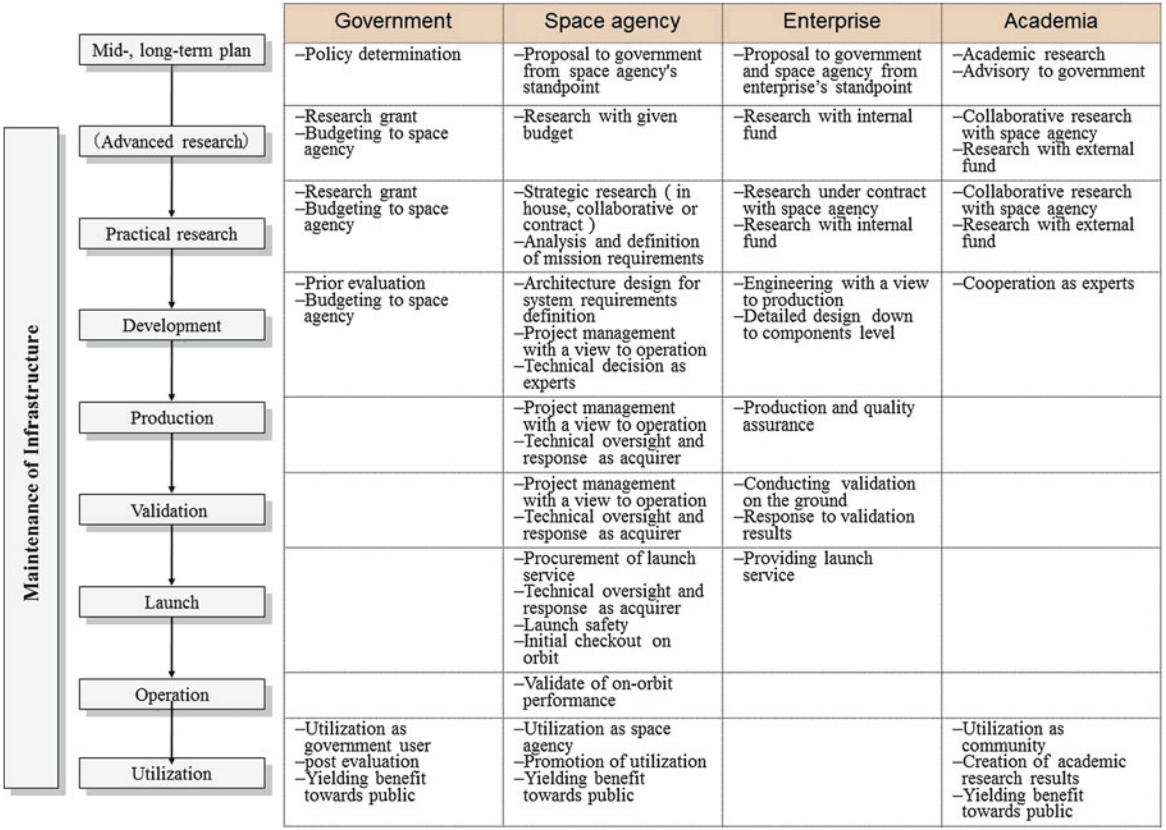
The key technologies of launchers are maintained and evolved by the government and JAXA in cooperation with academia and industry. Figure 51.4 shows the value chain analysis of Japanese space development (Okada 2010).

### 51.3.1 Technology Roadmap and Research Management

In order to continue successful missions and creating cutting-edge technologies, the process for establishing and operating a technological roadmap is required under strategy and research management. JAXA maintains an integrated technology roadmap, which forecasts the future technology trends for the next two decades and acquires specific technologies for the next decade offering the basic information. The objectives of the roadmap are:

- To show the consistent research and development (R&D) strategy throughout a mission
- To define core technologies of JAXA in comparison with the level and trend in the world
- To provide information that can be shared with anyone concerned within JAXA to promote the efficiency and diversification of R&D activities
- To share the understanding of the direction of aerospace technologies in Japan by showing it to the authorities, communities, organizations, and companies concerned.

Figure 51.5 outlines the description of the roadmap, which includes required technologies for a mission, milestones, and some external and internal analysis such as trend prediction and portfolios.



| | Government | Space agency | Enterprise | Academia |
|---|---|---|---|---|
| Mid-, long-term plan | –Policy determination | –Proposal to government from space agency's standpoint | –Proposal to government and space agency from enterprise's standpoint | –Academic research<br>–Advisory to government |
| (Advanced research) | –Research grant<br>–Budgeting to space agency | –Research with given budget | –Research with internal fund | –Collaborative research with space agency<br>–Research with external fund |
| Practical research | –Research grant<br>–Budgeting to space agency | –Strategic research ( in house, collaborative or contract )<br>–Analysis and definition of mission requirements | –Research under contract with space agency<br>–Research with internal fund | –Collaborative research with space agency<br>–Research with external fund |
| Development | –Prior evaluation<br>–Budgeting to space agency | –Architecture design for system requirements definition<br>–Project management with a view to operation<br>–Technical decision as experts | –Engineering with a view to production<br>–Detailed design down to components level | –Cooperation as experts |
| Production | | –Project management with a view to operation<br>–Technical oversight and response as acquirer | –Production and quality assurance | |
| Validation | | –Project management with a view to operation<br>–Technical oversight and response as acquirer | –Conducting validation on the ground<br>–Response to validation results | |
| Launch | | –Procurement of launch service<br>–Technical oversight and response as acquirer<br>–Launch safety<br>–Initial checkout on orbit | –Providing launch service | |
| Operation | | –Validate of on-orbit performance | | |
| Utilization | –Utilization as government user<br>–post evaluation<br>–Yielding benefit towards public | –Utilization as space agency<br>–Promotion of utilization<br>–Yielding benefit towards public | | –Utilization as community<br>–Creation of academic research results<br>–Yielding benefit towards public |

**Fig. 51.4** Value chain analysis of Japanese space development

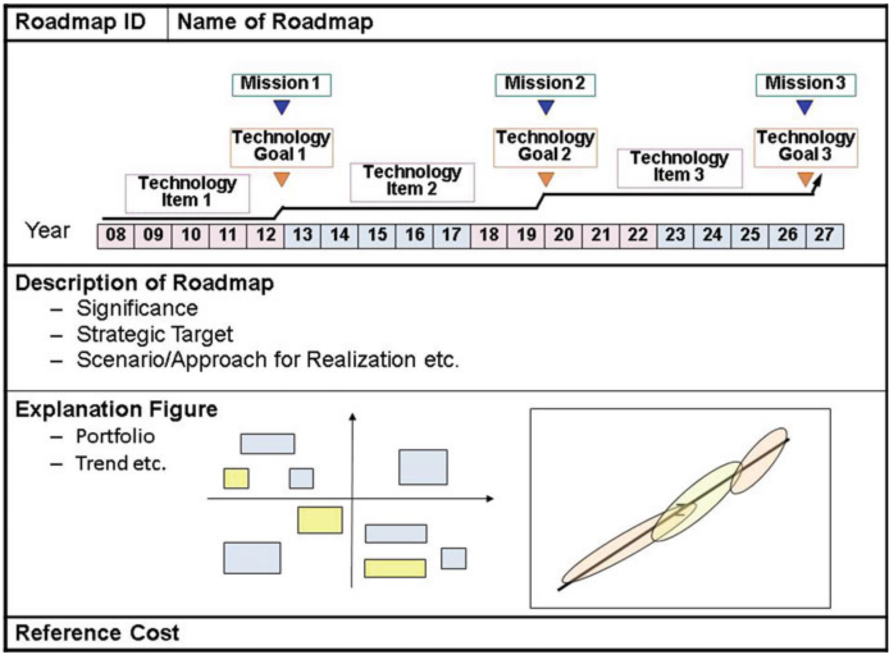


**Fig. 51.5** Description outline of JAXA technology roadmap

According to the technology roadmap, the research management is conducted at an agency level to "enhance research quality for future missions" by overseeing the entire field with a broad perspective while keeping transparency, objectivity, and fairness.

Researches are categorized into two types: the cutting-edge researches and the strategic researches. The researches on future transportation systems such as reusable systems and in-orbit systems are typically conducted by the former category. In the latter category, the researches are directly linked to the current or near future space transportation systems with the aim of improving and enhancing them.

## 51.3.2 Interuniversity Research Promotion System

In order to contribute space science in Japan, JAXA fulfills a role in interuniversity research promotion system. This system provides researchers with large experimental equipment, knowledge base and core functions/opportunities for network-type collaborative research as a center of academic research. Under the Space Engineering Research Committee, the steering body for the interuniversity research promotion system, several working groups are established and investigate future missions.

**Fig. 51.6** H-IIA launch vehicle No.1

## 51.4 Launch Vehicle Description

### 51.4.1 Current Launch Vehicles

There are two types of launch vehicles in Japan. They are liquid launch vehicles: H-IIA, H-IIB, and the solid launch vehicle Epsilon. An overview of these launch vehicles is provided below.

### 51.4.2 H-IIA

#### 51.4.2.1 Outline

The H-IIA is a Japan's flagship launch vehicle which consists of liquid oxygen/ liquid hydrogen cryogenic core stages with strap-on solid rocket boosters. The H-IIA was developed based on the earlier H-II technology, with the objectives of reducing launch costs, meeting various launch capability requirements, and ensuring reliability. The launch costs of a model with the same launch capability as the H-II has now been cut down to about half of the H-II. There are two variant configurations in operation. These are the H2A202 and the H2A204. The last number, 2 or 4, represents the number of the strap-on solid boosters.

Since the H-IIA launch vehicle's successful maiden test flight in August 2001 (shown in Fig. 51.6), a total of 22 H-IIA launch vehicles were launched until 2013. Except the Flight No.6, which was the only unsuccessful flight, a total of 21 H-IIA have been successfully launched, reaching the success rate of about 95 %.

After the technical transfer from then NASDA, Mitsubishi Heavy Industries, Ltd. (MHI) has provided the launch services and JAXA has been responsible for flight safety, range safety, and facilities since 2007.

The H-IIA is in a steady operation phase. As the first step toward the national flagship launch system in the next generation, upgrade of the H-IIA has started aiming at improving the vehicle's Geostationary Transfer Orbit (GTO) mission capabilities and payload environment conditions. This enables Japan to promote R&D and utilization of space, as well as to enhance the international competitiveness of the H-IIA launch vehicle.

#### 51.4.2.2 Performance

The standard GTO capability of the current H-IIA is 4 tons and 6 tons for H2A202 and H2A204 respectively. For the Geo-Synchronous Orbit (GSO), H-IIA has a standard delta-V of 1,800 m/s. The upgraded H-IIA decreases the delta-V to the international standard (1,500 m/s) with longer coast time and the third burn of the upper stage engine. The launch capability is expected to be about 3 tons and 4.5 tons for H2A202 and H2A204 respectively (Nakamura et al. 2010).

#### 51.4.2.3 Vehicle Configuration

The H-IIA is the Japan's main launch vehicle which consists of liquid hydrogen/liquid oxygen cryogenic, 4-meter-diameter core stages with strap-on solid rocket boosters called as SRB-As.

The engines serve as high-performance propulsion system utilizing liquid hydrogen and liquid oxygen propellants. The H2A202, with 4-meter-diameter single payload fairing, is 53 meters high and weighs 289 tons. Figure 51.7 shows the configuration of the H-IIA in comparison with the H-IIB which is the augmented type of H-IIA.

##### First Stage

The first stage is composed of the following: LOX tank, LH2 tank, center body section, interstage section, single LE-7A engine, and avionics system. Both propellant tanks use aluminum alloy isogrid structures with single-piece elliptical domes and PIF insulation. The LE-7A engine provides 1,100 kN of thrust with staged-combustion cycle which is the same as the Space Shuttle Main Engine (SSME). Encompassed is one of the highest-performance engines in the world and its specific impulse in vacuum is 440 seconds. The fuel turbo-pump is operated at around 40,000 rpm which runs over the third critical speed. The oxidizer turbopump is operated around at 18,000 rpm. The LE-7A is a modified model of the LE-7 engine of H-II with improved reliability and operability, while retaining most of the characteristics and performance of the LE-7 engine. Two or four solid rocket boosters (SRB-A) are attached to the first stage in order to augment the LE-7A engine thrust during ascent phase.

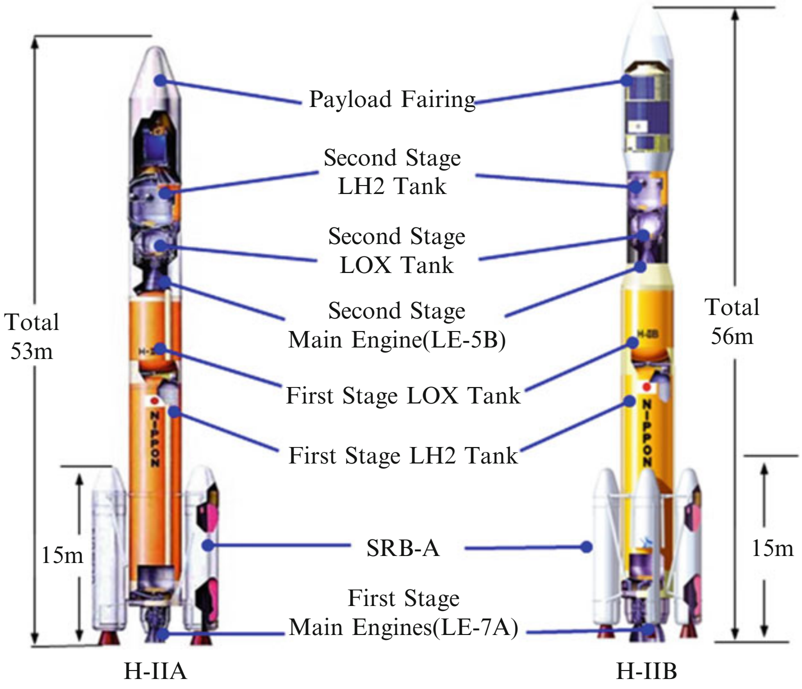


**Fig. 51.7** Configuration of H-IIA and H-IIB launch vehicle

### Second Stage

The second stage consists of the following: LOX tank, LH2 tank, highly reliable cryogenic LE-5B engine, and avionics system installed on the equipment panel. The LE-5B engine is a modified model of the LE-5A engine of H-II, with improvements in reliability and operability, enhancing the thrust from 121 kN to 137 kN. This engine is able to operate at 60 % of the rated thrust and has the world's premier multiple restart capability to meet various mission requirements. The LE-5B engine adopts a chamber expander bleed cycle, which operates the turbines by heating the hydrogen gas only in the chamber section. It realizes an inherently safe (without uncontained failure), reliable, and low-cost system.

The LH2 propellant tank uses the same aluminum alloy isogrid structure, insulation, and cryogenic technology as the ones of the first stage. The LOX propellant tank is made by welding two elliptical spun formed tank domes.

Attitude control is ensured by using reliable electromechanical actuators of the LE-5B engine and the hydrazine gas-jet reaction control system (RCS).

The RCS is also used for propellant settling of the second stage, before and after the spacecraft separation. The RCS is mounted under the component equipment panel of the guidance section and uses hydrazine as its propellant. Most components of the avionics system are mounted on the component equipment panel.

### Solid Rocket Booster

The H-IIA launch vehicle has two or four strap-on SRB-As that burn HTPB solid propellant. This provides extra thrust as the rocket accelerates through the atmosphere from liftoff for approximately 100 seconds for the H2A202, and 120 seconds for the H2A204.

The SRB-A is redesigned based on the solid rocket technology of the H-II SRB to enhance its reliability and operability. The motor case of the SRB-A is monolithic, made out of filament winding composite material (CFRP) using ATK Thiokol's Castor technology, and manufactured in Japan. The chamber pressure is twice as high as the earlier H-II SRB in order to enhance the launch capability. This high chamber pressure results in a larger nozzle expansion ratio, which means a higher specific impulse, and a smaller nozzle assembly. It also enables the use of an electromechanical thrust vector control (TVC) system for gimbaling the nozzle.

### Payload Fairing

The payload fairing protects the spacecraft from environments to which the spacecraft is exposed from the time of encapsulation to the atmospheric ascent phase. The main structure is a bonded sandwich panel using a very thin aluminum skin and a lightweight honeycomb core which realizes a significant weight reduction.

Three types of payload fairing (4-meter-diameter single/dual and 5 meter single) are available. Each type is compatible with the H2A202 and H2A204.

### Inertial Guidance and Avionics System

The H-IIA launch vehicle uses the same strap-down inertial guidance system as the H-II, consisting of an inertial sensor units (ring laser gyro) and a guidance control computer. The inertial guidance system computes the flight direction and the velocity of the rocket and corrects, if any, automatically the deviations. Thus, it is controlling the entire vehicle during the flight in order to reach the designated orbit (JAXA 2012a).

Each liquid stage has a Guidance and Control Computer (GCC). The computer boarded on the second stage (GCC2) conducts the checkout and control of the second stage in addition to the guidance and navigation of the vehicle. The GCC1 which is installed on the first stage checks out and controls the first stage and the SRB-As. The GCCs are linked by a data bus, which meets MIL-STD-1553B.

Most of the data processing equipment is mounted on the second stage, and the output of the control signal to the equipment is performed by the GCC2. The programs installed on the GCC1 are controlled by the program loaded on the GCC2.

The major functions of the second stage avionics have redundancy to maintain high reliability during mission time. In order to conduct the checkout of the vehicle efficiently, major packages have built-in-test functions which the GCCs can monitor.

### Launch Complex and Operation

The launch operations of the H-IIA are carried out in the Tanegashima Space Center (TNSC) located at the southeastern end of Tanegashima Island.

**Fig. 51.8** Yoshinobu launch complex in TNSC

The TNSC is the largest rocket range in Japan and accommodates a number of facilities necessary to launch a spacecraft. There are two launch pads in the Yoshinobu launch complex of TNSC, as shown in Fig. 51.8. The first one has been modified to host only the H-IIA and the second one is newly constructed for the launch of both H-IIA and H-IIB. The vehicle is assembled, checked, mated to payload/payload fairing in the Vehicle Assembly Building (VAB). On the day of the launch, the vehicle is then moved to the launch pad and is launched after terminal operations including the final checkout and filling up with cryogenic propellants. The VAB has the capacity to check out two vehicles at the same time. It takes about one month to assemble and to check out for launch (NASDA 1997).

#### Downrange Facilities

The launch vehicle tracking and telemetry data are received by the ground stations of JAXA. These are located on Tanegashima Island, Okinawa Island, Ogasawara Island, and Christmas Island of the Republic of Kiribati. If needed, the Santiago Downrange Station in Chili can be used with the cooperation of Chili University (NASDA 1997).

### 51.4.3 H-IIB

#### 51.4.3.1 Outline

The H-IIB is the largest launch vehicle in Japan, consisting of liquid oxygen/liquid hydrogen cryogenic core stages with four strap-on solid rocket boosters. The H-IIB

**Fig. 51.9** H-IIB launch vehicle No.2

launch vehicle has two major purposes. The first one is to launch the H-II Transfer Vehicle "KOUNOTORI" (HTV) to the International Space Station (ISS). HTV is Japan's "cargo ship" which does not only carry the necessary daily commodities for the astronauts but also transports experimental devices, samples, spare parts, and other necessary items. The second purpose is to respond to broader launch needs by making combined use of both H-IIA and H-IIB launch vehicles. In addition, the H-IIB's larger launch capability makes it possible to perform the simultaneous launch of more than one satellite and reduces costs. This contributes to ensuring the vitalization of the Japanese space industry (JAXA 2012b).

The H-IIB has been developed based on the H-IIA technology. The maiden flight of H-IIB/HTV was launched successfully from the Tanegashima Space Center in September 2009. The H-IIB launch vehicle was jointly developed by JAXA and Mitsubishi Heavy Industries, Ltd. (MHI). MHI concluded the basic agreement with JAXA according to a public-private joint development principle.

The H-IIB is expected to open the door to new possibilities for future missions (Figs. 51.9 and 51.10).

#### 51.4.3.2 Performance

The H-IIB launch vehicle has the capability to inject 16.5 tons of payload into the HTV injection orbit (apogee altitude: 300 km, perigee altitude: 200 km, inclination: 51.65°), and approximately 8 tons of payload into GTO. The GTO missions are considered cost-effective launches for dual satellites.

**Fig. 51.10** KOUNOTORI (HTV) No.2

### 51.4.3.3 Vehicle Configuration

The H-IIB launch vehicle is a two-stage launch vehicle that uses liquid oxygen and liquid hydrogen as propellant. Its overall length is approximately 56 m (with a fairing for the HTV), and its gross mass is approximately 531 tons at launch (Ishikawa et al. 2009).

The components of H-IIB are intended to maintain and improve the reliability of the launch vehicle and increase the efficiency of the launch operation by adopting, or modifying parts common to the H-IIA launch vehicle.

#### First Stage

The H-IIB has two liquid rocket engines (LE-7A) in the first-stage, instead of one for the H-IIA. It has four SRB-As attached to the body, in comparison to the standard version of the H-IIA which had two SRB-As.

In addition, the H-IIB's first-stage body has a diameter of 5.2 m in contrast to the 4 m of the H-IIA's. The total length of the first stage has been increased by 1 m from that of H-IIA. This enhancement results in H-IIB being able to load 1.7 times more propellant than H-IIA.

Clustering several engines, whose performance is already fixed, has the advantage of shortening the period and reducing the cost for development (JAXA 2012b).

#### Second Stage

The second stage of H-IIB is almost the same as that of H-IIA. In addition, for the H-II Transfer Vehicle "KOUNOTORI" (HTV), launched by the H-IIB, a controlled reentry of the H-IIB second stage was introduced already since its second flight in order to deorbit the second stage safer after completing its mission.

**Payload Fairing**

The extended 5-meter-diameter fairing based on H-IIA's is equipped for the H-IIB which is utilized for "KONOTORI" and other larger payloads.

## 51.4.4 Epsilon Rocket

### 51.4.4.1 Outline

The Epsilon rocket is a solid propellant rocket suitable for a new era. The purpose of the Epsilon rocket is to launch small satellites responsively. This means that it is focused on a low-cost, user-friendly, and ultimately efficient launch system and is aiming to take advantage of the increasing need for small satellites with a compact launch system. It is based on the earlier M-V Launch Vehicle which was a multistage solid propellant rocket with the best performance in the world (discontinued in 2006). The performance is further improved, allowing more frequent launches with largely reducing operational costs through enhancing efficiency of operations such as assembly and inspection. The increased launch opportunities will make space development activity to accelerate. The biggest goal of the Epsilon rocket is to make space more accessible through making rocket launches easier.

The attention should also be paid to the innovative design concept of Epsilon. It aims at developing the next-generation technologies such as the autonomous checkout system and the mobile launch control. Such novel ideas will not only put the Epsilon rocket at the forefront but will also bring transportation technologies to higher level. They will be also applied to the H-IIA rocket and may eventually be seen as part of world standards after the development of Epsilon. In addition, the simplified launch control may be seen as indispensable technology of future reusable rocket systems. Thus, the concept of Epsilon is beyond the scope of mere solid propellant rockets. The Epsilon rocket aims at achieving the innovative transportation technologies that can be equally applicable to liquid fuel rockets as well as future space transportation systems (Morita et al. 2011).

### 51.4.4.2 Performance and Vehicle Configuration

The Epsilon rocket has two types of launch configurations. The first has three stages, each of which consists of a solid propellant motor like the M-V rocket. The second also has three stages with an optional tiny post-boost stage (PBS) on the third stage. By using this option, a wide variety of orbits including sun synchronous orbit, that small satellites require, can easily become within the reach. In addition, the accuracy of the trajectory injection can be increased to as high as that of liquid propellant rockets, much better than that of the M-V rocket. It should be noted that the orbit insertion precision of solid propellant rockets is, in general, lower than that of the liquid propellant launchers simply because the total impulse of the last stage

| | Standard Configuration | Optional Configuration |
|---|---|---|
| Propellant | Three-staged Solid | Three-staged Solid<br>+Compact Liquid Propulsion |
| Launch Vehicle | | |
| Length (m) | 24 | 24 |
| Mass (ton) | 91 | 91 |
| Launch Capacity | | |
| (LEO) | 1200 kg (250 km x 500 km) | 700 kg (500 km circle) |
| (SSO) | - | 450 kg (500 km circle) |

**Fig. 51.11** Epsilon rocket

of solid propellant rockets cannot be controlled. The typical specifications of the Epsilon rocket is shown in Fig. 51.11.

#### 51.4.4.3 R&D Activities for Future Space Transportation System

Japan has tackled reentry technology for more than 10 years. The core activity had been the HOPE-X project which was led by a NAL/NASDA joint team until JAXA was established on October 1, 2003. The strategy employed in the HOPE-X project

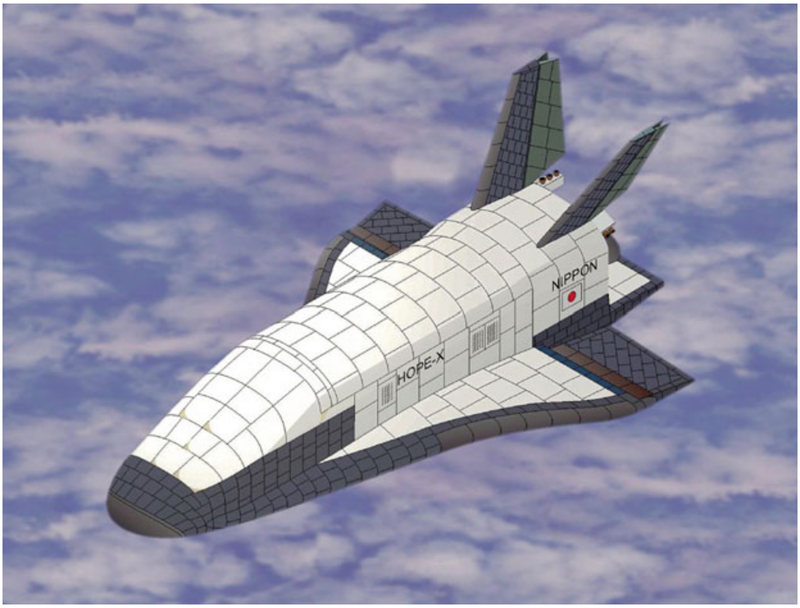


**Fig. 51.12** HOPE-X

was a step-by-step approach through a series of small flight experiments. The HOPE-X vehicle, the final configuration illustrated in Fig. 51.12 is an unmanned experimental mini-shuttle vehicle to be loaded on top of a single-stage H-IIA booster. Unfortunately, the development of a flight model of the HOPE-X vehicle was discontinued in 2001. Consequently no opportunity has been provided to demonstrate overall reentry technology by flying a vehicle throughout the whole flight envelope. However, a satisfactory technology readiness level with respect to reentry has been attained although several technical issues such as real gas effect remain unsolved (Ishimoto et al. 2004).

## 51.5 Launch Vehicle Exploitation

### 51.5.1 Privatization and Technology Transfer of the H-IIA and H-IIB

In 2002, the Council for Science and Technology Policy (CSTP) and Space Activities Commission (SAC) of the Japanese Ministry of Education, Culture, Sports, Science, and Technology (MEXT) decided to privatize the Japanese main launcher, H-IIA. A special team was set up, discussed the privatization of H-IIA, and issued a final report.

Following this report, then NASDA decided to transfer the technology to a private sector and designated Mitsubishi Heavy Industries (MHI) as the prime contractor for the H-IIA launch service by setting up a contract including the condition of the privatization between JAXA and MHI. The transfer was finalized in March 2007, followed by the first privatized mission carrying JAXA's satellite "SELENE (Kaguya)" on board in September 2007 (Morikawa 2011).

The main users of the H-IIA are the Japanese government and JAXA. Typical missions of Japanese government are meteorological satellites of the Ministry of Land, Infrastructure, and Transport and information-gathering satellites of the Cabinet Secretariat. Furthermore MHI succeeded in its first commercial launch of the Korean Multi-purpose Satellite 3 (KOMPSAT-3) of the Korea Aerospace Research Institute (KARI) in 2012.

Concerning the H-IIB, the full privatization has completed after the third launch of H-IIB in 2012.

### 51.5.2 Support Subprogram

Although the launch service of the flagship launch vehicle was privatized in order to sustain autonomous access to space in Japan, it is necessary to establish a complete space transportation program and to support it with appropriate government policies. In Japan, as in other countries, there are difficulties concerning succeeding launch systems and technologies maintaining industrial base of production and operation and meeting changing requirements of missions flexibly and responsively.

Therefore the following measures should be implemented in an integrated and systematic support program:

1. Enhancement of reliability
   - Technical data accumulation by acquisition of extensional flight data
   - Quality assessment of key components
   - Parts replacement program
2. Maintenance of infrastructures and facilities
   - Maintenance of infrastructures and facilities for manufacturing and launching
   - Renewing aging facilities
3. Core technology R&D and system study for future missions

## 51.6 Future Prospects

The Strategic Headquarters for Space Policy promoted discussions for the revision of the Basic Plan for Space Policy in view of giving priority to the policy issues under constrained fiscal conditions. In the discussions, it is mentioned that keeping a certain number of launch opportunities is necessary to maintain the industrial base and suggested that the government investigate possible support measures for acquiring commercial missions in addition to the government missions. It is also suggested that a development strategy, including international cooperation, be investigated from the aspect of sustaining the technology development capabilities of launch vehicle and an internationally competitive system.

**Fig. 51.13** Concept of the next-generation flagship launch vehicle

Following the policy mentioned above, the development of the next-generation flagship launch vehicle (Ohkubo et al. 2011) which will renovate the launch system infrastructure of Japan in the 2020s were determined in June of 2013. The major purposes of the vehicle are as follows (Ohkubo et al. 2011):

- To save the total cost on space transportation program
- To possess the world's highest competitiveness
- To have a potential of upgrading to manned system
- To increase international collaboration for international cooperative exploration

The extremely high reliability is one of the design concepts of the next-generation flagship launch vehicle which answers the purposes mentioned above. The high reliability design process method and base are also the prospective key elements leading to the future transportation system such as reusable systems like aircrafts. In other words, the next-generation flagship launch vehicle is the first step toward future transportation systems.

On the other hand, cutting-edge technologies such as advanced thermal protection system are required for future space transportation systems. In order to achieve maximum effect under the budgetary constraints Japan is facing, it is necessary to efficiently manage the R&D of the next-generation flagship launch vehicle and future transportation system. Figure 51.13 shows one of the concepts of the next-generation flagship launch vehicle. These discussions took place at the policy level in 2013.

## 51.7 Conclusions

This chapter has provided the main information of the past and present Japanese launch programs and presented the trends for the future of Japanese launch program.

The government, JAXA, and industries cooperate with each other in order to ensure access to space for the purposes of national security, industrial promotion, and technology/science. They also play their own respective role which is clearly defied according to the Japan's circumstances.

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# The Indian Space Launch Program

# 52

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## Contents

**Abstract**

Dr. Vikram A. Sarabhai initiated the Space Program in India in the 1960s, to utilise the potential of space technology and its applications for national development. With the launch of sounding rocket from the shore of Thumba located in the city of Thiruvananthapuram on November 21, 1963 India entered into the

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space arena. Since then in the last four and half decades, India has made considerable progress in the development of Space Launch Vehicles. The first development of Satellite Launch Vehicle-3 (SLV-3) was initiated in the early 1970s, and in the span of 10 years, it was successfully flown in July 1980 by placing a 40 kg satellite into orbit. This effort helped to understand the intricacies of launch vehicle technologies. Further technology developments in the areas of strap-on booster, bulbous payload fairing, canted nozzles, closed-loop guidance, and overall mission management were mastered in the next development vehicle, Augmented Satellite Launch Vehicle (ASLV) with payload capability of 150 kg. Parallely efforts were on to develop Polar Satellite Launch Vehicle (PSLV) for launching of operational remote sensing satellites into Sun Synchronous Polar Orbit (SSPO). PSLV provided a quantum jump in the development of several critical technologies like large solid motor, earth-storable liquid engines, composite motor case, strapdown navigation system, etc. This vehicle has multi-mission capability with missions such as Low Earth Orbit (LEO), Sun Synchronous Polar Orbit (SSPO), and Geo Transfer Orbit (GTO). and also has provision to carry multiple satellites. During the same period ISRO initiated the development of Geosynchronous Launch Vehicle (GSLV) with three stages, employing solid, liquid, and cryogenic propulsion modules for launching 2t class of operational communication satellites into GTO. Initially a procured cryogenic stage from Russia was used for the upper stage. At the same time, the technology developments needed for cryo-engine and stage systems were undertaken. The engine was successfully qualified through a series of ground tests, short and long duration at different levels. The cryo-stage is flight tested successfully in January 2014. For launching 4 t class of communication spacecraft the development of GSLV Mk-3 was initiated. It is a three-stage vehicle consisting of a large solid propellant booster, liquid stage with clustered engines, a high thrust cryo-engine operating in gas generator cycle, and lightweight composite structures. One of the important missions accomplished in the recent past is the launch and recovery of a Space capsule Recovery Experiment (SRE). This mission enabled to master the re-entry technologies and recovery procedures required for the design of future.

## 52.1 Introduction

It was the vision of Dr. Vikram A. Sarabhai who initiated the Space Program in India in the 1960s, to utilize the potential of space technology and its applications for national development. The Indian space endeavor started with a modest beginning with the launch of sounding rocket from Thumba on November 21, 1963. Since then in the last four and half decades, India has made considerable progress in the development of Indian Space Launch Vehicles. The development of Satellite Launch Vehicle-3 (SLV-3) was initiated in the early 1970s, and in the span of 10 years, success was achieved in July 1980 by placing a 40 kg satellite into orbit. The developmental effort of SLV-3 helped immensely to understand the intricacies of launch vehicle technologies. Augmented Satellite Launch Vehicle (ASLV) with payload capability of 150 kg enabled further technology developments in the areas of strap-on booster, bulbous payload fairing, canted nozzles, closed-loop guidance, and overall mission management. Parallely Indian Space Research Organisation (ISRO) took the challenging task of developing Polar Satellite Launch Vehicle (PSLV) for launching of operational remote sensing satellites into Sun Synchronous Polar Orbit (SSPO). PSLV provided a quantum jump in the development of critical technologies like large solid motor, earth-storable liquid engines, composite motor case, strapdown navigation system, etc. This vehicle became a versatile platform for the host of missions such as Low Earth Orbit (LEO), Sun Synchronous Polar Orbit (SSPO), and Geo Transfer Orbit (GTO). The capability of PSLV to carry 1.3 t to GTO was also established with the launch of Chandrayaan-1 recently. This vehicle has provision to carry multiple satellites with multi-mission capability. Concurrent to the development of PSLV, ISRO initiated the development of Geosynchronous Launch Vehicle (GSLV) with three stages, employing solid, liquid, and cryogenic propulsion modules for launching 2 t class of operational communication satellites into GTO. Initially a procured cryogenic stage from Russia was used for the upper stage. At the same time, the technology developments needed for cryo-engine and stage systems were undertaken. The engine has been successfully qualified through a series of ground tests, short and long duration at different levels. The cryo-stage was successfully flight tested in January 2014. GSLV Mk-3 was initiated to meet the demands of the launching 4 t class of communication spacecraft. It is a three-stage vehicle consisting of a large solid propellant booster, liquid stage with clustered engines, a high thrust cryo-engine operating in gas generator cycle, and lightweight composite structures. It is expected to provide the cost-effective launch services. Another important mission accomplished in the recent past is the launch and recovery of a Space capsule Recovery Experiment (SRE). This mission helped to master the reentry technologies and recovery procedures required for the design of future reusable launch vehicles.

Several advanced technologies like large semi-cryogenic boosters, air-breathing propulsion, and the development of reusable launch vehicles (RLV) have been undertaken to meet the long-term demands of the country. ISRO has initiated the development of Technology Demonstrator for reusable launch vehicles (RLV-TD), and this vehicle will be flight tested within the next 1 year. As a long-term goal, India has carried out detailed studies on different options and technologies needed for a human space mission. Compared to an unmanned space vehicle, a host of new technologies are required to accomplish such a complex program.

Indian space launch system has achieved the capabilities to launch remote sensing (IRS) and communication (INSAT) series of satellites which are the two major operational space systems in India. The indigenously designed and developed operational launch vehicles, viz., Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV), have launched operational satellites to provide diverse space services in the crucial areas like telecommunication, TV broadcasting, distance education, telemedicine, weather monitoring,

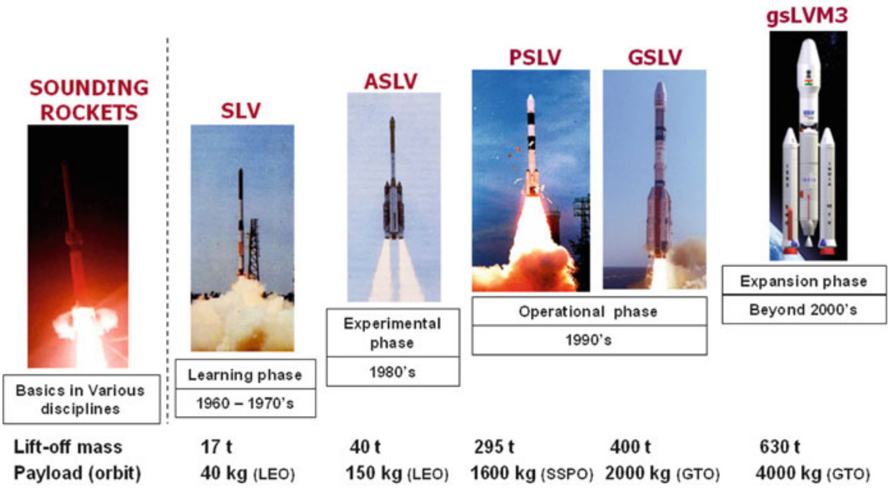


**Fig. 52.1** Evolution of Indian launch vehicles

disaster warning, natural resources management, agriculture, and many more. Up till now PSLV has launched several remote sensing satellites, having the highest payload mass of around 1.8 t in Sun Synchronous Polar Orbit (SSPO). Further, the GSLV has launched four satellites of GSAT type, the heaviest mass of payload being 2.24 t in Geo-stationary Transfer Orbit (GTO). PSLV has also demonstrated its versatility to launch a satellite into GTO. In each of these launches, the orbit injection accuracy has met the stringent specifications laid down as per mission specification. Having achieved operational capabilities, clear roadmap has been laid for the Indian space launch program with technology developments specifically (a) for performance improvement of the operational vehicles and (b) to meet the long-term needs of advanced launch vehicles. Many of the Indian geo-stationary satellites exceed 2.5 t which is beyond present capability of GSLV and is expected to grow from 4 to 4.5 t, in the near future. Noting this demand, ISRO has been working on the development of GSLV Mk-3. This vehicle will have the capability to place payloads of 4 t in GTO and 10 t class in Low Earth Orbit (LEO). This vehicle is targeted to make its first launch in the next 2 years. Currently, developments in launch vehicle technology all over the globe are directed towards reduction in the cost of launch by an order of magnitude. Towards this, ISRO has initiated the development of reusable launch vehicles (RLVs) including the possible use of air-breathing engines. In addition, detailed feasibility studies have been carried out on human space mission to explore new scientific and technological frontiers, which call for human rating of the launch vehicle, for improved safety and reliability. The evolution of the Indian launch systems is given in Fig. 52.1. This chapter presents the progress made so far in the Indian Space Launch Program highlighting the future directions too.

**Table 52.1** Typical satellites, their applications, and preferred orbits

| Applications | Typical mass, kg | Typical orbit range, km | Altitude, km | Velocity, km/s |
|---|---|---|---|---|
| Scientific | 200–500 | 300–500 | 300–500 | 7.67 |
| | | 25–50° inclination | | |
| Remote sensing | 800–1,800 | 500–1,000 circular around 90° inclination | 500–1,000 | 7.45 |
| Telecommunications | 2,000–4,500 | 200–36,000 GTO* | 180–200 perigee | 10.24 |
| | | 0° inclination | | |

## 52.2 Space Craft for Different Applications and Their Demands on Launch Systems

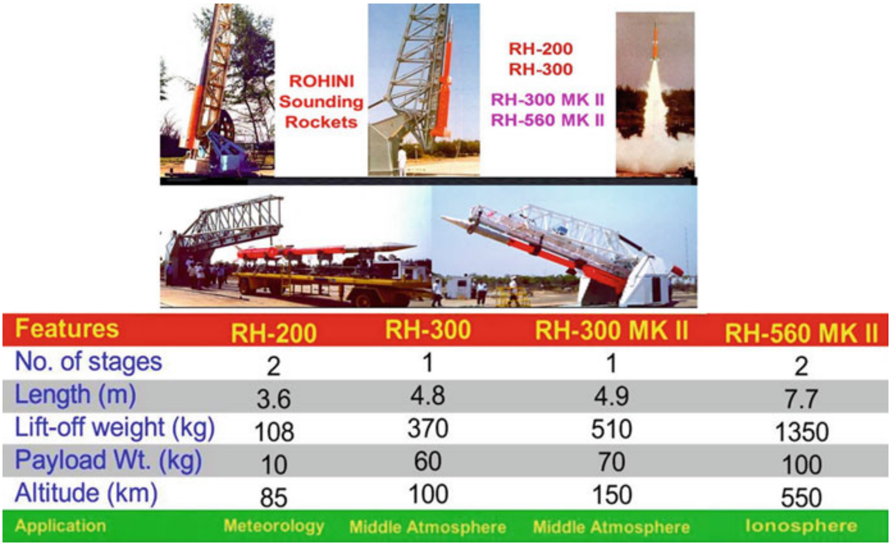
The specific functions of the spacecraft should be defined first to meet the intended application needs, and accordingly its size, weight, payload, and orbit are defined. These are the basic inputs which define the performance characteristics of its launch vehicle. For GTO orbit the launch vehicle has to inject the satellite with perigee of 180–200 km and apogee of 36,000 km. Onboard satellite fuel is used to circularize the orbit to the required altitude. Typical application satellites, their mass, preferred orbits, and orbital injection requirements are given in Table 52.1.

These basic requirements have been considered in the development of Indian launch systems, and development has been specifically focused towards the (1) design of launch system meeting stringent performance specifications, (2) setting up of various required test facilities, (3) vehicle mission management aspects, and (4) establishment of launch complex and post-launch support facilities.

## 52.3 Progressive Development of Launch Systems to Meet the National Needs

The specific approach followed for the development of Indian launch vehicles to meet the demand of the country is given below:

I. Development of increasingly more versatile and complex technologies required to launch heavier satellites with higher injection accuracies
II. Improvements in systems based on the lessons learned from problems faced and failures
III. Retaining the pedigree of already developed stages and technologies to the maximum extent in order to achieve higher reliability and reduce the overall development cost and time
IV. Enhancing the versatility and cost-effectiveness of vehicles by incorporating multiple satellite launch capabilities and deriving their variants to cater to a wider range of autonomous payloads.



| Features | RH-200 | RH-300 | RH-300 MK II | RH-560 MK II |
|---|---|---|---|---|
| No. of stages | 2 | 1 | 1 | 2 |
| Length (m) | 3.6 | 4.8 | 4.9 | 7.7 |
| Lift-off weight (kg) | 108 | 370 | 510 | 1350 |
| Payload Wt. (kg) | 10 | 60 | 70 | 100 |
| Altitude (km) | 85 | 100 | 150 | 550 |
| Application | Meteorology | Middle Atmosphere | Middle Atmosphere | Ionosphere |

**Fig. 52.2** Sounding rockets of ISRO

The development efforts of Indian launch vehicles including the sounding rockets and their specific technical features have been elaborated in the following sections.

### 52.3.1 Sounding Rockets

Indian space launch effort started with the launching of a tiny rocket known as Nike Apache from the shores of Thumba Equatorial Rocket Launching Station (TERLS) located in a city, Thiruvananthapuram, on November 21, 1963. Since then, a wide range of sounding rockets of different sizes have been launched from this range. Figure 52.2 gives a summary of the operational Rohini sounding rockets. These sounding rockets enabled to carry out a host of scientific studies like meteorology, onset of monsoon, equatorial electrojet, D-region of the ionosphere, upper F-region of ionosphere, chemical and mass composition of gases above normal atmosphere, and radiation as the X-rays from space which can be detected only above about 350 km.

### 52.3.2 India's First Satellite Launch Vehicle SLV-3

Based on the technologies developed in sounding rockets, it was decided in the early 1970s to develop a multistage rocket system having the capability of placing 40 kg payload in Low Earth Orbit (LEO). These efforts led to the development of India's first satellite launch vehicle SLV-3. This vehicle was a four-stage vehicle, all using solid propellants. It used fins to have built in aerodynamic stability. A payload fairing protected the satellite from aerodynamic heating. It had an analog autopilot, onboard event programmer, inertial attitude measurement system, and telemetry, tracking, and tele-command avionics. The SLV-3 program indeed helped immensely to develop technologies in diverse disciplines of rocketry. It also gave confidence to take up projects of greater complexities. This project enabled the scientists to develop the comprehensive modeling and simulation of the trajectory of the vehicle from lift-off till the injection of the satellite into orbit. A number of simulations with off-nominal conditions for various vehicle parameters led to mapping of the sensitivity functions, fixing the tolerances to the large number of variables of the vehicle, and subsequently Monte Carlo simulations. All these procedures have become a standard procedure in ISRO for designing a vehicle, clearing it for flight, and for resolving a large variety design and acceptance issues.

Though the first flight test conducted in the year 1979 was not successful, it provided invaluable insight into the design and development of multidisciplinary aspects of launch vehicle systems, various interfaces like launcher to satellite, and launch complex operations, tracking, telemetry, and command networks, among others, paving the way for the smooth operation of the subsequent three successful flights. Intricacies related to a host of critical technical areas of satellite launch vehicles such as solid propulsion, segmented structures for solid propellant motors, flight dynamics related to aerodynamic stability, staging, autopilot, open-loop guidance, control power plants, injection of satellite into orbit, and overall mission management were learned through three successful launches of SLV-3 during 1980–1983.

### 52.3.3 Augmented Satellite Launch Vehicle (ASLV)

Considering the need to achieve higher payload capability for scientific experiments and space applications, Augmented Satellite Launch Vehicle, ASLV, was conceived. This vehicle is basically the augmentation of SLV-3 by adding strap-on motors, which helped to enhance the payload to 125 kg in LEO. The new developments carried out during this phase included strap-on boosters, bulbous payload fairing, canted nozzles, closed-loop guidance, inertial navigation system based on stabilized platform, digital avionics based on M6800 processor, and development of the launch complex facilities required for vertical integration. ASLV met with two successive failures, but detailed failure analysis enabled better understanding of several key technologies. Important ones are the relatively more difficult atmospheric regime of flight in respect of peak aerodynamic pressure, autopilot design, uninterrupted controllability, control-structure interaction, influence of prevailing wind structures, demands for clean stage separation, and real-time event management by in-flight decision making based on onboard observations. It was also decided to add closed-loop guidance even with solid propellant stages for achieving lower dispersions in satellite injection conditions. With two consecutive successful launches of ASLV, many of the critical mission management aspects were mastered.

### 52.3.4 Polar Satellite Launch Vehicle, PSLV

Along with the development of ASLV, the development of PSLV was initiated parallely for launching one tone class of operational remote sensing satellites into Sun Synchronous Polar Orbit, SSPO. It certainly was a quantum jump in technology developments in terms of size and complexity. Figure 52.3 gives the basic configuration of PSLV. It consists of four stages: (a) large solid motor with 139 t propellant loading, (b) earth-storable liquid propellant main engine with 37 t propellant loading, (c) high-performance solid propellant motor with composite motor case in upper stage, and (d) final stage with twin engines of 2.5 t liquid propellant loading. Some of the new technologies introduced in PSLV are engine gimbal control for liquid propellant engines; flex nozzle control for solid propellant rocket motors; digital autopilot; closed-loop guidance with three-axis guided injection, employing a Redundant Strapdown Inertial Navigation System, RESINS; and all digital avionics. A large and heavy mobile service tower provided launch pad assembly and check out facility.

All the PSLV systems functioned well in the first flight conducted in 1993, but the mission could not succeed in injecting the satellite into orbit due to a software implementation error. This led to the strengthening further the ground simulations, additional testing of the vehicle hardware and software systems to its widest probable range of variables, prior to launch.

Out of 23 launches of PSLV till the first quarter of 2013, 22 consecutive launches have been successful, thus demonstrating its reliability. It has also performed versatile missions with different types of orbits and payloads. PSLV has injected satellites with different sizes and mass into a wide range of mission-defined orbits. This versatile vehicle has launched satellites in different orbits like SSPO, GTO,

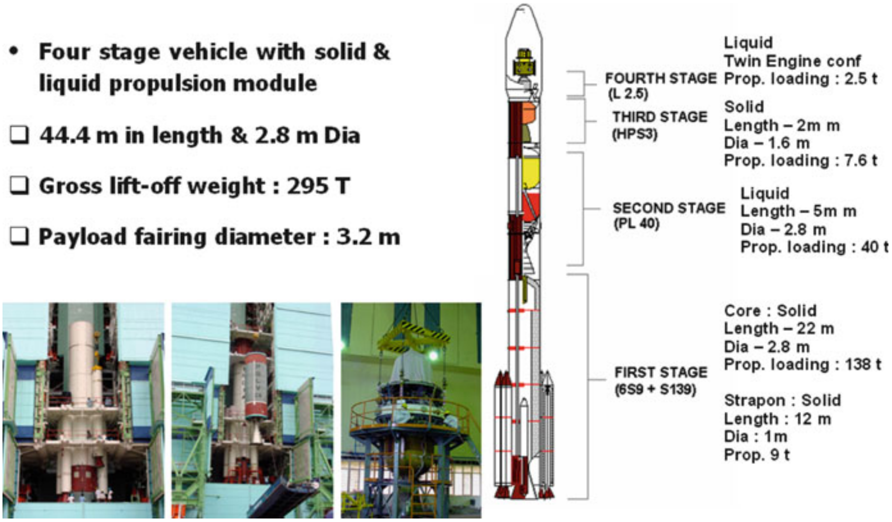


**Fig. 52.3** PSLV configuration

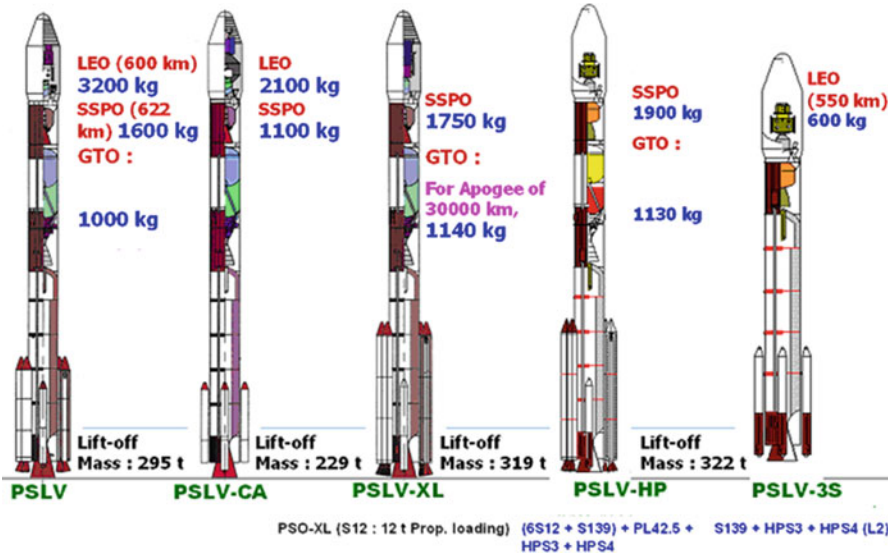


**Fig. 52.4** PSLV variants and payload capability

multi-satellite mission up to ten satellites, multi-orbits in single mission, and several dedicated commercial satellites. In order to optimize the launch cost of PSLV, different configuration variants have been envisaged to cater to different mission requirements as shown in Fig. 52.4. These configurations provide wide variations in payload capabilities ranging from 600 kg in LEO to 1,900 kg in SSPO. Core-alone configuration without strap-on motors is designed to launch two satellites of 400 kg in LEO. The payload capability has been increased on a continuous basis by improving the vehicle performance by (a) extending the propellant loadings of strap-on motors and liquid stages, (b) performance improvement of upper stage, (c) overall inert mass reduction by adopting composite structure wherever feasible, (d) optimization of strap-on firing sequence, (e) miniaturization of avionics packages, etc.

The capability of PSLV to carry 1,000 kg to GTO has also been established with the launch of Kalpana-1 a weather satellite. The existing strap-on motors have been augmented to increase the payload capability, and this extended configuration was used to launch the Chandrayaan-1, the first Indian mission to Moon. The vehicle has provision to carry several micro satellites in the vehicle by having a suitable mix of micro and mini satellites. So far several such small spacecraft from various countries have been launched successfully. A dual launch adapter is available to carry two major satellites of around 500–600 kg.

### 52.3.5 Geosynchronous Satellite Launch Vehicle (GSLV)

Concurrent to the development of PSLV, ISRO initiated the development of the GSLV for launching 2.5 t class of communication satellites into GTO. In order to

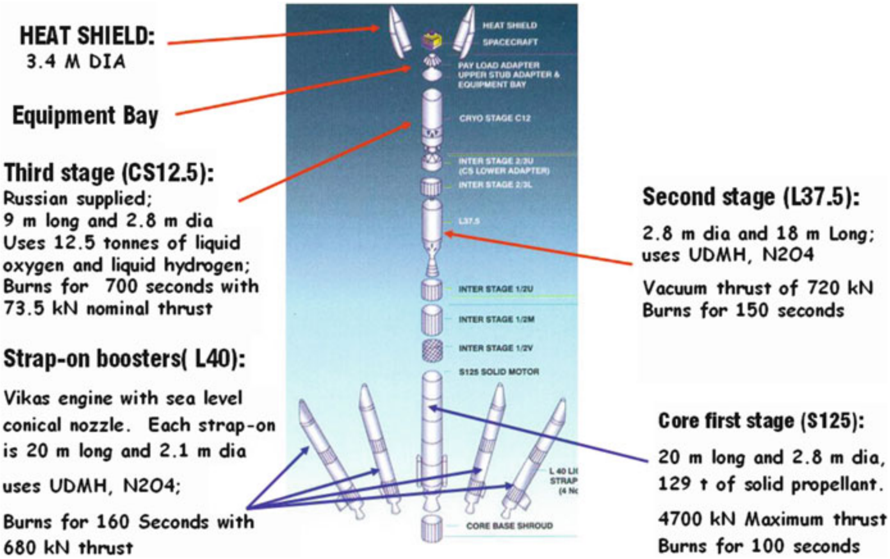


**Fig. 52.5** GSLV configuration

improve the reliability and to maximize the payload capability, the GSLV is configured with only three stages, employing solid, liquid, and cryogenic propulsion modules for its stages, as shown in Fig. 52.5.

GSLV retains the pedigree of many subsystems used in PSLV, to get advantage of higher reliability, reduced development cost and time. The third stage of GSLV is cryo as it delivers higher specific impulse. Initial launches employed procured cryogenic stage from Russia. The total avionics system for Russian cryo-stage for stage and propulsion control such as mixture ratio and thrust regulation has been developed by India and successfully tested in all three flights. GSLV has successfully flown two developmental flights and two operational flights with communication satellites. However, one developmental flight with indigenous cryo and two operational flights failed. The failure analysis indicated certain quality lapses in operational flights. Regarding the failure of the indigenous cryo-stage which was flown in December 2010, the detailed failure analysis brought out specific problems faced by cryo-subsystems in the flight. Necessary corrective actions have been implemented. The modified stage and the engine were successfully flight tested during January 2014.

Starting from the payload of 1,540 kg for the first developmental flight, the payload is systematically improved to 2,250 kg. These improvements were due to propellant loading increase, high-pressure engine for liquid stages, uprating the cryogenic engine thrust, inert mass reduction, trajectory shaping, and equipment mass optimization. The introduction of vehicle steering utilizing the wind structure measured on the day of launch, quite close to the time of launch, has resulted in significant reduction of aerodynamic loads on the vehicle. This procedure and the

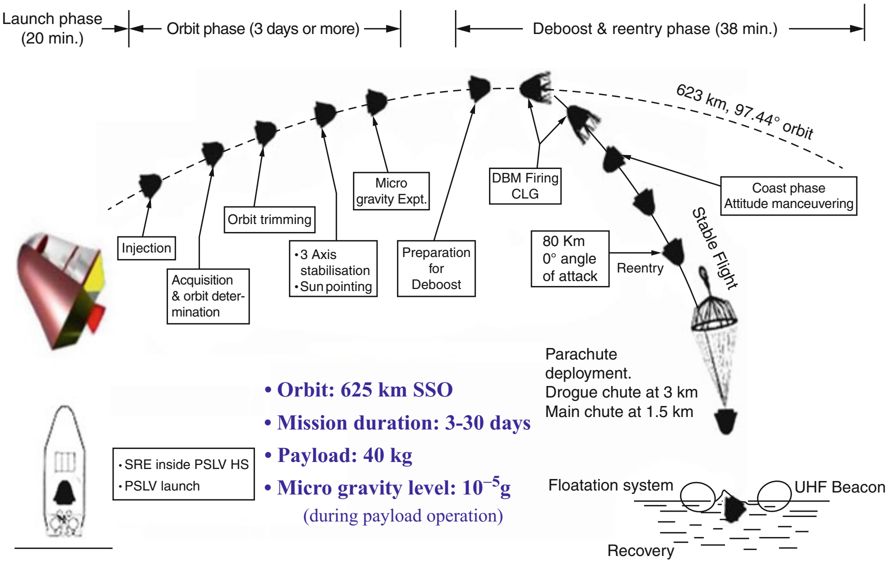


**Fig. 52.6** SRE mission profile

measures to protect the vehicle from rain have made the vehicle an all-weather and all-season launch vehicle.

### 52.3.6 Space Capsule Recovery Experiment (SRE)

Around the early 1990s, after successfully developing the technologies required for expendable launch vehicles and satellites, it was decided to develop a Space Capsule Recovery Experiment (SRE) as a forerunner to meet the future recovery and reentry technological requirements which are required for the future advanced missions including reusable launch vehicles. Accordingly SRE was conceived in 2001 with an objective of developing a recoverable capsule. It was also decided to use this module to conduct orbital microgravity experiments and recover it safely back to Earth at precise location. The mission and capsule development posed a number of challenges, and it demanded the integration of launch vehicle and satellite technologies along with tracking and recovery management. SRE mission was successfully accomplished on January 22, 2007. Figure 52.6 shows the mission profile of SRE.

Some of the important technologies developed include (1) lightweight and reusable thermal protection system; (2) aero-thermal structure design/analysis; (3) hypersonic aerothermodynamics; (4) navigation, guidance, and control of reentry vehicle; (5) deceleration systems; (6) floating systems and recovery systems/operation; and (7) management of communication block out. All these technologies were validated in 2007 in a successful recovery operation of SRE, precisely at the identified location, near the east coast of SHAR in Bay of Bengal.

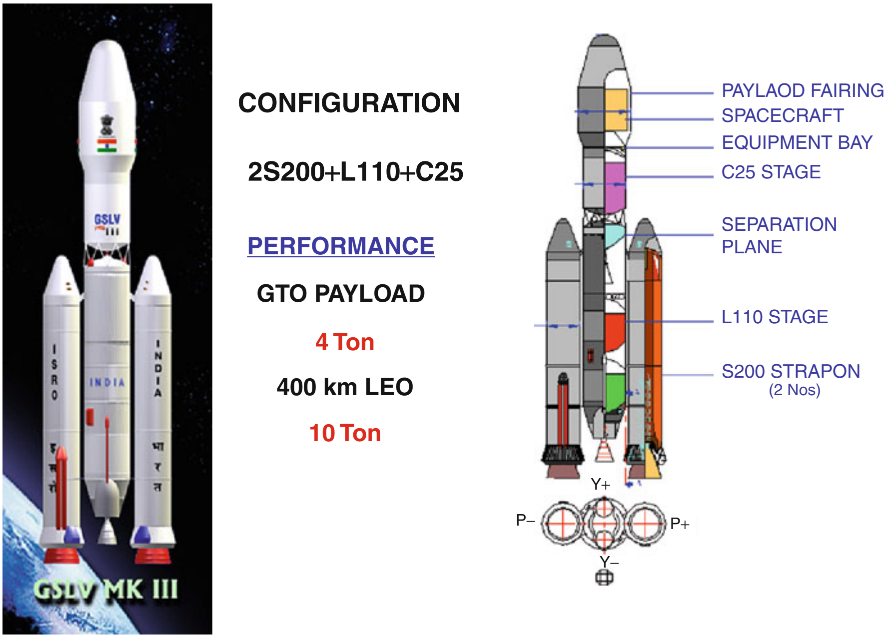


**Fig. 52.7** GSLV Mk-III configuration

**Table 52.2** gsLVM3: propulsion modules

| S-200 | L-110 | C-25 |
|---|---|---|
| • 200 t HTPB propellant system<br>• Flex nozzle control<br>• Contoured nozzle<br>• M 250 motor case<br>• High mass ratio | • 2 Clustered HP engines<br>• UH25, $N_2O_4$ propellants<br>• 196 burn duration | • 18 t Engine in GG cycle<br>• 25 t LOX/$LH_2$ cryo-<br>• 3 burn capability<br>• 4 deg gimballing<br>• Crown cone LOX tank |

### 52.3.7 Geosynchronous Mk3 (gsLVM3) Development

The development of gsLVM3 was initiated to meet the demands of the launching of 4 t class of spacecraft as well as to offer cost-effective launch services. Figure 52.7 shows the configuration of gsLVM3.

It is a three-stage vehicle with two solid strap-on motors of 200 t propellant loading and liquid core of 110 t propellant loading with the clustering of two engines. The upper stage with a cryo-engine has a propellant loading of 25 t. The overall characteristics of the stages are given in Table 52.2. Important technology developments among these are (a) a large solid propellant booster, (b) a flex nozzle control system for the large solid booster, (c) liquid stage with clustered engines, (d) a high thrust cryo-engine operating in GG cycle, (e) composite structures,

(f) improved FDI schemes in avionics and control systems, and (g) miniaturized avionics and TTCP with improved bandwidth. While the development of all subsystems of the vehicle is complete, the cryo-development would take at least one more year due to its complexity. Therefore, to gain the overall experience with respect to overall mission and also to verify the performance of all other critical subsystems including the first and second stages, it has been decided to have an experimental mission with a dummy cryo-stage. This experimental flight will take place within the next 1 year.

## 52.4 Important Facilities Realized During the Development of Indian Launch System

Launch vehicle development demands several facilities at different locations. It is beyond the scope of this chapter to present all such facilities. But some of the important facilities which have played a crucial role in characterizing the overall vehicle and also in the validation of such complex system have been highlighted below.

### 52.4.1 Wind Tunnel Facilities for Characterizing the Vehicle Aerodynamics

The wind tunnel facilities available in the country have been extensively used to generate data in all Mach number ranges including supersonic and hypersonic Mach numbers regime to finalize the configurations and aerodynamic characterization. These data were used extensively for structural and thermal designs, performance evaluation, and control design for all Indian launch vehicles. In addition to the conventional force and pressure measurement tests, special tests such as stage separation tests and aeroelastic tests are also carried out for ensuring the clear stage separation and structural dynamic design of launch vehicles. In order to meet the aerothermodynamics design data generation requirements of future reusable launch vehicles of ISRO, the limited test facilities in the country are being used to generate data in the hypersonic Mach number range of 6–12.

### 52.4.2 Overall Vehicle Simulation Test Facility

ISRO has attached great importance on the development of detailed simulation test facilities for validating and verifying the performance of the vehicle particularly the onboard systems which carry out the navigation, guidance, and control (NGC) functions. The integrated simulation facility has been created with several simulation test beds with multiple computers and real-time operating software. Some of the test beds are (i) onboard computers-in-loop simulations, (ii) aggregated hardware-in-loop simulations, and (iii) actuator-in-loop simulations. A typical facility with all actuators established for this purpose is given in Fig. 52.8.

**Fig. 52.8** Actuators in the loop simulation facility

A major component is an Angular Motion Simulator (AMS) for onboard inertial navigation sensors and systems which simulates the three-axis angular motion of the vehicle during flight. In autonomous simulation, thousands of runs are taken using digital computers to validate the algorithms design and overall system design. Once the system design is validated, the onboard hardware and software with actual processing elements and associated software are tested in detail. Extensive simulations are carried out with both nominal and failure conditions under various environments to evaluate the system performance.

### 52.4.3 Launch Complex Facilities

ISRO has established launch complex at the Satish Dhawan Space Center, SDSC, to cater to the launching of a variety launch vehicles at increasing frequency.

Mobile service tower (MST) and umbilical tower of the First Launch Pad, FLP, permit vertical assembly of a vehicle at launch pad. The FLP shown in Fig. 52.9 can handle both PSLV and GSLV. Facility at FLP comprises launch pedestal, MST, and an umbilical tower, UT. The umbilical tower houses all the fluid lines for propulsion stage servicing. MST is 85 m tall building, fabricated out of structural steel weighing 2,500 t, and provides environmental protection and access to launch vehicle during integration, checks, and servicing. A cryo-arm is provided for servicing the cryo-stage of GSLV vehicle. After completion of vehicle buildup, checks, propellant filling, and countdown activities, the MST is moved back during launch.

**Fig. 52.9** PSLV on First Launch Pad

In order to service increased frequency of launches and to accommodate larger launch vehicle, like gsLVM3, ISRO has built a larger Second Launch Pad, SLP. SLP comprises a Vehicle Assembly Building (VAB) for vehicle build up on a Mobile Launch Pedestal (MLP) and a fixed umbilical tower for servicing and checkouts. After stacking at VAB, the vehicle is moved to UT about a km away. The servicing of the stages, such as pyro arming and checks, is carried out. VAB can withstand cyclonic winds and seismic disturbances.

### 52.4.4 Launch Complex and Launch Support Facilities

Launch complex facilities facilitate the smooth integration of the vehicle and satellite and allow continuous checkout of the integrated vehicle and satellite parameters to ensure that they are within the allowable bands till the launch of the vehicle. The seamless integration of vehicle subsystems is carried out with great care, and detailed checks are carried out at each phase of aggregation. To protect the integrated vehicle and subsystems from the environmental conditions, the gas and fluid filling and checkout operations are carried out through remote control. The computerized checkout system checks all vital parameters of various subsystems. The alignment, calibration, and initialization of inertial systems just before launch and loading of flight-critical input data at the last minute are all totally automated. During the flight, the vehicle is tracked closely till the injection of the satellite into orbit. Also, the telemetry transmits the data with adequate bandwidth and resolution, to verify the performance and health of the subsystems of the vehicle. In addition, a tele-command link also exists to destruct the vehicle in case of a malfunction in the vehicle which can cause damage to life and property.

## 52.5 Future Directions for Space Program in India

Indian launch vehicle program has identified certain advanced technologies for development to meet the long-term needs. Currently identified technologies are the development of (1) large cryogenic and semi-cryogenic boosters, (2) air-breathing propulsion, and (3) building blocks for reusable launch vehicles (RLV). Further, in order to explore new frontiers in science and technology, studies on human space mission have also been carried out.

### 52.5.1 Air-Breathing Propulsion

Reducing requirement of propellant is fundamental to low-cost access to space, as propellant forms about 85 % of launch vehicle mass out of which bulk of the propellant is oxidizer. In air-breathing propulsion, the entire requirement of oxidizer onboard can be eliminated. ISRO has initiated the development of dual mode ram jet (DMRJ) based on the detailed studies of the options available. Fuel injection, mixing, ignition, and flame holding as air travels at speeds greater than 1 km per second are the real challenges, and ISRO has demonstrated successfully a stable supersonic combustion through a series of ground tests for an equivalent flight Mach number of two to ten. Theoretical studies including extensive use of CFD tools have supported design and analysis. A simple flight test demonstrator is conceived using an existing sounding rocket as a carrier, and it is planned to flight test a scramjet engine in flight Mach number range of 6–7. The realization of the vehicle and engine has made rapid progress. Also, a major test facility capable of up to four times the flow rates of the current scramjet test program has been realized, and this test facility can test and evaluate scramjet combustors up to flight Mach number eight.

### 52.5.2 Reusable Launch Vehicle

The reusable launch vehicle (RLV) aims to bring down the cost of orbiting per kg of payload by an order of magnitude, through reuse of the vehicle systems. Extensive studies on configuration options single stage to orbit (SSTO)/two stages to orbit (TSTO) have concluded that with the current levels of technologies of propulsion and materials, only a TSTO is feasible. Towards realizing the TSTO and associated new technologies, ISRO has undertaken the development of a Reusable Launch Vehicle Technology Demonstrator. It has a wing-body configuration and will be capable of flying in a corridor similar to that of the first stage of a TSTO-RLV. Its return flight will have high angles of attack in the upper atmosphere, in order to reduce the kinetic energy before reaching lower altitudes. It will use aerodynamic controls during the atmospheric flight. The entire flight will be autonomous. This RLV-TD will be designed using available technologies, and it is planned to adopt new technologies in a progressive manner. Some of the technologies to be perfected through the experimentation are related to hypersonic aerothermodynamics, reusable thermal protection systems, reusable structures including control surfaces, autonomous flight management, NGC for reentry and controlled descent, in-flight health monitoring system, and abort systems.

### 52.5.3 Indian Human Space Program

Since human exploration of space is going to be the next frontier, a detailed feasibility study report on Indian Human Space Program has been carried out. Compared to unmanned launch vehicle, a host of new technologies are required to accomplish such a complex program. Various key technologies required for human space mission have been identified. A host of new technology development programs needed for systems like crew module, service module, launch escape system, environmental control and life support system, and avionics systems have been initiated.

## 52.6 Conclusions

From a humble entry into space arena in the early 1970s, India has made significant progress in launch vehicle technologies with end-to-end visualization of the entire system. They include multidisciplinary technology development, setting up of appropriate research and development laboratories, establishing critical facilities at industry, developing elaborate quality assurance protocol and test and evaluation procedure, and launch operations. Presently, India has PSLV as an operational satellite launch vehicle capable of launching on demand both remote sensing and communication satellites into prescribed orbits with high precision. Although a few GSLV have been successfully launched, attempts are on to attain the same level of maturity in this vehicle too. These vehicles provide diverse space services to the country. This chapter has attempted to present the Indian launch vehicle systems, required technologies, subsystem design aspects, and launch process. Also, the technology developments being carried out for enhanced payload capabilities as well as future technology demonstration studies for advanced space transportation systems are also included.

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# Space Launch Programs in Emerging Countries: Brazil

# 53

Francisco Carlos Melo Pantoja and Joana Ribeiro

## Contents

**Abstract**

Brazil started making its first steps into the space arena in the early 1960s and since then has made significant progresses. This chapter provides an overview of the Brazilian Space Launch Programs from sounding rockets to the current developments and future perspectives.

## 53.1 Introduction: The Beginnings of the Brazilian Space Program

The year of 1957 was marked by two important events. The first one took place on the first of July when the International Geophysical Year (IGY) began. And the second event happened on October 4 when the Soviet launched the first satellite into

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space, the Sputnik, a crucial motive of the Space Race beginning. After the year 1957, the whole world started to look at space activities, even Brazil.

At the same year, two graduate students Fernando Mendonça and Julio Alberto de Morais Coutinho from ITA (Aeronautics Technological Institute) built the first Brazilian station as their final work. The station was able to monitor the Sputnik, and in 1958, the station was receiving signals from the Explorer 1, the first American satellite.

Only in 1961 did the Brazilian government made the first steps forward, something more substantial in terms of space program during the Janio Quadros government. The president motivated by the inter-American meeting on space research created a commission responsible for the studies and suggestions of the policies for the Brazilian Research Space Program. This commission proposed the creation of the GOCNAE (Grupo de Organização da Comissão Nacional de Atividades Espaciais), a civil organization subordinate to CNPQ (Conselho Nacional de Desenvolvimento Cientifico e Tecnológico), and focused on the following areas: astronomy, radio astronomy, communication satellite, and optical satellite. All these initiatives made Brazil to be among the first countries to officially include space activities in their government program.

Since the GOCNAE foundation, many challenges appeared in order to start the national space activities. The first challenge was the developing of projects with limited financial resource that would show results to the country; in that time their budget was less than 2 % of the American space budget.[1] The second challenge was the struggle to find qualified human resources to work in these projects. There were no professionals to work at the space sector in Brazil; therefore, GOCNAE had to select hundreds of the best Brazilian students in engineering and physics and send them to NASA and other centers of excellence in the USA to specialize.

In order to launch their experiments, GOCNAE in collaboration with the Brazilian Air Force and NASA planned to build the first sounding rocket launch site at Rio Grande do Norte. The Air Force created GETEPE (Grupo Executivo e de Trabalhos e Estudos de Projetos Especiais) to be in charge with the plan and to conduct this project implantation. In December of 1965, CLBI (Centro de Lançamento da Barreira do Inferno) was inaugurated with the launching of Nike Apache, one of the American sounding rockets. Since 1965, CLBI has launched more than 2,000 rockets[2] carrying thousands of scientific experiments. During 1966 until 1978, an important cooperative program started: EXAMETNET (Experimental Inter-American Meteorological Rocket Network). This program was organized by three national space organizations: Argentina, Brazil, and the USA. Their purpose was to establish and demonstrate the capabilities of an interhemispheric network of meteorological sounding rocket launch sites.[3] Almost 200 sounding rockets were launched from CLBI. There were two types of sounding rocket used for this program: Arcas and Loki. The cooperation between the Brazilian and the US space programs lasted until 1985, with hundreds of American sounding rockets launched; see Fig. 53.1.

The sounding rocket activities around the world fell sharply after the 1980s (see Fig. 53.2), and the increased use of meteorological satellites is a possible

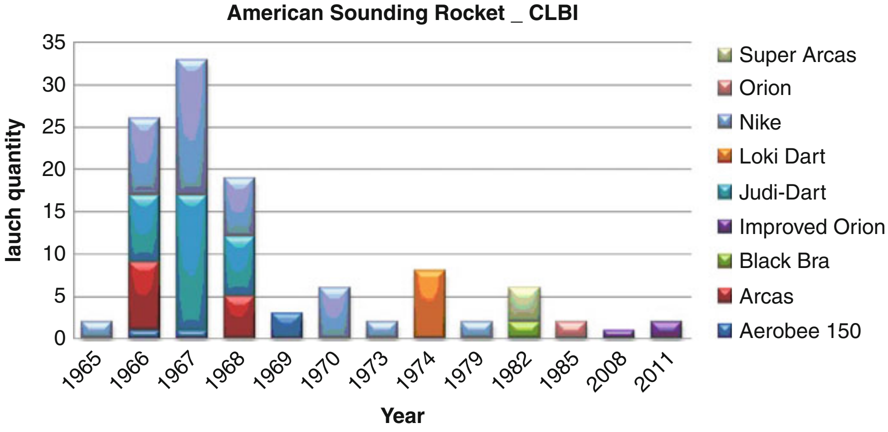

**Fig. 53.1** American sounding rocket launching from CLBI

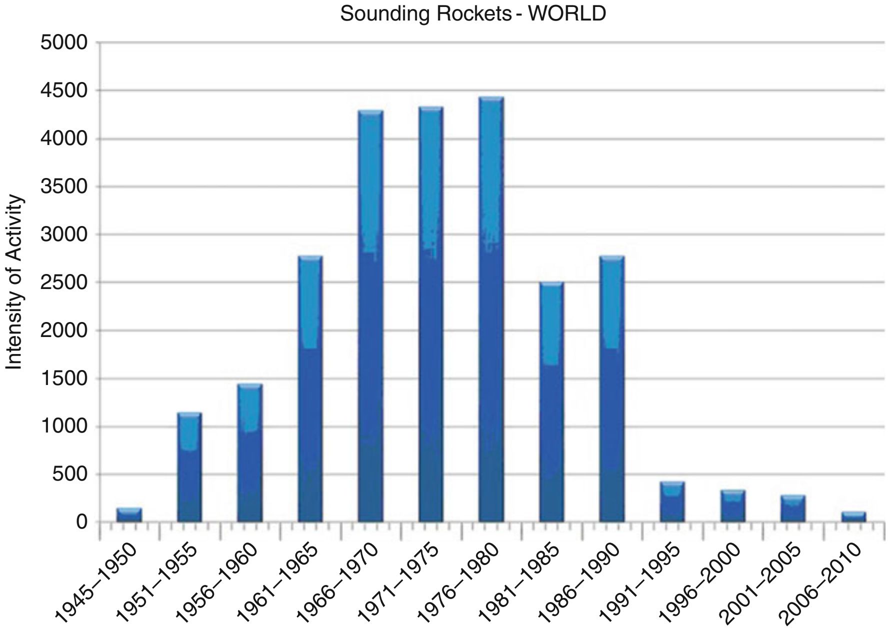

**Fig. 53.2** Worldwide intensity of activity in sounding rockets in the time span 1945–2010

explanation for this. The use of rockets exclusively for meteorological purpose was getting scarce because the scientists began to give more attention to the information generated by the satellites, instead of using rockets (Gouveia 2003).

The time that the US/Soviet Space Race was going at full steam, the Brazilian government decided to structure their space program around the two important initiatives, GOCNAE and GETEPE, which was possible to have until today. The two most important Space Institutes in Brazil are INPE (Instituto Nacional de Pesquisas Espaciais) and IAE (Instituto de Aeronáutica e Espaço). INPE, established in 1961, is the organization responsible in developing and building satellites, and IAE, established in 1969, is the organization responsible in developing and building vehicles to be launched.

## 53.2 The Brazilian Space Launch Program

### 53.2.1 The History of IAE

The IAE history started when GETEPE timework made their first developments with sounding rockets. In 1966, GETEPE and Avibras, the first Brazilian space industries, worked together for the conception, development, and manufacture of the first Brazilian sounding rocket, SONDA I. In 1967, its first prototype with two stages was launched from CLBI. Avibras made more than 200 launches for meteorological purposes. The SONDA I's technological innovation process had been completed, and another technological innovation step needed to be made in order to conquest new applications that space technology could offer.

In 1967, GETEPE started to develop and build sounding rockets inside CTA (Centro Técnico Aeroespacial). The first project was a mono-stage rocket called SONDA II inspired by Black Brant III. The industries had their contribution to this project but only in some specific components, while research and development of space materials was centralized at CTA. In April of 1970, SONDA II had its first successful flight.

With the research and development center implemented at CTA, it was possible to design a gradual evolution of the Brazilian sounding rocket. In 1969, they started the conception of SONDA III, also inspired by Black Brant, BB IV (Table 53.1).

The next important step for Brazilian space activities took place in 1971 when GETEPE became extinct and IAE (Instituto de Atividades Espaciais) became subordinate to CTA (Centro Tecnológico da Aeronáutica) nowadays DCTA (Departamento de Ciência e Tecnologia Aeroespacial) was created. Also in the same year, INPE and COBAE (Comissão Brasileira de Atividades Espaciais) were created. The Brazilian space program was consolidated and integrated by the establishment of a space policy and related responsibilities. IAE became responsible for the development of satellite launch vehicles and sounding rockets, and FAB (Força Aérea Brasileira) became responsible for the launching site. INPE took the responsibility for the development of satellites and ground segment. COBAE (Comissão Brasileira de Atividades Espaciais) became responsible for the space program coordination. Their major achievement was the creation of the MECB in 1978 (Missão Espacial Completa Brasileira), which developed two types of satellites and launched them with a national launch vehicle from a Brazilian territory.

**Table 53.1** List of SONDA family – Brazilian sounding rocket

| | SONDA I | SONDA II | SONDA III | SONDA IV |
|---|---|---|---|---|
| Total length (m) | 3.1 | 4.534 | 6.985 | 9.185 |
| Max. diameter (m) | 0.127 | 0.3 | 0.557 | 1 |
| Stages | 2 | 1 | 2 | 2 |
| Total mass (Kg) | 59 | 368 | 1,548 | 6,917 |
| Payload mass (Kg) | 4.5 | 70 | 150 | 500 |
| Apogee (Km) | 70 | 100 | 500 | 700 |
| Flights | >200 | 61 | 31 | 3 |
| Year of first | 1967 | 1970 | 1976 | 1984 |

The Brazilian national space technologies development was driven by the Brazilian Sounding Rocket Program and the satellites program. As an example, the SONDA III was the first one to be adopted with national technologies (like separation stages system, destruction system, attitude control system, and a system payload recovery at sea). In 1974, during the SONDA III development, IAE took a further step to reach to a satellite launch vehicle with the conception of SONDA IV. This rocket had two stages: the first stage rocket motor was totally a new development and the second stage had the SONDA III's first stage as its motor. This rocket, besides aiming to enlarge the Brazilian payload launch capability, acted as a school for the Brazilian engineers to learn how to develop a three-axis control system to pilot and guide the future satellite launcher. The first flight took place in 1984 and made only three flights.

### 53.2.2 Sounding Rockets

IAE developed the family VSB-30 sounding rocket. It is a bi-stage which carries scientific and technological payloads of 400 kg, for experiments in the range of 270 km altitude. The experiments in microgravity, VSB-30, can remain payload about 6 min above the altitude of 110 km. There have been 11 launches and all were successful. This rocket was the first Brazilian space product in the international market and also the first to receive an international certification. Figure 53.3 shows the Brazilian sounding rocket activity since the first flight.

Table 53.2 is an overview of all sounding rockets made by the country until now.

### 53.2.3 The Rise of Brazilian Space Industry

The first space industry in Brazil was Avibras in 1961 which was responsible in building the SONDA I. Since IAE and INPE were funded, and new rockets and satellite projects were developed by them, a new demand for space components started. Since there were a few space industries in Brazil able to produce space components, the institute had to develop most of the equipments itself or buy from

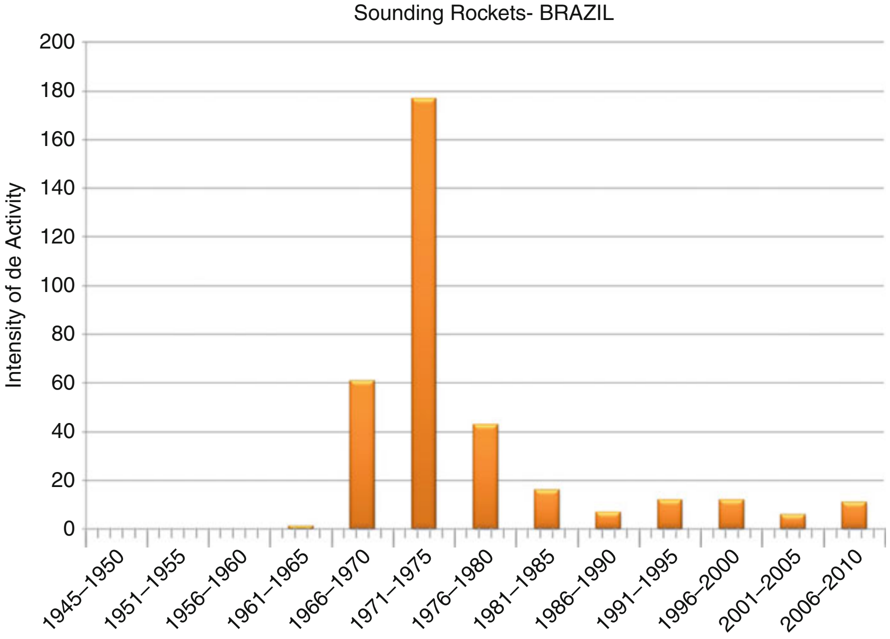

**Fig. 53.3** Brazil intensity of activity in sounding rockets in the time span 1945–2010

**Table 53.2** Overview of Brazilian sounding rocket

| Vehicle | Flights | Situation | Mission |
|---|---|---|---|
| SONDA I | 223 | Inactive | 4,5 kg for 70 km apogee |
| SONDA II | 61 | Inactive | 20 kg for 120 km apogee |
| SONDA III | 31 | Inactive | 60 kg for 600 km apogee |
| SONDA IV | 4 | Inactive | 500 kg for 700 km apogee |
| VS-30 | 7 | Operational | 260 kg for 160 km apogee |
| VS-30/Orion | 3 | Operational | 160 kg for 300 km apogee |
| VSB-30 | 9 | Operational | 400 kg for 250 km apogee |
| VS-40 | 2 | Operational | 500 kg for 650 km apogee |
| Orion(2) | 2 | Operational | 80 kg for 100 km apogee |

the USA. The space industry really rose after 1972 with the development of the SONDA IV, a more complex sounding rocket. Many small enterprises were formed by specialist who had worked at IAE.

The Brazilian space industry is mainly composed of small- and medium-sized enterprises, mostly in charge of supplying parts, components, and subsystems. At SINDAE (National Systems of Space Activities), where INPE and IAE/DCTA are the institutions responsible for the design, assembly, systems integration, and testing of satellites and launch vehicles, respectively, the private companies' actions are restricted to supply some parts, components, and subsystems ordered by these two institutions (Schmidt 2011).

During the development of the Brazilian space activities, the government did not create the appropriate commercial and financial conditions to support and maintain the space industries for a period until they find other alternative products to increase their profit, such as spin-offs. Industrial competitiveness is a key component in a country's science and technology policy, and the important goal for the Brazilian space development should be the enhancement of its industrial competitiveness. Futron's studies (2009) show that Brazilian space program has the lowest competitiveness index which is the consequence of the lack of relevant policies to support the national space industries. Furthermore, the Brazilian space competitiveness is getting worse compared to other nations like South Korea and India which are newer players in space activities.

When one takes into account the fact that space products have a high added value and require considerable investments, it is admissible to recognize that a strict dependence should exist between this industrial base and its practically exclusive client, the Brazilian government, at least at the stage of its consolidation (PNAE 2005). The industry participation in the Brazilian space activities should be seen as necessary for the country's space activities as industries typically can have, in contrast to government, a more flexible structure to purchase goods and services, can generate employment, and can reduce costs. However, the low competitiveness of the Brazilian space industry and at the same time its important role in the space program are well-known issues for AEB. A possible solution to this situation is not an easy task as many factors should work together.

The result is an immature level of space industry development in Brazil, and thus, most of the space developments in Brazil are done by the government's research institutions. Over the past years, the space industry has not had the opportunity to grow significantly. It has seen a gradual increase, but the total industry size is still very small, as well as the workforce. In 2009, only 289 people worked in the space industry (Ipea 2011). To put this in perspective, it should be mentioned that more than 18,000 people worked in the aviation industry (Embraer 2012). This weakness of the Brazilian space industry to grow is mainly due to the fact that there is lack of a consistent space program reflecting government demand that is necessary for increasing and sustaining the industrial capacity in the country.

Additionally, technology transfer from the institute to the industry has been lagging behind. As an example, in the case of the VSB-30, which is considered a successful project with many launches, the IAE is responsible for its manufacturing. The government's low support to the private sector to develop space technologies results to constant need for technology imports and project delays due to lack of access to some technologies.

Lately, the scenario of Brazilian space private sector is changing. New entrants like Odebrecht, Embraer, and Camargo Correa start their operations in the area of defense and security. Odebrecht and Camargo Correa are two multinational and well-known organizations in the field of civil engineering. Embraer S.A. is a big player in aviation, and its defense and security unit together with Telebras created a new company called Visiona Tecnologia Espacial which will be the core partner on the BR1SAT project. The BR1SAT project aims to build the first Brazilian satellite for defense and strategic communication. The project's cost is estimated to be $412 million. Embraer Defense and Security is the company in which most specialists believed to have the capacity to become 1 day the first Brazilian prime contractor. However, a long and difficult road is ahead of such a quest. The way new entrants will raise in the sector will depend on the investments that the government will make in the field of communication and security over the next years.

One important strategy that the institute is currently taking up is the development of a new vehicle wherein the industry has already been participating in since the beginning of the project conception phase, and positive results have already been seen. Even though this is a good start, many improvements in the country's industrial space policy must be made in order to reach a sustainable space sector development. The policy for the Brazilian space industry must focus not only on providing opportunities for supply and technology improvement of already developed technologies by the institute but also providing opportunities to develop and supply a new system for the launch vehicles (AAB 2010). In other words, the Brazilian space program must facilitate the creation of space technologies by the Brazilian space industry. A first step to this is for the Brazilian government to facilitate the appropriate allocation of resources in industry (budget and personnel) by providing frequent orders and thus creating a sustainable market for them.

### 53.2.4 International Cooperation

The international cooperation has an important role in the Brazilian Launch Program development due to its increased intensity overall in the Brazilian space program (PEB).

As Brazil has been an ally of the USA during the Cold War, a number of science and technological activities took place between the two nations. The first Brazilian cooperation within the US space program was in the 1960s, which supported the country to build its own first space site, CLBI. This interaction was an important component in building the knowledge required for launch site operation as well as rocket science and technology development for the start of the Sounding Rocket Program in Brazil. Unfortunately, after the ITAR implementation, this cooperation weakened. In the 1970s, IAE made strong cooperation agreements with France and Germany, sending many employees to study in their best universities. However, the intensification of the application of the MTCR rules strongly impacted the Brazilian rocket development with embargos and restrictions of material and services exportation. Table 53.3 provided an overview of the key partners of the Brazilian Space Launch Program.

DCTA and DLR (German Space Center which is a German space agency) signed an agreement for technological cooperation in 1971. According to Brig. Pohlmann (2011), director of DCTA, in 1971, aerospace research activities were among the

**Table 53.3** Key partners of Brazilian Space Launch Program

| Time | Country | Partnership focus | Future opportunities and restrictions |
|---|---|---|---|
| 1960s | USA | Launch site operation | Oppt: possible changes at export control |
| | | Basic knowledge in sounding rocket science and technology | Rst: Strong export control in any space technology |
| 1970s until today | Germany | Sounding rocket technological development | Oppt: VLM technological development |
| 1980s until 1990s | France | Training the IAE human resources in their space engineering universities | Oppt: collaboration for small launch vehicle |
| | | Initiatives to work together in liquid propellants development and at VLS project, but the MTCR restricted this partnership | Rst: IAE technological development in liquid propulsion |
| 1990s until today | Russia | Provision of services to review the VLS Alfa and the VLS projects | Oppt: collaboration for the medium launch vehicle development |
| | | Supply of subsystems, equipment, and raw materials | |
| 2000 until today | Ukraine | Creation of ACS (Alcantara Cyclone Space), a binational commercial company composed by Brazilian and Ukraine governments created in 2003 | Oppt: collaboration between IAE and the next Cyclone generations |
| | | Operate the Cyclone 4, launching from Alcantara that attends medium satellites | Rst: see Sect. 53.3.5.4 |

first five fields of strategic technology cooperation between Brazil and Germany. Both organizations, which are public institutions, have built over the past 40 years a strong partnership in Sounding Rocket Programs. Concrete results from these cooperations include studies and tests of a number of technologies launched on sounding rockets like VSB-30, VS-30, and VS-30/Orion. A platform for microgravity has also been included. There have been more than 25 launches from CLBI and are expected to be continued in the future. In 2011, DLR and SSC (Swedish Space Corporation) bought 21 rocket engines from the VSB-30 sounding rocket. Nowadays, DCTA wants to verify the possibility of extending its scope of cooperation with Germany (DLR) and start discussing future partnerships with Sweden. The next challenge for the partnership will be the realization of the VLM-1 project.

Another important cooperation for Brazil is the agreement with Ukraine to build and launch the Cyclone 4 from Alcantara. The Brazilian efforts to promote the commercial application of the Alcantara Launch Center started in 1996 when an agreement was signed between Infraero (Empresa Brasileira de Infraestrutura Aeroportuária), AEB, and the Air Force. A division was created within Infraero intended to find potential customers for CLA with specific focus to Italy (Fiat Avio) and Ukraine (Cyclone). In 2001, all the space activities conducted by Infraero were transferred to AEB. The first negotiations made between Fiat Avio and Infraero ended after many difficulties faced by both of them. On the other hand, the negotiations between Brazil and Ukraine progressed, and they signed an international treaty on October 21, 2003 in Brazil. There are many reasons behind this success:

- Ukraine was developing a new and more powerful version of their satellite launch vehicle, Cyclone 4, and since the dissolution of the Soviet Union, Ukraine has no available space center to launch it.
- The Brazilian northwest area is considered the best place for a launching site in terms of safety and covers all orbital directions launching.

Under this agreement, a joint venture company, Alcantara Cyclone Space (ACS), was created, defined by the treaty as "an international entity for economic and technical purposes" (Monserrat 2005). The international agreement establishes the responsibilities in three parts, for Ukraine, Brazil, and the binational ACS, which are:

- The responsibility of the Cyclone 4 development and production belongs to the Ukraine government, coordinated by the Ukraine Space Agency (NSAU).
- The responsibility of the CLA general infrastructure development belongs to the Brazilian government, led by the Brazilian Space Agency (AEB).
- ACS has the responsibility to design, construct, and operate the launch site. The ACS's budget is financed equally by the Ukrainian and Brazilian governments.
- ACS has the responsibility to commercialize the launch in order to sustain the manufacture facilities in Ukraine and to maintain the launching site in operation.

One of the issues that has been under debate is that the international agreement does not foresee rocket technology transfer. This means that the Brazilians have no involvement in the Cyclone development activities. The Cyclone 4 is under development in Ukraine by the main companies Yuzhnoye and Yuzhmash.

The launch site construction started in September 2010, and the expected year for the first launch of Cyclone 4 from CLA has been set for 2013. However, there have been a number of problems faced by ACS. These are (a) the tight commercial market dealing with many competitors and (b) the lack of financial support between the parties in Brazil and Ukraine.

### 53.2.5 Launching Vehicle Program

The launch vehicle programs in Brazil are VLS (Veículo Lançador de Satélite), VLM (Veículo Lançador de Microssatélite), all the launch vehicles from the Cruzeiro do Sul program, and Cyclone 4. Each has distinct technological characteristics which will be presented one by one.

#### 53.2.5.1 VLS

The VLS program started in 1980 by IAE/DCTA. The intention was to fulfill one of the three objectives set by MECB which was the development of a national launch vehicle. The technology acquired from the development of sounding rockets contributed towards the development of a small satellite launcher. The first VLS

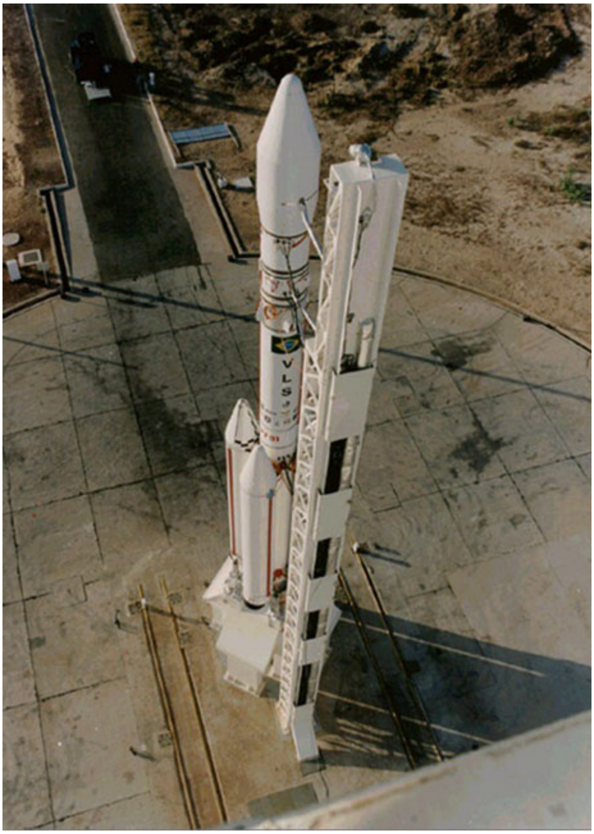

**Fig. 53.4** VLS-1 V01 at launching platform

configuration, VLS-1, is a four-stage vehicle with a solid propellant, able to put in orbits between 200 km and 1,000 km, satellites ranging from 100 to 350 kg (Fig. 53.4).

After an accident in 2003, IAE made some changes to the VLS program, where the system configuration was modified and two technological flight tests were established. Currently, VLS program is making progress with the planned tests, most of the modifications were made, and the new launching tower is ready (Fig. 53.5).

#### 53.2.5.2 VLM

VLM (Veículo Lançador de Microssatélite) is another important project for IAE in terms of technology development. A central player for this project's success is DLR. Since 2009, IAE and DLR agreed to initiate a feasibility study for a new launch vehicle to be able to meet the SHEFEX III (Sharp Edge Flight Experiment) mission requirements and to be able to launch microsatellites in low Earth orbit. There were two groups working at the VLM configuration. The first one was composed by Brazilian specialists called GENSIS (IAE System Engineering Time) and the second one case called Maromba at DLR. The selected configuration is based on three solid

**Fig. 53.5** VLS prototype at CLA new launching platform

stages where the first two stages are composed by the S50 engine which will be developed jointly by IAE and DLR. The last stage is composed by the S44 engine already qualified in flight. The estimated year for the first flight is 2015. The first configuration is able to launch a satellite of 200 kg in equatorial orbit of 300 km altitude. The second VLM version will have the last stage changed for a more powerful engine. This project is looking for a simple configuration in order to meet the "target cost." The first market for this vehicle is to fill the national demand for microsatellite, minisatellite, and nanosatellite as well as DLR's demands.

#### 53.2.5.3 Cruzeiro do Sul

Just after the Alcântara VLS accident in 2003, AEB and IAE have been working together to design the next launch vehicle that will succeed VLS-1. In 2005 the new national launch program was released, called Cruzeiro do Sul (Southern Cross), which considered a development horizon of 17 years. The Cruzeiro do Sul Program is based on the definition of a family of launch vehicles with the capacity to meet the mission requirements established by the National Program of Space Activities (PNAE). The project is composed of five launch vehicles called VLS Alfa, VLS Beta, VLS Delta, VLS Gama, and VLS Epsilon. The main goal of this project is to provide Brazil an independent access to space by developing a launch vehicle capable of putting satellites into GTO orbits, actually the Brazilian Geostationary Satellite (SGB), by 2022. The Cruzeiro do Sul's will be developed gradually in order to ensure that each phase is successfully completed (Fig. 53.6).

**Fig. 53.6** Cruzeiro do Sul launch vehicle family

### 53.2.5.4 Cyclone

Since the Soviet Union dissolution, Ukraine had to find their own way to launch their vehicle. However, this has been a problem, as for many years Russia and Ukraine government did not have good government relations. In 1997, Ukraine showed its interest in Brazil's Alcantara site. At that time Brazil was in its first negotiations between Infraero and Fiat Avio for a potential partnership which did not materialize. The Brazilian government immediately showed interest to negotiate with Ukraine about the Alcantara site since the prospect of launching communication satellites was very promising. Several issues, among others the US conditions for launching satellites and markets insecurity, made Fiat Avio abandon the prospect of making an agreement with Infraero. After that, the negotiation started between Brazil and Ukraine, and after 6 years, in 2003, both governments agreed to sign the treaty that established their partnership to build and launch Cyclone 4. Under this agreement, as mentioned already in the international cooperation section, a joint venture was created under the name Alcantara Cyclone Space (ACS) which was responsible for the design, construction, and operations of the launch site. The Brazilian government led

**Table 53.4** Summary frame of Brazilian Space Launch Vehicles

| | VLS-1 | VLM-1 | VLS Alfa | VLS Beta | VLS Gama | VLS Delta | VLS Epsilon | Cyclone 4 |
|---|---|---|---|---|---|---|---|---|
| Stage number | 4 | 3 | 3 + 4 booster | 3 | 3 | 3 + 2 booster | 3 + 2 booster | 3 |
| Total height | 19,4 m | 20 | – | – | – | – | – | 39,95 m |
| Gross lift mass | 49,7 t | 15,9 t | – | – | – | – | – | 198 t |
| Engines | S43(4)-28,4 t | S50(2)-19,6 t | S43(4) | P40 (1)-40 t | L1500(1)-150 t | L1500(1) | L1500(3) | RD-251 + RD855 |
| | | | S43(1)- | L300(1)-30 t | L300(1) | P36(2) | L300(1) | |
| | S43(1) | S44(1) | L75(1)-7,5 t | L75(1)-7,5 t | L75(1) | L300(1) | L75(1) | RD252 + RD855 |
| | S40(1)-4,45 t | | | | | L75(1) | | RD861K |
| | S44(1)-0,8 t | | | | | | | |
| Payload capacity | 115 kg | 120 kg | 600 kg | 800 kg | 918 kg | 2,130 kg | 4,000 kg | 1,600 kg |
| Orbit | 750 km (circular) | 200 a 700 km (equatorial) | 400 km (equatorial) | 800 km (equatorial) | 800 km (polar) | GTO | GTO | GTO |
| Flight number (no sucess/ sucess) | 2/02 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 |
| Next flight planned | 2014 | 2015 | 2016 | – | – | – | – | 2013 |
| Propellant | Solid | Solid | Solid/liquid | Solid/liquid | Liquid | Liquid/solid | Liquid | Liquid |

by AEB remained responsible for the CLA general infrastructure, whereas the Ukrainian government maintained its responsibility in the development of Cyclone 4.

The Cyclone 4 has three stages, and its similarity to Cyclone 3 relates to its first two stages. The third stage is a complete new development with greater capacity of propellant and with a rocket engine capable of multiple ignitions. This third stage also uses a new control system capable of more precise orbital insertion and has been redesigned to accommodate larger volumes for bigger payloads. The launch is foreseen for 2015 running almost 3 years behind.

A number of difficulties need to be overcome in order to ensure the success of the program. These are:

(a) Ukraine government financial problem with the payment of ACS capital
(b) Human resources able to work at the launch site
(c) How the program will be sustained after its development
(d) The mass capacity limitation of Cyclone 4 to launch into GEO (1,600 kg)
(e) Environmental issues against the use of hydrazine and tetroxide as propellant
(f) Brazilian community dissatisfaction with ACS since there is no knowledge transfer foreseen

ACS is making efforts in order to reduce the impact of these issues like the project of sustainable city, pressure by their minister for the payment of the capital related to Ukraine's contribution, and cooperation between Brazilian and Ukrainian actors, for example, the Brazilian university is sending some students to Ukraine.

Table 53.4 shows all the launch vehicle and their overall configuration.

## 53.3 Conclusions

New scenarios are observed in the Brazilian space program in terms of policies. The government wants to make improvements at Brazil's national capacity in developing space technology in order to ensure some level of autonomy and to become an actor in the space sector. It is clear that many space developments in Brazil are still waiting for a structured set of strategies to be put in place by the MCTI (Ministérios Ciência Tecnologia e Inovação), MD (Ministério da Defesa), and the government. The Brazilian economy is growing, placing the country as an important player in the worldwide activities. The chasing needs of Brazil for space applications are certain. The issue to be analyzed is how and who should be able to respond to them. Since Brazil is not yet an important player in space endeavors, the impacts and contributions of the Brazilian space program in space security are relatively low. However, the programs' potential should be considered once it will affect or will be affected by Brazil's future space policies.

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# Space Weapons' Concepts and their International Security Implications

# 54

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## Contents

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**Abstract**

The term *space weapons* is often used without further definitions, making discussions complicated and often misleading. This chapter tries to define the term space weapons in the three categories Earth-to-space, space-to-space, and space-to-Earth weapons and lay out some operational aspects of weapons in space together with a short history of space weapons. The three military space missions where space weapons could add value are described briefly, and seven different space weapon concepts are described as to their operational advantages and limitations along with some prerequisites for developing weapons in space.

## 54.1 Introduction: The Path of Conflict

War and technology have been in a symbiotic relationship since prehistorical times. In the first battle in recorded history, the battle for Megiddo ca 1460 B C when pharaoh Thutmose III fought a Levantine coalition, the technology of chariots was a decisive factor (Gat 2006). In 3,500 years of history, technology has been a driver for conflict, and conflict has been a driver for the development of technology. Space is the latest physical domain from which to wage war and in which the symbiotic relationship of war and technology threatens and contributes to our common security.

The purpose of war is primarily not to destroy the enemy's military capability but to force upon the enemy one's own will and values, i.e., to achieve a political objective (Kagan 2006). Thus, moving conflict into space does not mean that the superiority of space in itself will be the objective of the conflict. Space is, along with sea and air, a domain to exploit in the pursuit of leverage against an enemy whose powerbase still is and in a foreseeable future will be based on the ground. The exploitation of space for military purposes introduces new possibilities for asymmetries to consider both when planning offensive operations and the defense of nations.

Using space for military purposes does not necessarily mean space weapons, and space weapons do not necessarily mean weapons in space. Space, i.e., Earth orbit, has been used for military purposes for the last 50 years, and antisatellite (ASAT) weapons have been developed during the same time without a weaponization of space. The path of conflict in space and through space starts and ends on the ground. As long as there are risks of conflicts on the ground, as long as conflicts are drivers of the development of military technology, and as long as space is used for military purposes, there is also a risk that a conflict will spread into space and that space weapons will be developed, deployed, and used.

This chapter will give a short introduction to weapons and space. In Sect. 54.2, "Background," some definitions are discussed as are some operational aspects of military activities in and through space. In Sect. 54.3, a short history of space weapons and the ambition to acquire space weapons is presented. Sect. 54.4, called "Available and Emerging Weapon Concepts," gives an overview of some of the actual weapon systems developed and discussed on a generic level. Indications of performance are given without derived equations or detailed descriptions of the limitations of the systems. Sect. 54.5, called "System Exploitation," will briefly discuss how the presented weapons concept may be exploited for military effect, and Sect. 54.6, called "Future Prospects," will equally briefly discuss space weapons in relation to arms control negotiation. Some conclusions are presented in Sect. 54.7.

## 54.2 Background

### 54.2.1 Defining Space Weapons

The first challenge when talking about space weapons is to define what a space weapon really is. We usually do not talk about land, sea, or air weapons but guns, bombs, and missiles. The weapons are carried by, or aimed at, platforms such as tanks, warships, and fighter planes. In a space analogy we could still talk about guns, bombs, and missiles, but to the list of weapons platforms, we would add satellites, spaceships, and in the future maybe space planes.

A weapon affects its target by transferring energy from the shooter to the target in such a way that the target is disturbed, damaged, or destroyed. This energy can be applied in basically two ways: by transferring a mass, e.g., an explosive warhead from the shooter to the target, or by projecting directed energy, e.g., laser radiation on the target. The former types of weapons can be called mass-to-target weapons, and the latter type can be called directed energy weapons.

If an explosive warhead is used, it can be either conventional or nuclear. A weapon with a warhead without explosives that destroys the target by way of its own velocity is called a kinetic energy (KE) weapon. Directed energy weapons could be anything from jammers that compete with a legitimate signal in the target's antenna systems to a powerful laser or particle beam that heats a target from a long distance so much that the target is destroyed.

When characterizing modern weapon systems, it is customary to describe the relation between the position of the platform that carries the weapon and the position of the target in terms of from which domain (ground, sea, air) the weapon is fired into the domain where the target is located. A missile such as the US Harpoon that is designed to attack surface ships is called an anti-ship missile. When fired from a surface ship, it is designated a surface-to-surface missile (SSM), but when essentially the same missile is fired from an aircraft, it is called an air-to-surface missile (ASM). The same logic is used when discussing weapons targeting aircraft or ground targets. The logic can also be used for weapons and targets in space, with the simplification that land, sea, and air are given the collective label Earth. A missile that is designed to attack a satellite would be called an antisatellite (ASAT) missile. When fired from Earth into space, it would be an Earth-to-space weapon.

There are three different relations between weapon platforms and targets to consider for space weapons: Earth to space as described above, space to space when both weapon and target are situated in space, and space to Earth when a weapon is based in space but designed to attack targets on the ground, at sea, or in the air.

Earth-to-space weapons are typically missiles or directed energy weapons. The weapon is located on the Earth, meaning physically on the ground, on a ship, or in the air on an aircraft when it is fired against a target in space. The typical target in space is a satellite, but also antiballistic missile (ABM) systems[1] are space weapons when they target Intercontinental Ballistic Missiles (ICBMs) in the midcourse phase, when the ICMB passes through space[2].

Space-to-space weapons would be weapons placed in space prior to the time they are intended to be used against targets in space. The weapons platform would by definition be a satellite, and the targets would be other satellites or ICBMs in their boost or midcourse phase. Distances in space are long and the weapons would typically be some kind of missile or a directed energy weapon. An alternative would be to use the weapons platform as a weapon in itself, maneuvering the weapon satellite to actually collide with the target.

Weapons that are placed in space but engaging targets on Earth would be space-to-Earth weapons, sometime referred to by the acronym STEWs. The weapons platform is a satellite and the target could be anything on land, at sea, or in the air that can be targeted from space. The weapons themselves could be bombs, missiles, or directed energy.

### 54.2.2 Military Space Missions

It is convenient to distinguish between four various types of users of space, or *space activity sectors* (Hays et al. 2000). The *intelligence sector* is concerned with the gathering, analysis, and dissemination of strategic intelligence. It is not primarily a military interest but a national interest, even though the actual space systems in many cases are operated by a nation's armed forces. The *military sector* uses space integrated to the armed forces to enhance military effect. Tactical intelligence from space is but one example. Others are the use of satellite communications in the field or GPS-guided munitions. The timescale can be very different between the intelligence sector and the military sector. While space reconnaissance for intelligence could be harnessed over months or even years into divulging development of potential enemies' capabilities, like the building of a nuclear weapons program, the tactical use of space could be time critical down to fractions of a second, e.g., a GPS position for a smart bomb.

The third sector is the *civilian sector* which uses space for national, nonmilitary purposes such as environment monitoring or research. The fourth sector is the

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[1] The term ABM will be used throughout the this chapter, without considerations of the difference in definitions between ABM and the term ballistic missile defense, BMD.

[2] For an extensive discussion on ballistic missile trajectories and the various challenges for ballistic missile defenses, see, for example, *Space Weapons and the Strategic Defense initiative* by Crockett L. Grabbe (1991).

*commercial sector* that supplies space services on commercial basis to whomever would like to buy them, including operators within the intelligence sector or the military sector.

Within the military sector, the US Department of Defense space mission typology (Hayes et al. 2000) describes four military space mission areas: *space support*, *force enhancement*, *force application*, and *space control*. Space support is about all missions necessary to access space, e.g., space launchers. Force enhancement is about using space-based services to enhance the capabilities on the ground, at sea, or in the air, e.g., satellite navigation for ground troops. Force application can loosely be defined as the use of military force to, from, or within space. Space control can be described as assured access to space, while negating the adversary the use of space.

A new military capability is developed and deployed when a new need or possibility arises or when an old capability can be replaced with one that does the job better or cheaper. In the mission area force application, there are two missions that require the development of capabilities using space weapons: global ground attack and ballistic missile defense. Global ground attack is a mission available to a few nations since 50 years through the deployment of ICBMs or submarine launched ballistic missiles (SLBM). For space-to-Earth weapons to augment or replace ICMBs/SLBMs, the space systems must reach targets otherwise unreachable, must have a shorter engagement time than missiles, and must be cheaper or in some other way be superior to the existing weapon systems. If none of these criteria are met, there is no rationale in developing space-to-Earth weapons for global ground attack.

Ballistic missile defense is a complex mission, comprising of different types of defense systems for the boost phase, the midcourse phase, and the terminal phase of the missiles trajectory. Space systems are crucial for command and control in all three phases, but it is primarily in the boost-phase and the midcourse phase, when the trajectory takes the missile and reentry vehicles through space, that space weapons could add value. It is important to make note of the difference in the ABM mission today as opposed to when the SDI concept was presented 30 years ago. Much of the criticism against SDI was based on the number of Soviet ICBMs/warheads to be countered and the cost of a system that would not be able to counter an all-out Soviet first strike with maybe as much as 1,500 missiles simultaneously being launch against the United States from known sites within the Soviet borders. The perceived threat today is a small number of missiles from any of a handful of rogue nations spread around the globe. Even if the critics of SDI were right then and the Strategic Defense would not have been able to perform in the Cold War context, that does not mean that individual components of the SDI concept would be unusable in today's context.

In the mission area space control, there is one mission that benefits from space weapons: the ASAT mission. It should however be noted that space control not only is about ASAT but also about Space Situational Awareness (SSA). The antisatellite mission does not necessarily mean using weapons against a satellite, since an adversary can be negated the use of space systems in a number of ways not requiring damaging or destroying the satellites, e.g., by jamming of communication links or attacking the satellite system's ground segment.

### 54.2.3 Operational Aspects of Space Weapons

A first thing to consider regarding Earth orbit is that nothing is stationary. An object in Earth orbit is in free fall around the Earth, traveling at a speed of about 7,000 m/s. At the same time the Earth is rotating around its axis. For Earth-to-space or space-to-Earth engagements, this means that the weapon will not necessarily be within range of the target when needed.

A direct ascent or directed energy Earth-to-space weapon will only be able to engage a target when it passes within range the weapons platform. This means that the weapon has to be deployed within the inclination of the satellite or under the expected flight path of the ballistic missiles it is supposed to engage. However, if the target is a satellite, the antisatellite weapon does not have to be deployed close to the area of conflict on earth. Anywhere on Earth within the satellite's inclination will suffice. From a national perspective this is important as a nation cannot base ASAT weapons on its territory if the latitudes are greater than the target's inclination. A nation, e.g., between 55° and 69° north, will not from its territory be able to target satellites with an inclination smaller than 55°. One way to overcome this restriction is to develop air-launched ASAT missiles where the aircraft launching the missiles can be deployed to bases anywhere in the world.

Another way to overcome the latitude restriction for ASAT weapons is to develop co-orbital systems. These do not attack the target directly but enter into orbit with the target. The co-orbital approach is of course only viable for ASAT systems and not ABM systems, as ballistic missiles per definition do not enter into an orbit.

With a single weapon satellite with space-to-Earth weapons in a low Earth orbit (LEO), the time between possible engagements of a stationary target on Earth is dependent on the orbit of the weapons platform and the latitude of the target. A target on the equator and a weapon satellite in an orbit with zero-degree inclination would allow for an engagement approximately every 90 min, but the weapon satellite would be restricted to engage targets close to the equator. If the same weapon satellite is in a polar orbit, it will over time pass over every point on Earth, but it might only have the capability to attack a target on the equator once a week, while the poles could be attacked every 90 min. What this says is that from a military perspective, the orbital characteristics of a weapon in space is a mirror of the intended use of that weapon, and since the orbital characteristics are determined on launch, there is no real gain in launching such a weapon before the intended geographical area of use has been determined. If a nation wishes to deploy weapons prior to a conflict without a geographical area in focus, that nation must consider deploying a constellation of weapon satellites in order to be able to attack an identified target within a given timeframe.

The case of space-to-space weapons in LEO is even more complicated. There are two possible types of targets: satellites and ballistic missiles. If the target is another satellite in a completely different orbit from the weapon, the geometry of the intercept would be complicated, and there is no way to generically predict an average time between possible engagements of a specific target. If the target is a ballistic missile, the weapon satellite must be in range of the expected flight path of the missiles at all times. The only way to tackle these problems is to develop a constellation of satellites such that there always will be at least one satellite covering the area of interest at all times. The other side of this approach is that it leads to a situation where there will be satellites covering most or all of the ground and space within the inclination of the weapon satellites at all times, creating a more or less global coverage.

The need to deploy constellations of satellites leads to the concept of *absentee ratio*. The absentee ratio is the number of weapons platform needed in orbit to have one available to engage a target within a desired timeframe. If a weapon system in LEO targeting Earth has a lateral range of 500 km on either side of the satellites ground track, and the weapon satellites are in polar orbits, there has to be 20 satellite orbits just to have the possibility to engage any target at the equator within 90 min. Since the deorbiting time would be at least 10–15 min, the actual engagement time could be 105 min. If this is to be cut to about 30 min, the same time as the engagement time for an ICBM, the launch of the space weapon would have to happen within 15 min instead of 90 min. This can be achieved with six satellites in each of the 20 orbits, for a total of 120 satellites, or an absentee ratio of 120.

## 54.3 Space Weapons: A Short History

The world's first artificial satellite, Sputnik 1, was launched in October 1957. More than 5 years earlier, in March 1952, the concept of weapons in space had been introduced to the public through an issue of Collier's magazine where Wernher von Braun described an orbiting space station possible to arm with nuclear weapons (Bulkeley and Spinardi 1986). Once the Soviet satellite was in orbit, the specter of nuclear weapons delivered from space prompted the development of antisatellite weapons. Since then, the world has seen three nations develop and test space weapons: the United States, the Soviet Union, and China. A fourth nation, India, has stated that they plan to develop space weapons.

### 54.3.1 The United States

The United States started already in the late 1950s to develop ASAT system against the perceived threat of Soviet satellites armed with nuclear weapons. These ASATs were Earth-to-space weapons, launched from either an aircraft or from the ground and equipped with nuclear warheads. Two different ground-based systems, the US

Army Nike-Zeus system and the US Air Force Thor system, were operational between the early 1960s and the mid-1970s. Both had megaton-class hydrogen warheads (Peebles 1983).

The effect of nuclear explosions in space was investigated in a series of tests in the early 1960s of which the STARFISH series is the most well known (Ness 1964). The effects of nuclear weapons in space are very different from the effects on the ground. The primary mechanism for destroying a satellite in a nuclear explosion would be the radiation in the X-ray part of the spectrum that affects all satellites within line of sight to the explosion and would damage or destroy a satellite, depending on the yield of the explosion and the distance to the satellite. What was shown in the experiments was that there were secondary effects that were at least equally damaging. The nuclear explosions in space created artificial radiation belts that damaged satellites passing through the belts. This of course affected all satellites, friends or foes, and not only the targeted satellite. Thus nuclear-tipped ASATs were less that optimal.

A quest for a more operational weapon started after the effects of high-altitude nuclear explosions became clear. A two-pronged presidential decision in 1977 directed the US authorities to both explore the possibility of an ASAT treaty with the Soviet Union and develop an air-launched ASAT missile (NSC 1977). This missile was explicitly decided to be nonnuclear, and the resulting system was the Air Launched Miniature Vehicle (ALMV) that was fired from an F-15 Eagle fighter aircraft. The ALMV worked by colliding with the target and destroying it by means of kinetic energy.

The ALMV took its place in space history on September 13, 1985, when the United States in their as of today last ASAT test destroyed the US research satellite P-78 Solwind in an orbit at 525 km. The debris from this test lasted in orbit for 17 years, putting other satellites at risk. This debris cloud illustrates the need to avoid tests of destructive, debris-creating ASAT weapons.

The United States latest venture into using a weapon against a space target is the 2008 shootdown of the dead satellite USA-193. This satellite was out of control and on its way to crash on Earth with a large amount of hydrazine onboard. It was shot down by the US-guided missile cruiser USS Lake Erie using a modified missile defense weapon, thus illustrating the residual capability of ABM systems to act as ASAT systems. The satellite was hit at a height of 247 km where the debris does not pose a threat to other satellites and the life expectancy of the debris is in the order of weeks, not years.

The most well-known space weapons ideas to come from the United States were probably the various space components of the Strategic Defense Initiative (SDI), also known as Star Wars. Under the auspices of SDI, a number of more or less exotic weapons were discussed as possible ABM weapons in space. One was the nuclear pumped X-ray laser and another was the autonomous interceptor missile system called Brilliant Pebbles. If deployed, these would have been ABM and not ASAT weapons, albeit with a residual ASAT capability.

### 54.3.2 Soviet Union

The Soviet Union started more or less in parallel to the United States to develop technology for ASAT weapons in the early 1960s. An ABM system with nuclear warheads was the ABM-1 Galosch that is thought to have a residual ASAT capability, with the same drawbacks as the US Nike-Zeus and Thor missile: the nuclear blast would destroy not only the target but any other satellite that passes through the radiation belt created by the explosion.

The main effort in ASAT development in the Soviet Union was the co-orbital ASAT, also known as the space mine, in Russian *Istrebitel Sputnik* or *IS* (Peebles 1983). In November 1963, the first technology demonstrator of a Soviet space vehicle that had the ability to change its orbit was launched (Siddiqi 2000). The ability to change orbit is essential for a co-orbital space weapon, as it is designed to be launched into space and enter into more or less the same orbit as its target. Once in orbit with and in close proximity to the target, a controller on the ground can decide if to detonate the weapon immediately or if it is to orbit with the target until a future time.

Between 1967 and 1982, about 20 tests of the IS system were made, and the system was declared operational in 1978 with the designation IS-M. The IS-M carried a conventional warhead. The system is said to have been capable of engaging satellites at heights between ca. 250 and 1,000 km. Tests were postponed during the US-USSR ASAT negotiations 1978–1979 but resumed in 1980. The designation from 1980 was IS-MU, and further tests were conducted until 1982 when the Soviet Union declared a unilateral moratorium on ASAT tests. The IS-MU remained in service until 1993 when it was decommissioned (Dvorkin 2010).

A weakness in a *co-orbital system* in comparison to a *direct ascent system* is that the time for an engagement is much larger. There could also be a limit on what target you can engage due to the inclination of the target satellite and the possible inclinations you can reach from your launch site with the amount of fuel carried by the interceptor satellite. Both the engagement time and the inclination limitation can be overcome by an air-launched direct ascent missile like the US ALMV. Thus the USSR started a development of an airborne ASAT weapon called KONTAKT that was to be launched from a MiG-31 fighter, but the development was canceled in the mid-1990s (Dvorkin 2010).

A system that could be called a Space Weapon was the *Fractional Orbital Bombardment System*, or *FOBS*. This was a Soviet system for delivering nuclear warheads over long distances, probably aimed mainly at the United States. By putting the warhead into Earth orbit instead of a ballistic trajectory, three advantages were gained. The first was that the attack could come from any direction, not only from the direction of the Soviet missile fields. The second advantage was that the range of a system that puts a weapon in to orbit and deorbits the warhead is truly global, while the range of an ICBM is limited by the curvature of the Earth. The third advantage would be that a launched missile is possible to "recall," in the sense that after launch, it could be commanded to deorbit its payload somewhere else than on the intended target. Since the Outer Space Treaty forbids placing nuclear weapons in orbit, the FOBS was supposed to use only a part of an orbit as not to breach the treaty. The development of FOBS stared circa 1962, and the system was probably operational between 1968 and 1982. After the SALT II negotiations, FOBS was decommissioned (Peebles 1983).

### 54.3.3 China

China and Russia are the two foremost champions of the suggested PAROS treaty presented to the United Nations Conference on Disarmament in 2002. Therefore, it came as a surprise when on January 11, 2007, China tested a destructive ASAT weapon on one of its own decommissioned weather satellites (Wright 2007). The missile was probably a modified medium range ballistic missile (MRBM) called DF-21. It hit the target at a height of 850 km creating more than 2,000 pieces of trackable debris. Due to the height, the debris is expected to stay in orbit for hundreds of years in a region commonly used for both military and civilian satellites.

### 54.3.4 India

India has yet to conduct an ASAT test but is actively pursuing an ASAT capability. In January 2010, the director-general of India's Defence Research and Development Organisation, DRDO, stated that India has begun development of weapons that can destroy enemy satellites in orbit (de Selding 2010). Very little is known of India's ASAT program, but it is thought to consist of a kinetic energy ASAT missile and possibly also directed energy weapons (Gopalaswamy and Wang 2010).

## 54.4 Available and Emerging Weapon Concepts

As noted above, the term space weapon is not well defined. Some space weapon concepts are more or less only existing weapon technology adapted to space. One example is the direct ascent kinetic energy ASAT missile which is a ballistic missile fitted with a seeker that can "see" a satellite against the cold space. Other concepts are unique to space, either in the physical phenomena exploited for weapons effect or in the unique advantages of the space environment. Examples of the former are particle beam weapons, and examples of the latter are hypervelocity rods. The technical feasibility of some concepts is open to debate, and the cost is in many cases prohibitive.

Neither a weapon on Earth pointing at space nor a weapon in space can exist in isolation. It is always a part of an intricate system consisting of sensors, decision makers, and weapon platforms bound together by a command and control system. The properties of space as a battlefield will make the issues of command and control

**Table 54.1** Possible space weapons concepts for the three main missions that require or benefit from space weapons

| Missions | Earth to space | Space to space | Space to earth |
|---|---|---|---|
| Global ground attack | n/a | n/a | Hypervelocity rods |
| | | | Space-based laser |
| | | | Precision munitions |
| Ballistic missile defense | ABMs | Space-based laser | n/a |
| | Ground-based laser | Space-based interceptors | |
| Antisatellite | ASAT missiles | Space-based laser | n/a |
| | Ground-based laser | Space-based interceptors | |
| | | Space mines | |

more complicated for space weapons than most weapons on Earth. However, these command and control challenges will in this context not be treated as a part of the weapons concept and will only be discussed briefly in the weapon system descriptions below.

Space weapons could add value to three different military space missions. Table 54.1 below lists some of the commonly discussed space weapons and relates the weapons to the various missions. The list is not exhaustive and other concepts or variations of the concepts can be added. Each concept will be discussed below in varying detail.

Ballistic missile defense weapons must of course be deployed as to be able to reach the missiles or reentry vehicles in their trajectory, but the shape and height of the trajectories are limited to ballistic trajectories at heights below circa 1,000 km. If the targets of the adversary's missiles are known or can be gathered from intelligence and the launching sites are known, the critical factor is the geographical location of ABM systems. The requirements of the performance of Earth-to space or space-to-space ABM systems are probably consistent regardless of exactly which threat missile the ABM is targeting.

Antisatellite systems have other challenges. The targets, the satellites, can be in any of an infinite number of orbits, ranging from a few hundred kilometers to the extreme high orbits at 120,000 km. Most satellites are to be found in LEO, medium Earth orbit (MEO), or geostationary Earth orbit (GEO), but there are other more exotic orbits like the highly elliptic Molniya orbit. To design an ASAT system with performance to target any satellite in any orbit would be extremely expensive and an overkill in view of the fact that most satellites are in LEO, which also are the easiest orbits to access with an ASAT weapon. Thus the design of an ASAT will to some degree mirror the expected targets or at least in which orbit the expected targets are to be found. The ASAT systems described in this section will be systems suitable for attacking satellites in LEO. In some cases there will be comments on the suitability for targeting satellites in other orbits.

The various concepts are described alphabetically below.

### 54.4.1 ABMs

The antiballistic missile mission comes in three distinct phases: boost-phase defense during the time the engine of the adversary's ballistic missile is burning, midcourse defense during the time the missile or at least the warheads are passing through space, and terminal defense when the missile/warhead reenters the atmosphere close to the target. A boost-phase defense must be placed close to the launching site of the missile. For boost-phase defense, space-based weapons could add value, but ground-based missiles are less effective during the boost phase because of the challenges in deploying them close to the launch sites.

Ground-based ABMs are suitable for midcourse and terminal defense The terminal defense would act within the atmosphere and is thus not a space weapon. For a ground-based ABM system to be effective, it should be placed under the expected flight path of the missiles. The launcher technology for ABMs is mature, as the ABM is just a ballistic missile in itself. That what makes it an ABM system are the seeker and the kill mechanism.

The current US ground-based interceptor (GBI) uses an exo-atmospheric kill vehicle which hits the incoming ballistic missile and destroys with kinetic energy. This technique makes it advantageous for the defense to shoot at an incoming missile head on, as this is favorable from an energy perspective. The combined velocity of the kill vehicle and the target when they fly towards each other creates more kinetic energy than if the kill vehicle slowly overtakes a target flying in the same direction.

A more exotic warhead described in the 1980s in connection to the Strategic Defense Initiative is the nuclear pumped X-ray laser. The idea is to use the energy from a nuclear explosion to create intensive laser radiation in the X-ray part of the spectrum. The laser would fire a fraction of a second before the nuclear blast destroys the weapon. This kind of system could be based on the ground or at sea on ships or submarines. On detection of a missile attack, the X-ray laser could be launched into space to detonate. X-rays are absorbed in the atmosphere which means that the weapon must be fired above the atmosphere at a target that also is above the atmosphere. The nuclear detonation of the X-ray laser would of course have all the drawbacks of nuclear detonations in space with artificial radiation belts in space and generation of an electromagnetic pulse (EMP) on the ground.

One feature of ground-based ABM systems is that they have a residual capability as ASAT systems. This was demonstrated in 2008 by the destruction of the US satellite USA-193 by a modified ABM. The modifications to the missile are said to be in software only, making it impossible to distinguish an ASAT-configured missile from an ABM-configured missile.

### 54.4.2 ASAT Missiles

Missiles as ASAT weapons have already been deployed and used, as described above. The technology is mature and the cost is, obviously, acceptable. Anyone who possesses a medium range ballistic missile has a potential ASAT weapon, but to turn the missile into a threat against satellites, a suitable warhead and homing device must be developed. The trade-off in this case is that a simpler warhead demands a more accurate homing device, and vice versa.

There are two basic concepts of ASAT missiles systems, the *direct ascent ASAT* and the *co-orbital ASAT*, or space mine. Conceptually, the direct ascent ASAT is a weapon that is aimed and fired at a target, in the same way an air defense missile targets an aircraft or an anti-ship missile is fired at a surface ship. The term *direct ascent* signals that the missile ascends directly towards the target, i.e., the weapon does not spend any time in Earth orbit.

As in the case of ABMs, the vehicle for a direct ascent ASAT is just a ballistic missile. The technology is mature an available to many nations. The guidance and control are the challenges. As the time to rise from Earth to LEO is in the order of minutes, the missile cannot be aimed directly at the target but must be aimed at a predicted spot where the target is expected to be in the near future. Thus an ASAT is not launched in anger on a "target of opportunity" but launched in a deliberate attack that has to be well prepared.

Once the ASAT is in the vicinity of the target, a seeker or homing device in the ASAT must lock on to the target and guide the ASAT until it is close enough to the target for the warhead to have the desired effect. The best option is probably an infrared sensor that can detect the heat signature of the satellite against the cold space.

When the ASAT is close enough to the target, the warhead is activated. There are a number of potential kill mechanisms that can be used in an ASAT warhead:

- Kinetic energy, where the ASAT has to collide with the target in order to destroy it by means of the kinetic energy in the collision. The collision between ASAT and target will create large amounts of orbital debris, jeopardizing the use of space for all.
- Conventional explosives that detonate in close proximity to the target. As there is no atmosphere in space, there will be no shock wave from the explosion. The explosive must therefore be surrounded with shrapnel or pellets that hit the target. This method is also debris creating. A warhead with conventional explosives will put a demand on the homing device to place the warhead within about a kilometer from the target (Peebles 1983).
- A high-powered microwave (HPM) source that damages or destroys the electronics of the target. This can be done either with microwaves tuned to use the target's antennas to get in to circuits or by a more brute force approach with a high-powered source on any frequency that enters the targets through gaps and seams in the satellites casing (Wright et al. 2005). The demand on the homing device would be about the same as for a conventional warhead, but the HPM affects the satellite by using electromagnetic creating less debris than an explosive warhead.
- Nuclear detonations that destroy the target by means of intense radiation. A megaton nuclear warhead needs to detonate within about 10 km from the target but will through the artificial radiation belt that is created ultimately

damage or destroy any other satellite that passes through the belt (Peebles 1983). The artificial radiation belts decay over time with about 10 % of the electron population surviving after 12 months (Hoerlin 1976)[3].

A satellite that is "shot down" does not crash like an aircraft. Since the orbit to begin with was just a free fall towards the Earth, the satellite or the debris will continue to orbit the Earth after the attack. As the US test of 1985 and the Chinese test of 2007 have shown, an ASAT can create large amounts of debris, and the debris can stay in orbit for a long time. The time it takes for the debris to deorbit depends on the height of the satellite that is attacked. A higher orbit means a longer time for the debris to deorbit.

When a satellite breaks up, each piece of debris goes in to an orbit of its own. Over time, the debris will spread into a cloud around the Earth. If the breakup is due to an ASAT attack, at least some pieces from the weapon will join the debris cloud.

### 54.4.3 Ground-Based Laser

The word *laser* is an acronym for *light amplification by stimulated emission of radiation*, which means that laser radiation is just a form of electromagnetic radiation. Laser light has a number of properties that distinguish a laser from a common light bulb. One such property is that the laser emits light at only one specific wavelength, another that the light is directed, i.e., all the energy from a laser is concentrated in a thin beam.

If enough light is concentrated in a small area, the illuminated surface will heat and the object will in due course be destroyed. This can be used as a weapon, and the fact that the light is concentrated in a thin beam makes it possible to use laser weapons over very long distances, thousands of kilometers. However, laser light is absorbed by the atmosphere. The absorption is dependent on the wavelength of the light. The atmosphere is opaque to X-rays and some infrared wavelengths but transparent to ultraviolet, visible light, and some infrared wavelength.

The wavelength emitted by a laser is dependent on the lasing medium. The classical helium neon (HeNe) laser emits red light, and a carbon dioxide ($CO_2$) laser emits in the infrared. The red lasers used for laser pointers are weak, in the order of milliwatts (mW), and the $CO_2$, used for industrial cutting and welding, can have an output of hundreds of watts.

To damage or destroy a target with a laser weapon, energies in the order of 200 megajoule (MJ) per square meter (20 kJ/cm$^2$) might be necessary (Bulkeley and Spinardi 1986). Since even a narrow laser beam has a small spread that over thousands of kilometers easily would spread to the size of about one square meter, the amount of energy that has to be directed onto the target would be

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[3] The survival of 10 % for 12 month is reported data from the Starfish experiment in 1962. The decay will vary with height and be considerably faster on low altitudes due to scattering in the atmosphere.

about 200 MJ. To achieve this with a laser "shot" one second long, the laser would have to emit at least 200 MW, which are six orders of magnitude over an industrial cutting laser[4].

The large amount of energy needed for a laser weapon makes ground-based lasers (GBL) a more realistic alternative than space-based lasers. The technology is available and both the United States and the Soviet Union have experimented with ground-based lasers for space applications. A GBL requires a large fixed infrastructure which makes it expensive and vulnerable in times of war. As ground-based lasers require large amounts of energy, they will probably only be an option for industrialized nations that already have an advanced energy infrastructure Furthermore, a GBL has to be built on either national territory or on a territory where the constructing nation has a long-term guaranteed access and access to the energy necessary.

A GBL is subject to the latitude restriction mentioned in Sect. 54.2 above. It can only engage targets that pass overhead within range of the laser. This makes a GBL primarily an ASAT weapon, suitable to engage reconnaissance satellites that pass over the GBL nations territory. The effect of the laser upon the target can be varied. The laser can be used to temporarily blind an optical sensor but it could, if the laser is powerful enough, be set to permanently damage or destroy the target.

Ground-based laser for the ABM mission was discussed as a part of the SDI (Grabbe 1991). In that context the GBL would be placed in the Continental United States and be used against missiles launched from the Soviet Union. This was to be achieved by two sets of mirrors. The first mirror would be placed in geostationary Earth orbit (GEO) at 36,000 km, and the second set of mirrors would be in LEO, covering the Soviet missile fields. When engaging Soviet missiles, the laser would send a beam to the GEO mirror, which would reflect the energy to the mirrors in LEO which would direct the energy on to the targets.

Regardless if the GBL is to be used for ASAT or ABM missions, there is one basic weakness and that is clouds. The laser wavelength has to be chosen in one of the "windows" where the atmosphere is transparent, but clouds will in any case stop the laser. The obvious way to remedy this weakness is to build multiple GBL units and place them in areas where there is a low probability of clouds.

### 54.4.4 Hypervelocity Rods

Often cited possible future space-to-Earth weapons are the hypervelocity rods, called "Rods from God" in popular literature. The rods would be free falling heavy missiles without warhead that are dropped from a great height and fall to Earth, destroying the target by way of kinetic energy from the fall. The concept can

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[4] The description of lasers for weapons application given here is very much simplified and is only included to give the reader an idea of the restrictions and challenges that applies to laser weapons in space.

be traced back to science fiction in the 1950s but won some credibility in the "real world" when hypervelocity rod bundles were listed in the US Air Force Transformation Flight Plan in 2003 (Defense Science Board 2001) as one of a number of key future system concepts. The concept is not described in the USAF document, beyond the statement that the rods would provide the capability to strike ground targets anywhere in the world from space.

The common description of the rod bundle is a satellite system with command and targeting capabilities and a number of tungsten rods that can be dropped from orbit on to a target anywhere in the world. The rods in themselves are often described as 6 m in length and with a diameter of 0.3 m (Adams 2004). This would put a single rod at about 8 t or a bundle of five rods at 40 t.

A more realistic size of the rods would be in the order of one meter in length and about 100 kg. The size is important as the rod must survive the heating when it passes through the atmosphere. If it is too small, it will turn to dust and about 100 kg is probably the smallest possible (Preston et al. 2002).

After a free fall from LEO to Earth, an object would hit the ground at about 3 km/s or Mach 10. The destructive power of the kinetic energy from such a fall is roughly equivalent to the object's weight in high explosives. Thus a 100-kg rod hitting the Earth at Mach 10 would equal the destructive power of a 100-kg ordinary high explosive bomb.

When a weapon satellite in orbit is to drop a rod, it cannot just be released. Remember that the orbit is just a free fall to Earth and simply releasing the rod would keep it in orbit with the weapon satellite. The launching of a rod would require at least two actions: first, if the rod is ejected by the satellite, the satellite will recoil and this leads to a need for an engine on the satellite to counter the recoil and keep the satellite in orbit. The satellite would need to carry fuel to counter the recoils for every rod that is ejected. Second, the rod has to slow down. Even if ejected it will still be traveling 7 km/s parallel to the Earth surface and basically still be in orbit. It needs a push to start falling towards Earth, and if the target is directly below the satellite, the push needs to be in order of 7 km/s (Preston et al. 2002). For various reasons it is desirable to have the rod penetrating the atmosphere more or less vertically, thus the rod has to be decelerated, regardless of the distance to the target.

When the rod passes through the atmosphere, it cannot be allowed to fly, but it must fall, ideally more or less straight down. The challenge would be to design the body of the rod in such a way as it does not have any aerodynamical properties at all. If it stops falling and starts flying when it passes through the atmosphere, the impact point will become unpredictable and the weapon will most probably miss its target. The next challenge in designing the rods is the problem of heating when the missile enters the atmosphere. The rod must have a way to get rid of excess heat during the time in the atmosphere. Ablative coating cannot be used as there is no guarantee that the ablation will be symmetrical. If the missile is deformed by the ablation and starts to tumble, it will become unpredictable and miss the target.

Finally, the rod must hit the target with enough velocity, i.e., kinetic energy, left after being decelerated in the atmosphere, but not so hot as to be liquefied by the heat. There are indications that the rods would liquefy at about 1 km/s (Garwin 2003), which is considerably less than the 3 km/s needed to equal a conventional bomb.

### 54.4.5 Precision Munitions

A seldom mentioned space-to-Earth weapon would be a system of reentry vehicles dispersing "smart bombs" in the atmosphere. The idea would be to mate currently available technologies like the JDAM GPS-guided bomb and reentry technology from space programs to create a system that releases a reentry vehicle that withstands the heat from the passage through the atmosphere. Once the vehicle has been decelerated and reaches a height of a few kilometers, the guided munitions it carries are released to home in on the designated targets.

The release in orbit of an RV with precision munitions will have the same challenges as the release of a hypervelocity rod, but the demand of vertical penetration of the atmosphere and no aerodynamical properties are much less stringent. The guided munitions will use proven technology.

The absentee ratio of a system with precision munitions will be a trade-off between desired response time and fuel to extend the lateral range of the reentry vehicles.

### 54.4.6 Space-Based Interceptors

The original plans for the Strategic Defense Initiative called for space-based interceptors (SBI) to be deployed as part of a boost-phase missile defense. The system would basically be an ABM launcher on a satellite in LEO. Each satellite could carry a number of missiles, and it could either be designed to operate autonomously in an ABM role (cf, BRILLIANT PEBBLES) or it could be controlled from the ground.

The range of a space-based ASAT/antiballistic missile is dependent on the amount of fuel it carries. It is reasonable to assume much shorter ranges than for directed energy weapons. An SBI would probably have a range measured in hundreds of kilometers rather than in thousands. The kill mechanism employed would most probably be kinetic energy.

The range limitation will lead to trade-offs for anyone contemplating an SBI system. If the system has a range of, e.g., 300 km and it is to be able to attack ballistic missiles at a height of 100 km, it could obviously not be orbiting higher than 400 km. However, the lateral range in this configuration would be nil. A possible trade-off would be to orbit the SBI at 300 km, giving it a lateral range against ballistic missiles of about 200 km.

A system as in the example above orbiting only at 300 km would need to adjust the orbit fairly often and would need a large amount of fuel just to stay in orbit. Without this fuel the satellite orbit would decay within a few months. A way out is to choose a higher orbit and increase the range of the missiles, but once again to the cost of more fuel.

To achieve global coverage, missiles having a lateral range of 200 km orbiting at 300 km would lead to a five-figure absentee ratio. It would not be very effective as an ASAT as it would only be able to target satellites below 600 km.

The missile would need a homing device and the most probable is an infrared seeker. It would be tuned to home in on the exhaust of a ballistic missile or on the IR signature of a satellite. This limits the usability of an SBI for the boost-phase ABM mission. The IR seeker would effectively go blind in the atmosphere as the heat building up from the friction would obscure any signature from the target. This requires the SBI to stay outside the atmosphere, over about 100 km. Thus the SBI in this configuration would only be able to target ballistic missiles in the short period when the missile has risen above 100 km and the engine is still burning, typically a period of 30–60 s.

Once the missile has deployed its independent reentry vehicles (RV), it will be the RVs that will have to be targeted which is much harder to do since they have no, or a very small, IR signature.

Using SBIs in an ASAT role and for the midcourse ABM mission is more plausible. With the same range as assumed above, 300 km, and orbiting at 700 km, it would cover LEO between 400 and 1,000 km. The seeker would be tuned to find the cold bodies of satellites or RVs against space and not be dependent on the hot exhausts of the rocket engine. The absentee ratio for ranges in the order of 300 km would still be large if global ABM coverage is to be achieved. However, the ASAT mission does not demand the same leakproof coverage as the ABM mission, and even one single SBI satellite would give the operating nation an ASAT capability.

As the geometry for interception of a satellite in a completely different orbit from the SBI would be complicated, there is no guarantee that even over time any satellite in LEO would come within range of one single SBI. Once again, to the cost of more fuel and a larger absentee ratio, a better coverage could be achieved.

### 54.4.7 Space-Based Laser

A long time favorite for a space-to-space weapon is the space-based laser, SBL. Even though laser technology is mature, the technology for a powerful laser based in space is not. Placing a laser in space, outside the atmosphere, has the important advantage that the wavelength can be chosen with less regard to atmospheric absorption than for a ground-based laser. Still a limiting parameter would be the amount of energy needed to affect the target. Another limiting factor is the size of the mirror needed to focus the laser beam on the target.

Due to the nature of the light, there will always be a certain spreading of laser beam. To make the laser in to an effective weapon, there is a need to make this spreading as small as possible on the target, i.e., focus at much energy as possible in as small an area as possible on the target. The spreading increases with range and wavelength and decreases with the size of the mirror (Bulkeley and Spinardi 1986).

The design of a space-based laser would be a trade-off between size and range, and it would be dictated by the wavelength that is emitted by the lasing medium. The former US plan[5] to test the feasibility of an SBL was built on a chemical laser using hydrogen fluoride (HF) that emits laser light at 2,7 μm (Defense Science Board 2001). With this wavelength and a mirror 10 m in diameter, the spot size at 3,000 km would be about 1 $m^2$ (Bulkeley and Spinardi 1986). A shorter wavelength of the laser could use a smaller mirror to reach the same effect, or with the same mirror a shorter wavelength would translate to a longer range.

One advantage with the long range is that a constellation could be deployed on higher altitudes, above 1,000 km. Global coverage could be achieved with an absentee ratio between 20 and 30 (Preston et al. 2002). The challenges in deploying even one SBL in an orbit at 1,000 km are huge. The weapon has been calculated to have a weight of about 40,000 kg with the largest part being a very sensitive high precision mirror with a diameter of 8–10 m (Defense Science Board 2001). Currently, there are no launchers capable of putting that kind of payload into orbit.

There are numerous challenges in the design of an SBL if it is to carry out its assigned task of ballistic missile defense effectively. The optics must be able to keep the laser spot steady on a target 3,000 km away long enough to project the energy needed to destroy the target. Vibrations from the weapon might affect the optics and thus the beam quality. By increasing the power of the laser, the time required to keep the laser beam on the same spot on the target decreases. In the example with the GBL, above a 1-s "shot" was assumed. During the discussions on the SDI in the 1980s, lasers with a power of 25 MW were assumed (Bulkeley and Spinardi 1986), requiring the beam to stay on target for about 8 s. Which is the harder to achieve; a steady beam for 8 s or an eight times as powerful laser is a trade-off to be studied.

If the purpose of the SBL is ballistic missile defense, the SBL has to switch from one target to the next fairly quickly. To switch from one target to the next, the mirror has to move and then stabilize before the next "shot" can be fired. There is a risk that the movement induces oscillations in the system that degrades its effectiveness.

The SBL might be more suitable in an ASAT role than in the ABM role, due to the fact that most satellites probably are structurally more vulnerable than ballistic missiles. An SBL design focused on the ASAT mission could use lower power lasers and probably a smaller mirror. The time demand for switching from one target to the next would probably not be as stringent as for the ABM mission.

Theoretically, a space-based laser could be used as a space-to-Earth weapon. The critical parameter would be the wavelength of the laser beam. The HF laser would not do as it does not penetrate the atmosphere down to ground. A shorter wavelength, preferably in the visible or ultraviolet range, should be used. There are

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[5] The plan, called Integrated Flight Experiment, to test technologies needed for a space-based laser on a demonstrator satellite was canceled in 2002.

other chemical lasers and there are other laser technologies, such as the free electron laser, that might make a high power laser with shorter wavelengths feasible.

The problem with clouds for an SBL in a space-to-Earth mode would be the same as for the GBL in an Earth-to-space mode. The choice of targets for an SBL in space-to-Earth mode is also a challenge. If the SBL can be made to distinguish and target ballistic missile against the background of the surface of the Earth, it might be possible to distinguish and target aircraft in flight, at least aircraft using afterburners. Otherwise, an SBL might only be able to attack stationary targets on the ground that are vulnerable to laser.

### 54.4.8 Space Mines

As opposed to a direct ascent ASAT, a *co-orbital ASAT* does enter in to Earth orbit. Conceptually, the delivery of a co-orbital ASAT is a satellite launch where the weapon is not the launcher but the satellite. Once the weapon satellite is in orbit, it becomes a space mine.

Space mines would not be deployed in mine fields like sea mines or land mines. There are three reasons for this. The first is that nothing is stationary in space and the mine must in itself be in an orbit. A minefield in space would be constantly moving. The second is the vastness of space even close to Earth. The volume of space that is occupied by LEO, ca 100–1,000 km above the Earth, has a volume of roughly $6*10^{11}$ $km^3$, or 600 trillion cubic kilometers. The probability that a mine in space by chance would destroy anything, and much less the intended target, is close to nil. The third reason is that all satellite operators routinely track and maneuver their satellites to avoid collisions with space debris. A chance encounter with a space mine would be avoided in the same way an encounter with debris is avoided.

A space mine will always be a guided weapon targeting a specific satellite. To do that, the easiest way is to enter into an orbit together with the target, thus co-orbital ASAT.

The most efficient from an energy perspective is to launch the co-orbital ASAT directly into the same orbit as the target. This restricts a co-orbital system into targeting satellites with an inclination equal to or higher than the latitude of the launch pad launching the ASAT. If so designed, the co-orbital systems could go into one orbit and then change it into an orbit close to the target's orbit, overcoming the latitude limitation. The price for this approach is the use of far more energy than a direct ascent weapon, first, energy to go into Earth orbit and then energy to change orbit. More energy means more fuel and more fuel means a heavier and thus more expensive system.

The co-orbital ASAT is even less a weapon to be fired in anger than the direct ascent ASAT. The launch of the co-orbital ASAT must be timed with the target satellite's orbit as for the ASAT to be able to reach its target with available fuel. Once the co-orbital ASAT is in orbit, it has to be controlled from the ground like any other satellite.

A co-orbital ASAT would probably be the weapon of choice to attack satellites in higher orbits. To attack a satellite in GEO, the co-orbital ASAT would be injected into a geostationary transfer orbit (GTO) and then made to enter GEO where it would be allowed to drift until it is close to its intended target.

The kill mechanisms for co-orbital ASATs could be much the same as for direct ascent ASATs, with the same disadvantages of space debris and artificial radiation belts.

## 54.5 System Exploitation

### 54.5.1 The Maturity of Space Power

The world today can be described as multipolar (as opposed to bipolar with the two superpowers the United States and Soviet Union) with many actors vying for a place in space. The technical development coupled with political ambitions entails a world where several actors seek to obtain space power. This is nothing controversial, as the basic treaty levelling the playing field of space, the Outer Space Treaty (OST) of 1967, clearly states that "Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind (. . .)."

There are as many definitions of the term space power as there are analysts and authors. Space power could be something to have, something to be, or something to use. Space power can be defined as "the pursuit of national objectives through the use of space capabilities",[6] i.e., a nation can strive for a position as a "power" by the exploitation of space. This is not the same as being a power in space in the way that a nineteenth-century nation with a large navy could be described as a "sea power." Space power does not necessarily mean "having power in space." This, if true, is an important distinction as it implies that a nation can have space power or could be a space power without any military offensive capabilities in space.

Space is in many nations a political tool to drive development. Space projects are national prestige projects, and the current trend of integrating space into military capabilities has led to an increasing number of nations engaging in space activities and trying to become space powers.

### 54.5.2 Military Use of Space as a Driver for Antisatellite Weapons

The use of space-based systems for military and intelligence purposes is as old as the space age. The three basic services provided by space systems have been the same over these past 50 years: Earth observation, communication, and

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[6] This definition and a discussion on space power in Europe can be found in Nicholas Peter: "Space Power and Europe in the 21st Century," ESPI Perspective No 21, April 2009.

navigation. Each of these services has been developed into a broad spectrum of capabilities that are becoming integrated into various weapons systems and command and control system in an ever increasing number of armed forces around the world.

The value of space services integrated into terrestrial systems cannot be overstated. Space increases range, precision, bandwidth, and knowledge, creating an advantage in military terms for the nation using space versus a nation that is not. This is what is referred to as *force enhancement* (Hays et al. 2000). The use of space to enhance military capabilities has of course also created a need to integrate space as an environment and space systems as potential targets into the planning of future military operations. Any nation taking the precaution of planning a defense against a possible future adversary with integrated space capabilities will at some point in time start to think about negation of space assets.

The reliance on space leads to the concept of *space control* (Hays et al. 2000) which in short means that a nation develops doctrines, capabilities, and technologies to assure access to space for itself and its allies, while negating the adversary the use of space. Space control is not primarily about space weapons; it is about knowing what happens in space and to a large degree dictating what is allowed and what is not. Space Situational Awareness (SSA) is an important part of space control, as is the knowledge of the adversary's ground facilities and the possibility in case of war deny the enemy the use of these ground facilities. As a last resort, a nation that subscribes to the concept of space control may find it necessary to develop ASAT capabilities.

As the world has seen, ground-based ASAT weapons already exist and have been tested. There is no reason to believe that it is possible to put the genie back in the bottle. Ground-based ASATs are here to stay and they will proliferate like nuclear weapons and missile technology before them. The fact that ground-based ASATs have been shown to work could however mean that the development of space-based ASATs like the SBI or SBL will be delayed.

The actual use of an ASAT weapon against an enemy would be an act of war. This could be the start of a conflict, the "Space Pearl Harbor" that the Rumsfeld Commission of 2001(Commission to Assess United States National Security Space Management and Organization 2001) wrote about, or it could be one among many engagements in an ongoing conflict. The first operational use of an ASAT weapon would most probably be a political and not a military decision. This is due to the long-term effects on the space environment from the use of debris-creating ASAT weapons and the risk of collateral damage.

In case of war, space systems belonging to all activity sectors mentioned above will to some extent be potential targets, as the dual use of space systems is extensive and commercially owned space systems are to an ever increasing degree being used to supplement military systems. The possibility of neutral and nonbelligerent states to be drawn into conflict due to damage to or destruction of their space systems should be taken into consideration by anyone who contemplates using ASAT weapons.

### 54.5.3 The Quest for Boost-Phase and Midcourse Defenses

The technologies necessary to develop ballistic missiles and space launchers are proliferating. In many areas it is a question of national pride to have mastered "rocket science," and missile projects are a part of the same political tool to drive development as space projects.

Ballistic missiles come in many shapes and sizes. The short-range missiles, with ranges of a few hundreds of kilometers, will have trajectories that do not take them into space and flight times in the order of a few minutes. Interception of these missiles will have to take place within the atmosphere, and even if systems like the SBL could be developed to target short-range ballistic missiles, alternative ground-based missile systems are available or could be developed with less effort than an SBL and deliver the same capability.

The larger challenge is to build a defense against ICBMs with ranges over 10,000 km. An ICBM typically has a number of independent reentry vehicles together with an even larger number of decoys. After the boost phase, which will be about 3 min long, the reentry vehicles and decoys separate from the missiles, and what was one missile could become 10 warheads and a hundred decoys. Thus one target in the boost phase becomes 100 targets in the midcourse phase. This is one of the reasons why it is preferable to destroy the ICBM in the boost phase. Another reason is that the hot flame of the exhaust of the missile makes it easy to detect and follow.

A boost-phase defense could be enhanced by space-based weapon system, e.g., space-based interceptors and lasers. However, such a system must have global coverage, or the nation intent on using its ballistic missile otherwise just would wait to launch until the space-based systems are out of reach. The space-based systems themselves would also be vulnerable to ground-based ASAT attacks.

If an ICBM slips through the boost-phase defense and deploys its reentry vehicles and decoys, there will be a flight time of about 20 min, depending on the range, when the RVs are passing through space. Space-based weapon systems could augment ground-based interceptors in this phase but with the same disadvantages of requiring global coverage and being vulnerable to ASAT attacks.

### 54.5.4 Avoid Going Nuclear Through Space

Only the five major space powers, the United States, Russia, EU, China, or India, would have the means and the know-how to develop and deploy space-to-Earth weapons in a foreseeable future. Those powers, or in the case of EU some member states, already have access to ballistic missile technology and thus have the capability after deployment to attack targets almost anywhere in the world.

There are, however, two reasons why space-to-Earth systems could be of interest. The first is that a ballistic missile attack could be interpreted as a nuclear first strike, creating a nuclear response. Space-based ground attack might be a way to avoid this.

The second reason would be the deployment. While deployment of weapon systems to areas of operation far from national territory often requires a large logistical footprint in the area, the deployment of a space system is done from national territory and is the same regardless of the distance to the area of operations. Once in orbit, a space-to-Earth system could have a shorter response time than a ground-based system, but the time would be dependent on the orbit of the weapon and the latitude of the target.

There seems to be no rationale for anyone to build a constellation of space-to-Earth weapons in peace time only to create a global strike capability. However, as long as there are various arms races between peer competitors, there is always a possibility that technology demonstrators of various aspects of space-to-Earth weapons will be developed. Such a development in one nation may trigger a development of similar capabilities by a competitor, much like the Indian declaration on developments of ASAT after the Chinese ASAT test. Another scenario is that a niche competitor to a major power will try to create an asymmetric advantage by developing space-to-Earth weapons.

### 54.5.5 The Larger System Supporting Space Weapons

To exploit the potential advantages of space weapon systems, they cannot be developed in isolation. The three missions discussed above, ABM, ASAT, and ground attack, all demand C4ISR support[7] with different properties.

For an ABM system to be effective, there should be an indication of ballistic missile launch as soon as the missile engine ignites. For a boost-phase defense to work within the circa 180-s-long boost phase of an ICBM, the launch warning must sound within a few seconds of the launch. This is usually accomplished by early warning surveillance satellites with infrared sensors that scan the surface of the Earth looking for heat signatures of missile launches. Three such satellites in GEO cover most of the Earth surface except the poles.

The warning is relayed from the early warning satellites by way of communications satellites to the missile defense that is activated, whether or not there is a human decision involved will vary with the circumstances. The warning will also be forwarded to the probable target area in order for the population to go to shelters. The warning could also be the trigger for a decision maker to launch a retaliatory strike. All this time critical information need a well-designed and tested communications system.

If the adversary's missile has leaked through the boost-phase defense and deployed the reentry vehicles, there is a need for a dedicated ABM surveillance and tracking system to follow the RVs through space. The information from this tracking system must be relayed to the midcourse defense, once again highlighting the need for secure and fast communications.

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[7] Command, control, communications, computers, intelligence, surveillance, and reconnaissance.

The ASAT mission will require a space surveillance system that has the capacity to catalogue and follow objects in Earth orbit. This can be done with telescopes and radars from the ground in combination with sensors on satellites. All data from the sensors must be processed to a comprehensive space situational picture that identifies the objects in orbit and attributes orbital parameters to each object. These parameters can be used to predict the future position of a space object.

In general terms, a space picture will be better if the sensors are spread around the Earth, including at high latitudes. This means that the best possible space sensor network will not probably be national but international.

Even if the communications for a space picture do not have to support the time critical requirement of a communications system for ABM, communications between the sensors and the processing of data for the space picture need to be secure and timely.

When enough orbital data has been gathered on a potential target, an ASAT could be launched with some probability of success. Today, orbital parameters are available over the Internet on almost all objects in Earth orbit that can be followed from the ground. Even though this data is sufficient for most modeling of the space environment, it would not be good enough to use for weapons applications. Satellites are controlled from the ground and orbits are adjusted. The data accessible through the Internet can be old, and there is no guarantee that the target's orbit has not been adjusted. A nation that is interested in developing ASATs should also develop a space surveillance system, or at least sensors dedicated to gather orbital data for the ASAT system.

One reason to acquire space-to-Earth weapons is to be able to attack targets that would not be within range of terrestrial systems. A prerequisite for this is to be able to gather data on those targets. The first piece of information is of course the position, but more advanced knowledge of the potential targets, like the intended use, presence of nuclear material, etc., is also important.

Most of this target information will have to be gathered by satellites. Especially if the potential targets are in areas with restricted access. A nation developing space-to-Earth weapons would first have to secure access to high resolution satellite imaging and other space reconnaissance capabilities.

There is little point in trying to exploit space weapons if the prerequisites in C4ISR do not exist. Thus space weapons will only be an option for those nations that have an advanced military structure, probably the nations who have gone furthest in the transformation towards network-enabled capabilities.

## 54.6 Future Prospects

The discussion on space weapons and space weaponization has gone through three, more or less, distinct phases. The first phase started at the dawn of the space age and continued until the bilateral ASAT talks between the United States and the Soviet Union were discontinued in 1979. This period is characterized by the bilateral nature and close coupling between space weapons and nuclear weapons.

The initial driver for the development of ASAT weapons was the thought that satellites could be armed with nuclear weapons and had to be destroyed in space before they could launch the weapons. The early ASAT weapons where in themselves nuclear. From this time there are treatises that are bilateral in nature but hinge on the east-west relation and have a clear bearing on nuclear weapons issues. Regarding space, the two best examples are the Partial Test Ban Treaty (PTBT) from 1963 and the Outer Space Treaty (OST) from 1967. A number of nations signed both these treaties, but at the time of their negotiation, there was only a small number of nations, basically the United States and the Soviet Union along with a few of their allies, that had the technological skill and the economical means to carry out research and development which could lead to a breach of the treaties. Once the threat of nuclear armed satellites diminished, the interest for multilateral space security measures seems to have diminished as well.

During the 1970s, the bipolar character of the space security issue remained, and the discussions and treaties were also bilateral between the United States and the Soviet Union, culminating in the abandoned bilateral ASAT negotiations in 1978–1979. Before that, space weapons and space security had played a role in SALT I and SALT II as well as the ABM treaty. It is important to realize that the role of space weapons in these bilateral agreements was not primarily about nuclear weapons but about surveillance and reconnaissance. SALT I clearly stated that it was forbidden to target the *national technical means of verification* (NTMV), i.e., specific surveillance and reconnaissance satellites, with ASAT weapons. Other satellites were not excluded which explains why both the United States and the Soviet Union in this period developed nonnuclear ASAT technologies and tried to reach an ASAT agreement banning all ASAT weapons.

The failure of the ASAT talks in 1979 marks the transition into the second phase of space weapons and space weaponization discussions. When the bilateral talks failed, the Soviet Union took the ideas from the bilateral talks and presented them to the *United Nations Conference on Disarmament* (CD), making the discussion once again multilateral. Shortly after that, US president Ronald Reagan held the famous Star Wars speech, making a connection between space weapons and antiballistic missile (ABM) weapons. This period which continues until the end of the Cold War is characterized by multilateral discussions in the United Nations between actors that themselves are not actively engaged neither in space nor ballistic missiles. It is basically a part of the larger effort in building peace and security between the east and the west, and the discussion dies when the Cold War ends in the early 1990s.

From this period comes the apprehension that space weapons are bad and should be banned, without distinction as to what capability or mission a space weapon contributes. This has nothing to do with space weapons using nuclear warheads or space weapons targeting reconnaissance satellites. It probably has more to do with the fact that space weapons in this period in time equaled ABM weapons and an effective ABM shield would be destabilizing. The capability to defend the nation against a ballistic missile attack would provide the nation in possession of the ABM system a rationale for launching a first strike and rely on the ABM system to defend against a retaliatory strike, making the ABM nation the "winner" in a nuclear exchange (Grabbe 1991).

The third phase of space weapons and space weaponization discussions started ever so slowly in the late 1990s or early 2000s. The driver is no longer nuclear weapons or ABM but the fact that space has become an integral part of everyday life in all industrialized countries and is quickly becoming a tool for the development of welfare and security in the developing counties as well. The argument inherited from the Cold War multilateral discussions that space weapons are bad and should be banned on the grounds that they are destabilizing is no longer necessarily true nor the most important argument.

In the third phase it is not the military capabilities for a few nations that are threatened by space weapons, but military and civilian capabilities for most nations. Everybody has something to gain by exploiting space today, and everybody has a lot to lose if space would become weaponized and even worse if space become an actual battlefield where space weapons create large amount of space debris. This is the most important reason today to prevent a weaponization of space.

## 54.7 Conclusions

The term space weapon is not well defined. It could mean a ground-based weapon for ballistic missile defense or an antisatellite weapon. It could also mean a weapon deployed in space for any of a number of purposes. If ground-based antisatellite weapons by definition are space weapons, space weapons have been around for 50 years.

Space-based systems are used for force enhancement by armed forces all over the world. This will most certainly create situations when someone engaged in a conflict will see a military value in targeting his opponent's satellites. As ground-based ASAT missiles have been shown to work, are economically feasible, and within the technological capabilities of many industrialized nations today, the proliferation of ground-based ASATs will probably continue.

The ballistic missile defense in the bipolar world of the 1980 was seen as destabilizing and not to be pursued. The perception that defense against ballistic missiles would not work came more from the number of missiles and reentry vehicles in a super power first strike, than from perceived technical problems with the proposed ABM systems. In the context of today, these objections are not valid. The main ballistic missile threat today is a small number of missiles from a rogue nation. As a defense against this threat, ABM systems are being developed and most probably will continue to be developed.

As the conceptual difference between a ground-based ASAT and a ground-based ABM system is slight to none, they should in the international arms control discussions be treated together, not separately. However, it is probably not possible to reach an international treaty banning ground-based ASAT and ABM weapons as the proliferation and development have gone too far. What might be achieved is a treaty banning destructive testing of these weapons in space.

Regarding space basing, the situation is quite different. No weapon system has of yet been deployed in Earth orbit. Many missions that could use space-based systems could equally well use ground-based system, with ASAT and ABM as examples. Thus there is currently no driver for space basing of weapon systems.

The most probable course of events is that one or more nations develop demonstrators and in orbit experiments with weapons platforms in space. The best candidate for such a demonstrator is the space-based laser, SBL. If developed into an operational system, the absentee ratio of about 25 is the lowest for the technologies described above, and a SBL would support all the three missions, ground attack, ASAT, and ABM.

If one nation embarks upon the road leading to dedicated space-to-Earth weapons, it is more probable that some system with precision munitions is developed and not a system with hypervelocity rods. While a system with precision munitions is within the technical capabilities of any space power that also has an advance defense industry, the feasibility of hypervelocity rods is questionable at best. There is a lot of research and development left before, if ever, hypervelocity rods would add value as a weapon system.

As long as the development is restricted to demonstrators with a limited life span and not full constellations, the direct threats from these systems are negligible. The indirect effects however are not. The development of a system in one nation could induce a similar development within a competing nation, thus starting an arms race.

Since ASAT technology exists and has proliferated, the weapons demonstrators would in case of conflict be probable targets for ASAT attack. Thus they would only be contributing to the space debris population and not to international security.

This problem exists on an even grander scale, should constellations of space weapons be deployed. A preemptive strike, one space power to another, would in the future most certainly include attack on any orbiting weapon stations. This would create an enormous amount of debris, probably making LEO unusable for satellites for a long time.

The conclusion is that space basing of weapons should at all costs be avoided. If, for any number of reasons, an international treaty banning the placement of weapons in space cannot be reached, voluntary statements of non-weaponization from the major space powers and confidence-building measures should be sought.

Space weapons are not anyone’s to develop. A nation needs to mature both as a space power, a military power, and arms producing power before an undertaking in space weapons development can start. The number of nations that in a foreseeable future could walk up the path of conflict by developing space weapons is limited. They should be able to sit down and find a way off the path before it is too late.

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# SSA Concepts Worldwide

# 55

Brian Weeden

## Contents

**Abstract**

Satellites in orbit around the Earth face a number of threats. A key enabler for detecting and protecting against these threats is space situational awareness (SSA). This chapter will briefly summarize the history of SSA and provide a description of major SSA programs and their development around the world. It concludes with a discussion of the major issues and challenges with improving SSA in the future and improving space security.

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## 55.1 Introduction

Satellites in orbit around the Earth face a number of threats, including natural threats such as severe space weather and human-generated threats such as space debris, radio-frequency interference, and hostile activities. Determining and measuring the impact of these threats on the day-to-day operations of satellites is an important element of the long-term sustainability of the most highly used regions of Earth orbit and critical to space security.

A key enabler for detecting and protecting against these threats is space situational awareness (SSA). SSA is a complex topic that means many things to many people but can be generally defined as information about the space environment and activities in space that can be used to operate safely and efficiently; avoid physical and electromagnetic interference; detect, characterize, and protect against threats; and understand the evolution of the space environment.

This chapter will briefly summarize the history of SSA and provide a description of major SSA programs and their development around the world. It concludes with a discussion of the major issues and challenges with improving SSA in the future and improving space security.

## 55.2 Background and History

Although humans have been observing the stars and planets for millennia, it wasn't until the launch of the first artificial satellite, Sputnik, by the Soviet Union on October 4, 1957, that humans started to focus significant attention on tracking objects in orbit around the Earth. For the next few decades, space surveillance was an important part of the Cold War conflict between the United States and Soviet Union. During this time, the militaries of both countries built large networks of ground-based tracking facilities that collected data on human-generated objects in Earth orbit. Consisting primarily of large tracking radars and optical telescopes, these facilities were often dual-purposed with other military missions, such as ballistic missile warning and tracking. The main focus of space surveillance at this time was on determining the precise orbit of human-generated objects in orbit around the Earth.

Over the course of the Cold War, space surveillance capabilities became more sophisticated. New techniques were developed to help characterize space objects with the goal of determining their function and whether or not they posed a threat to either other space objects or people and facilities on the surface of the Earth. Militaries began to share some space-surveillance data with civil space agencies, whose scientists used the data along with other resources to develop models of the population of space objects and in particular space debris.

Space debris is the remnants of humanity's activities in orbit. It consists of dead satellites, spent rocket stages, fragments, and other assorted detritus. Research done by two influential NASA scientists in the 1970s and 1980s predicted that by the early twenty-first century, the population of human-generated space debris would be dense enough that it would continue to grow on its own due to collisions between pieces of debris (Kessler 2009). This growing population of space debris would also pose a greater risk to satellites than the existing population of natural debris asteroids. The growth of long-duration human spaceflight in orbit around the Earth, and in particular the development of the International Space Station, prompted space agencies to develop procedures for determining potential collisions between space debris and human-occupied spacecraft.

By the 2000s, concerns over the growing population of space objects had increased significantly and with it the importance of space surveillance as a tool for measuring the growth in the space debris population and measuring the potential threat it posed to satellites. The term space surveillance was replaced by SSA to indicate the new focus on not just tracking space objects but generating information about the entire space environment, including space weather and radio-frequency interference (Weeden et al. 2010).

Currently, SSA is one of the most important topics in space security. More than 50 countries operate nearly 1,100 active satellites in orbit around the Earth providing a wide range of services and benefit (Union of Concerned Scientists 2014). The space debris population has grown to more than 22,000 objects larger than 10 cm that are tracked and another estimated 500,000 objects between 1 and 10 cm in size that are currently too small to track consistently (Shelton 2014). In addition to remaining a significant element of national security, SSA is increasingly being used by all satellite operators to help protect their satellites and determine the cause of on-orbit mishaps and malfunctions.

## 55.3 Technologies and Techniques

### 55.3.1 Space Object Tracking

At the heart of SSA is information on the location of objects in orbit around the Earth. This is primarily done by tracking stations located on the Earth. Radars form the backbone of an SSA system. Developed during World War II, radar consists of at least one transmitter and receiver. The transmitter emits radio waves at a specific frequency; some of these waves reflect off the target and are measured by the receiver, which is then able to calculate location of the target in relation to the radar.

There are three main types of radars used for SSA (Weeden et al. 2010). Bistatic radars have one or more transmitter and one or more receivers that are separated by some distance. The transmitter(s) and receiver(s) can be spread out over many miles, and by continuously emitted radio energy, they can create a “fence” that will detect any objects passing through it. Monostatic radars have a single receiver colocated with a single transmitter. The receiver and transmitter are usually mounted in the middle of a parabolic dish that can be rotated and elevated. Also known as mechanical tracking radars, monostatic radars mounted in this fashion are especially well suited to precision tracking of one or a few objects. The third type of radar, phased arrays, is comprised of a collection of small, identical antennas, usually mounted on a fixed “face,” which can vary the phases of their respective signals. By doing so, the effective radiated energy can be “steered” or focused in a specific direction, and in many cases multiple independent “beams” of energy can be individually steered to many targets at once.

The primary advantage of radars is that they can actively measure the range and range rate, providing an accurate measure of the distance to a target. Other significant advantages included the ability of some radars to accurately track many objects at once or use a radar fence to alert objects passing over a specific area and queue other sensors. The main disadvantages of radars are their cost, size, complexity, and the electrical power required to generate the radar beam(s).

Optical telescopes form the second major type of sensor used to track space objects. They operate in the same fashion as telescopes used for astronomy applications: electromagnetic (EM) radiation emitted by an object is gathered and focused to form an image using lenses, mirrors, or a combination of the two. Refracting telescopes use lenses, while reflecting telescopes use mirrors. Catadioptric telescopes used a combination of mirrors and lenses. Although telescopes can be designed for many different parts of the EM spectrum, the visible portion is most often used for SSA and in particular sunlight.

The main advantage of optical telescopes for SSA is their range and ability to cover large areas quickly. Above 5,000 km (3,100 miles) altitude, it becomes very time consuming and difficult for radars to search for objects. Optical telescopes can perform this function much faster and easier. The main disadvantage of optical telescopes is that they require specific lighting conditions and clear skies. To overcome some of these limitations, space-based space surveillance sensors have been created by mounting optical tracking telescopes on satellites to allow them to track other objects in orbit.

As an object in orbit passes over a radar or telescope, data is collected on the object’s precise position at each moment in time. This positional or metric data, called observations, is commonly passed to a central analysis center where it is combined with observations from all the other tracking sites which collected data on the same object, although in some cases each sensor can operate independently.

Multiple tracks of observations on each object are combined through a process called track association (Weeden 2012). Mathematical techniques known as orbit determination are then applied to these tracks to produce an element set, which can be used for predicting where an object is in orbit at a given time. These element sets, along with tasking instructions for the next time period, are passed back to the tracking sites to collect further information. An iterative process is established to continually track and update the element sets for all objects in Earth orbit. These element sets are then stored in a satellite catalog which is continuously updated and corrected through a process known as catalog maintenance.

Satellite operators also have other techniques at their disposal for determining the orbit of their own active satellites. The position of satellites that are in constant communication with the ground can be calculated through precise measurement of the radio-frequency emissions. Commercial satellite laser ranging (SLR) facilities around the globe can also be used. In addition, some satellites have onboard systems for determining their location, such as global position system (GPS) receivers, and can communicate their location through telemetry signals to ground controllers.

### 55.3.2 Object Characterization

Analysis of metric data can also be used to help characterize a space object and determine its function through a process commonly known as space object identification (SOI). SOI is information collected about an object in addition to its position relative to a sensor. For example, as a radar is tracking an object, the amount of radar energy reflected will vary over time if the object is tumbling. The same thing can happen with the brightness of an object as it is tracked by a telescope, resulting in flashes of light.

This information can be used to drive the object's general size and shape and whether or not it is rotating or stabilized which can be used to primarily distinguish between categories of space objects. For example, an object showing a steady RCS of 10 m squared as it passed over a radar sensor indicates it is likely a medium-sized payload that is functional and 3-axis stabilized. But an object showing an RCS that fluctuates between 5 and 20 m squared throughout the pass indicates it is likely a cylindrical, rotating rocket body.

Some of the more powerful radars and telescopes can also be used to create an actual image of an object, revealing its shape. In the case of the telescope, powerful enough optics can produce what we would normally consider to be photographs of an object in the visible range of the spectrum but could also use wavelengths in the ultraviolet or infrared portion of the spectrum to capture additional information. Certain high-frequency radars can also produce images of a type; by integrating the radar return over a period of time, a pseudo-image can be made showing an object's shape in three dimensions.

Analyzing metric data on an object over time can also reveal important information. Certain clues can be determined by the type of orbit or maneuvers performed by the object, such as specific patterns of maneuvers or station-keeping, as well as abnormal activity. However, for the most part, the space object's function and capabilities are difficult to determine just based on metric data.

Thus, in recent years, metric data has been combined with other types of data to provide a more holistic picture. For example, radio detection gear can be used to detect and capture signals emitted from spacecraft to provide additional clues as to characterization and potential function of the space object. By adding additional information on space weather, planned spacecraft maneuvers, and imagery of satellites, it is possible to characterize space objects and in some cases determine intent of space actors.

### 55.3.3 Space Weather

An important aspect of SSA is monitoring the space weather caused by the Sun's activity. Changes in the activity of the Sun result in varying levels of particles and energy emitted by the Sun, which in turn have significant impacts on both satellites and the Earth. Space weather can create problems with a satellite's electrical system or malfunctions due to hardware and software interactions. It can also cause RF interference and make it difficult or impossible to communicate with a satellite over certain frequencies or to receive satellite broadcasts. On the ground, space weather can cause similar interference in terrestrial communication networks. Severe space weather events can cause disruptions in the electrical grid.

Space weather also is an important consideration for maintaining a satellite catalog. For satellites orbiting in medium Earth orbit (MEO) and geosynchronous Earth orbit (GEO), radiation pressure from photons emitted by the Sun has a significant effect on their orbits. The Sun's activity also has an important effect on the Earth's atmosphere. For satellites orbiting in low Earth orbit (LEO) at altitudes less than 1,000 km, atmospheric drag has a significant effect on their orbits. Atmospheric drag causes LEO satellites to orbit lower and lower and eventually reenter the Earth's atmosphere, a process known as natural decay. Detecting when objects might decay and where on the Earth they might impact is an important aspect of SSA.

Space weather is monitored using a variety of tools. Satellites with specialized sensors orbit in a location called the L1 Lagrangian point between the Earth and Sun. Their sensors stare at the Sun, watching for significant events and providing early warning before they can impact the Earth. Other satellites in orbit around the Earth have sensors that monitor the Sun and the radiation and magnetic environment around the Earth. Ground-based observatories are also used to monitor the Sun and the Earth's atmosphere. Data from these various sources is analyzed and used to develop both models of the Sun's behavior as well as provide prediction and real-time warning of space weather events.

## 55.4 Current SSA Capabilities and Systems

### 55.4.1 The United States

The US military currently operates the largest satellite tracking network and maintains the most complete catalog of objects in Earth orbit in the world. Between 1958 and 1960, the tracking of space objects was divided between three organizations: the US Air Force Air Research and Development Command, the Advanced Research Projects Agency, and the US Navy Space Surveillance Network (Weeden and Cefola 2010). In 1960, the Secretary of Defense established a single integrated network, the Space Detection and Tracking System (SPADATS), that combined Air Force and Navy space-surveillance efforts in the operational control of the North American Aerospace Defense Command (NORAD). Eventually, separate centers for space defense and space surveillance were established in Cheyenne Mountain Air Force Station in Colorado. In 1994, these centers were combined to form the Space Control Center (SCC).

In 2006, US Strategic Command created the Joint Functional Component Command for Space (JFCC Space) at Vandenberg Air Force Base (Weeden 2012). The commander of JFCC Space serves as the single point of contact for all US military space matters to plan, task, direct, and execute space operations. To do so, the Joint Space Operations Center (JSpOC) was created to serve as the primary SSA and space command and control entity for the US military, incorporating the functions previously performed by the SCC in Cheyenne Mountain. In September 2007, the JSpOC took operational control of the space-surveillance mission from the SCC, with the US Air Force continuing to provide many of the personnel and capabilities used by the JSpOC.

Although today there are many parts of the US government that do various SSA activities, the bulk of the SSA mission is done by the military, and the JSpOC is the hub. The JSpOC is staffed by military members from all services and several foreign allies, civil servants, and private sector contractors. As part of this mission, the JSpOC is responsible for providing SSA for the US military and maintains the US military's satellite catalog of man-made objects in orbit around the Earth and provides portions of the data and analyses to other US government entities and the world (Chow 2011).

The US military maintains a globally distributed network of more than 20 tracking sites across a significant portion of the globe known as the Space Surveillance Network (SSN). It consists largely of phased array radars located around the periphery of the United States and the northern polar region that are used primarily for missile warning. The SSN also contains a few mechanical tracking radars and a large space fence located along the southern United States. These radar capabilities are complemented by a number of optical tracking facilities located around the world and a space-based tracking telescope onboard the Space-Based Space Surveillance (SBSS) satellite. These tracking sites feed data to the JSpOC at Vandenberg Air Force Base in California where the primary satellite catalog is maintained.

The main drawback of the US military's SSA capabilities lies in the location and distribution of the tracking sites. Many of their tracking radar locations are optimized for their original missile warning functions and are thus located on the northern borders of the United States. This means the system has excellent coverage in the Northern Hemisphere. However, there are no US active military tracking sites located in South America, Africa, Asia, Australia, or Antarctica. As satellites in every orbit, aside from geostationary, are continually moving over the Earth's surface, this presents large gaps in the tracking coverage and sometimes large gaps in time between tracks.

A second drawback is the age of the tracking sensors and the systems used to analyze the data (Weeden 2012). Many of the tracking sensors date back to the 1950s and use outdated technology such as vacuum tubes and lack modern computer controls. These create limitations in both the quantity of data that can be collected and the size of the object that can be tracked. Likewise, much of the computer hardware and software located in the JSpOC which is used to maintain the satellite catalog is outdated. It contains hard-coded limitations such as the total size of the catalog and atmospheric and gravity modeling. Recent attempts to get around these restrictions have resulted in systems which have been designed and built outside the formal military acquisition channels. While functional, these systems are a temporary stopgap measure at best.

The third major deficiency in the US military's SSA system is the lack of data from other actors (Weeden 2012). Entities which own or operate satellites are able to determine the satellite's location with greater precision than is normally possible by third-party tracking. Satellite owner-operators also have data on upcoming maneuvers and orbit changes for their satellites. Very few of these owner-operators share their data with the JSpOC, mostly due to the lack of a trusted relationship between the US military and these potentially international partners. Lacking this pre-maneuver data, the US military is forced to react to maneuvers and task sensors to find and reacquire satellites, which leads to gaps in coverage and potentially losing track of an object.

The US military is working on several efforts to improve its SSA capabilities (Shelton 2014). Life extension and upgrade programs are underway for several of the legacy sensors in the SSN. A new space fence that utilizes S-band radar is being developed that will enable the US military to track many thousands of objects as small as a few centimeters. New wide-field optical telescopes are being deployed that can survey large portions of the GEO belt very quickly and detect changes such as maneuvers or breakups. The US government also established a number of bilateral agreements with other countries such as France, Canada, Germany, Japan, and Australia to share SSA data and perhaps even serve as hosts for new sensors to expand the geographic coverage (Haney 2014).

### 55.4.2 Russia

Russia operates the second largest network of sensors and also maintains good catalog space objects (Weeden et al. 2010). The former Soviet Union established the necessity of a monitoring system for space objects around 1960 with the primary customer being the Ministry of Defense. Development work began in 1962, with the central command and control facility near Moscow and two remote nodes in Sary Shagan, Kazakhstan, and near Irkutsk in Siberia.

Space surveillance was the responsibility of the units that were part of the Air Defense Forces. These units were created in the 1960s to support the missile defense program, and their mission was expanded to early warning and space surveillance. As was the case with the United States, the Soviet radar network focused primarily on missile early warning with space surveillance as a secondary mission.

Until 1976, early warning and space surveillance were operating as separate divisions. In 1976, they were transferred to a newly formed 3rd early-warning army of the Air Defense Forces (which at the time was a separate service of the Soviet armed forces) (Podvig and Zhang 2008). In 1992, Russia created Military Space Forces (UNKS) to support operations of military satellites and the Missile and Space Defense Forces, which included early-warning and space-surveillance units. In 1997, everything was transferred to the Strategic Rocket Forces, but in 2001 space operations, early warning, and space surveillance formed a separate new branch of the military, which in 2011 was renamed the Air and Space Defense Forces.

The Russian military tracking network is currently known as the Space Surveillance System (SSS) and also consists mostly of phased array radars used primarily for missile warning, along with some missile defense radars and optical telescopes (Weeden and Cefola 2010). Several of the SSS sensors are located in former Soviet republics and are operated by Russia under a series of bilateral agreements with the host countries.

The main optical tracking facility is located in northern Tajikistan. Known as Okno or "window," the facility includes a number of optical telescopes that can track objects in all orbital regimes, including LEO, as they pass over Russia. A newer optical facility dubbed Okno-S is located near Primorsky Krai in the Russian Far East.

The Russian military also operates a system called Krona in the Northern Caucasus that combines radars, laser trackers, and optical telescopes that identify and characterize satellites. A new system called Krona-N that utilizes only radars is also in operation near Nakhodka in the Russian Far East. Data from the various space-surveillance sensors are fed to the Main Space Intelligence Center located near Moscow which serves as the central hub for SSA, similar to the JSpOC in the United States.

The Russian SSS has many of the same limitations as the United States, with the problem of geographic sensor distribution being even more pronounced. All of the Russian tracking sites are located in Asia or Europe, and, as such, Russia has no real ability to track satellites when they are not overhead Russian territory. This leads to degraded accuracy of low Earth orbit objects, and a very limited catalog of objects in geostationary orbit as those stationary over the Western Hemisphere cannot be tracked by the Okno systems. To offset these limitations, the Russian military has maintained relationships with academic and research institutions that operate optical telescopes for astronomy or other scientific purposes.

### 55.4.3 Significant SSA Capabilities in Other Countries

Europe does not currently possess an integrated SSA network, although several individual countries in Europe operate some significant individual sensors (Weeden and Cefola 2010). The United Kingdom, France, Germany, and Norway operate tracking radars, and several countries operate optical telescopes of varying capabilities. The European Space Agency (ESA) also operates some scientific sensors that can be used to track space objects in a limited manner.

In 2008, ESA initiated an SSA Preparatory Programme to begin the process of creating a future European SSN system (Bobrinsky 2010). The Preparatory Programme is developing plans, architectures, and policies to provide space surveillance of Earth orbit, space weather prediction and warning, and tracking and identification of hazardous near-Earth objects (NEOs) such as asteroids. However, political challenges hindered ESA's efforts and in 2013 the space surveillance and tracking program was transferred to the European Commission. In early 2014, the Commission approved 70 million euros for a proposal to combine and integrate data from multiple European space surveillance sensors. Several countries in Europe are also negotiating bilateral data-sharing agreements with the United States.

It is assumed by many observers that China possesses radars that are used for SSA, although this is not officially acknowledged by the PRC and little information is available publicly (Weeden and Cefola 2010). The same physics and strategic, political, and geographic considerations that govern the location of the United States, Russian, and European SSA sensors will govern the location of Chinese SSA sensors and the technology used. China is believed to have a network of phased array radars, each likely to have 3,000 km range and 120° of azimuth coverage. China does not possess radars outside of its borders and thus lacks radar coverage outside of eastern Asia. However, China also operates six Yuanwang-class tracking ships which can be deployed to broaden its coverage. These ships are primarily used to support China's human spaceflight activities and could be deployed to provide SSA for other activities.

More information is known about China's optical telescope capabilities for SSA than radars, in part because of China's participation in the Inter-Agency Space Debris Coordination Committee (IADC). China's main optical SSA capabilities are operated by the Purple Mountain Observatory, which operates multiple telescopes in four separate locations that can track satellites throughout all orbital regimes. However, like Russia, China lacks coverage outside of its borders and thus does not have global coverage of the GEO belt.

In February 2013, Canada launched two satellites dedicated to SSA/The Canadian Space Agency's Near Earth Object Surveillance Satellite (NEOSSat) has the ability to detect and track both asteroids in orbit around the Sun and objects in high altitude orbits around the Earth. Sapphire, the first Canadian military satellite, is dedicated to tracking space debris and satellites in high altitude Earth orbit and in early 2014 became an operational contributor to the US SSN.

### 55.4.4 Nongovernmental SSA Capabilities

The International Scientific Optical Network (ISON) is a partnership of scientific and academic institutions around the world organized by the Russian Academy of Sciences in Moscow (Weeden and Cefola 2010). ISON consists of nearly two dozen observatories in 11 countries which operate more than 30 telescopes that are used for space surveillance. ISON is a heterogeneous mix of telescopes of various sizes and capabilities, but as a network it can track a wide range of object sizes throughout deep space and provide a significant number of observations. ISON currently shares some scientific data on space debris with ESA and data on NEOs with other groups.

In October 2009, three of the leading commercial satellite operators formed the Space Data Association (SDA), a not-for-profit entity based in the Isle of Man (Space Data Association 2012). The purpose of the SDA is to collate data provided by participating satellite operators on the locations of their satellites with other external sources and to provide warning of potential collisions or radio-frequency interference (RFI). The SDA chose Analytical Graphics, Inc. (AGI), as its lead contractor in April 2010. AGI established initial operating capability in August 2010 and achieved full operational capability in September 2011. The SDA plans to establish three data centers, one each in North America, Europe, and Asia, to provide backup and redundancy. The SDA is also in negotiation with the US government and other SSA providers on potential data-sharing agreements.

There are also many amateur satellite observers around the globe that use telescopes, binoculars, and other equipment to track satellites. Some have the capability to image satellites or detect radio-frequency transmissions. Although they are only loosely organized through the Internet, the amateur observing community presents a nontrivial SSA capability. In particular, they have demonstrated the ability to routinely track classified national security payloads from several countries.

### 55.4.5 The Future of SSA

The world has changed significantly since the first space-surveillance capabilities were developed. Instead of two superpowers conducting and controlling much of the activity in space, an increasing number of nations are using space for civil, commercial, and military benefits. Twelve nations have developed the capability to place objects into Earth orbit. Seventy nations and international organizations currently operate more than 1,100 active satellites, and there are nearly half a million pieces of space debris larger than 1 cm that pose a collision threat to those satellites.

SSA capabilities have not kept pace with these changes. The national SSA capabilities operated by the United States and Russia still have by far the most capability, but they are struggling to meet today’s demands. The huge leaps in computer hardware performance, drops in cost, and modern software techniques are largely unutilized. More importantly, both the US and Russian systems are still controlled by their respective militaries and rely largely on the premise that national security is their only customer.

The vast majority of satellite owner-operators conduct their activities in orbit without knowledge of the objects around them or the space environment. Although space is by definition vast, certain regions of Earth orbit provide unique utility, and those regions are becoming increasingly congested. This combination of congestion and lack of information can lead to incidents in space, such as the February 2009 collision between the American Iridium 33 and Russian Cosmos 2251. The thousands of pieces of debris created by this event increased the risk of collision for other satellites in the same region. A similar catastrophic collision in geostationary Earth orbit (GEO) that generates a large amount of debris is one of the worst-case scenarios for the long-term sustainability of Earth orbit.

The world does not suffer from a lack of SSA sensors or sources of data that could help improve SSA. Rather, there are challenges that prevent the ability to use the sensors and data that do exist in a reliable and efficient manner and share or combine data between sensors and networks. Some of these barriers are technical in nature and stem from the legacy hardware and software used in existing SSA sensors and networks. There are also technical challenges to overcome in data formats, tasking, calibration, authentication, and data validity.

Improving SSA capabilities also faces significant policy challenges. Many of the legacy SSA capabilities are operated by militaries and have strong security elements. The SSA data available to satellite operators could be used by competitors to gain an advantage. These elements make it difficult to design data-sharing policy that ensures security and privacy concerns are met.

However, none of these obstacles are insurmountable, and the value of improving SSA globally for all space actors likely outweighs the political and economic cost of overcoming these issues. Enhancing global SSA capabilities through collaboration and sharing will improve the long-term sustainability of the space environment by providing all space actors with the information necessary to act safely, efficiently, and responsibly. SSA can also act as a transparency and confidence-building measure (TCBM) to reduce mistrust and misperceptions in space, thereby reducing the risk of conflict and degradation of the space environment. SSA could also serve as an important element of verification or enforcement in future space agreements.

An important question is what form future SSA capabilities will take. One possible framework would be an extension of the existing model, where individual countries or organizations have separate SSA capabilities and there is a degree of data sharing and cooperation between them. This framework has advantages from a political and security standpoint as it would allow more control over the data and some actors to have independent capabilities. The disadvantages are that it would likely include excessive redundancy of capability and an uneven amount of information available to all space actors.

A second possible framework would be to create an international organization, perhaps nongovernmental, that serves as a central clearinghouse and repository for SSA data. Individual countries or organizations would share data with this organization who would in turn maintain a satellite catalog and provide analysis products for all space actors. This framework would likely result in the most complete set of SSA services available to all space actors but would have to overcome political resistance to creating new international organizations and potentially placing them outside of the control of any individual country.

Other frameworks, including hybrids of these two, are also possible. Whatever the case, the future of SSA will hinge on the ability to fuse together at least three data sets – positional data on space debris, positional data on active satellites, and space weather – from a variety of data sources. It will also require delineating between SSA capabilities that are necessary to support civil and commercial operations and safety of spaceflight from those that are fundamentally national security and military in nature.

## 55.5 Conclusions

Over the last 50 years of human activities in space, SSA has shifted from a secondary mission performed mainly by Cold War superpowers alongside missile warning to an important mission on its own that is increasingly being done by a wide variety of actors for reasons other than national security. As humanity's use of and reliance on space increases, so will the importance of SSA as the foundation of space security and sustainability. From monitoring the space debris population and activities in Earth orbit to providing collision warning and alerts, SSA is a crucial tool to enhancing space security.

The US military operates the largest SSA network and maintains the most complete catalog of objects in Earth orbit. The Russian military also maintains a significant network and catalog of space objects. Many other countries operate one or more individual SSA sensors that can contribute in a limited fashion. Nontraditional entities, such as nongovernmental organizations and private citizens, are also emerging as potential sources of SSA data. However, none of the existing SSA capabilities are sufficient to meet the current need.

Significant challenges need to be overcome to enhance SSA capabilities, ranging from upgrading legacy hardware and software to developing data policies that enable sharing between actors while protecting national security and proprietary commercial information. Various frameworks, ranging from increased sharing of data between existing SSA sources to the creation of new organizations to serve as central sharing hubs and data repositories, could be considered to address the various technical and policy challenges.

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# The Space Sector Economy and Space Programmes World Wide

# 56

Christina Giannopapa

## Contents

**Abstract**

In the following chapter, an overview of the space-related budgets is presented. This should provide a quantitative perspective of the overall market value and financial performance of the space activities over the past 24 months. Accurate estimation of global space activities is complicated, due to nontransparent government space budgets in particular on defense-related programs and the lack of a standardized approach for measuring them. A forecast for government space budgets and programs is also provided.

## 56.1 Introduction

Space technologies and their applications are part of our everyday life. They vary from using mobile phones, watching live TV broadcasting, making banking transactions, weather forecasting, plain landing suing air traffic control systems, etc. Even though space activities are taking place already for more than half

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a century, there is no unified definition of what the space sector is, let alone space security.

The space sector started its life through classified military projects serving few governments and has been transformed over the years also to include commercial activities and more nations. However, in spite of being characterized by an intense international cooperation, relies above all on institutional captive markets with limited room for global competition. This is an important element in a return-on-investment analysis regarding public funding. It should be taken into consideration that accurate estimate of global space activities is a complicated task. This is due to the fact that there is lack of a standardized approach and there is lack of transparency in certain government space programs, such as defense-related programs. Additionally, the publication of financial figures by commercial companies is not uniform across the sector and varies in time.

The emergence of several BRIC[1] countries as established space powers is a second feature of the new international landscape. Their share in satellites launched as almost doubled in one decade. Space remains highly oriented towards the generation of scientific, social, and/or strategic returns rather than primarily an immediate source of profit in terms of commercial return, the latter nevertheless being a major concrete feature. Thus, the value of space research and development and subsequent operational assets is first of all political and considered in a long-term economic strategy, whereby institutional funding supports the inception, then the maturing of a specific domain. This is what has justified constant public investment since the dawn of the space age. In particular institutional budgets often contribute to the start-up and development of capital-intensive and high-technology sectors such as space (OECD 2011, p. 50).

As confirmed by the Organization for Economic Cooperation and Development (OECD), since the beginning of the economic crisis, the space sector has fared relatively well, in part because space is a strategic sector, often supported due to national imperatives and institutional funding, because space still supports the implementation of national objectives, and thanks to the good position of telecommunications in growing mass markets (OECD 2011, p. 29). The cyclical nature of the industry in replenishing satellites as well the continuing commercial successes of many space services have contributed to the dynamism of the entire value chain. This is a fundamental element for the future forecast of space in Europe insofar as space cannot be considered a "stop and go" economy, meaning that any break in public investments would result in an immediate loss of industrial capabilities (human or otherwise) which could not be easily restarted later on, as the capabilities to implement space would have been lost and would have to be rebuilt through massive investments.

This chapter defines the space sector according to OECD and provides an overview of the space-related budgets. Institutional as well as commercial space

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[1] Brazil, the Russian Federation, India, and China.

activities are considered. It provides a quantitative perspective of the overall market value and financial activities over the past 2 years. A forecast for government space budgets and programs is also provided.

## 56.2 The Space Sector Economy and Activities

There is no unified definition of what is the space sector and there are a number of definitions. According to OECD (2011), the space sector has nine main product groups of high technology: (1) aerospace, (2) computers and office machines, (3) electronics and telecommunications, (4) pharmacy, (5) scientific instruments, (6) electrical machinery, (7) chemistry, (8) nonelectrical machinery, and (9) armaments (Hatzichronoglou 1997). There is no specific "space activity classification." In the United Nations International Standard Industrial Classification (ISIC),[2] most parts of the space sector are included under different categories. Therefore, isolating the space sector from aerospace and defense sector remains a challenge for a number of countries.

The space sector over the years has become more commercial, and different space applications have emerged outside the traditional research and development (R&D), calling for a wider definition of space economy. This wider "space economy" can be defined using different angles. It can be defined by its products (e.g., satellites, launchers), by its services (e.g., broadcasting, imagery/data delivering), by its programmatic objectives (e.g., military, robotic space exploration, human spaceflight, Earth observation, telecommunications), by its actors/value chains (from R&D actors to users), and by its impacts (e.g., direct and indirect benefits). One drawback is that narrow definitions might ignore important aspects, such as the R&D actors (e.g., labs and universities) and the role of the military (i.e., as investor in R&D budgets and a customer for space services), or ignore scientific and space exploration programs altogether (OECD 2011, p. 16).

Thus, OECD provides the following definition (OECD 2011, p. 16):

> The space economy is the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilising space. Hence, it includes all public and private actors involved in developing, providing and using space-related products and services, ranging from research and development, the manufacture and use of space infrastructure (ground stations, launch vehicles and satellites) to space-enabled applications (navigation equipment, satellite phones, meteorological services, etc.) and the scientific knowledge generated by such activities. It follows that the space economy goes well beyond the space sector itself, since it also comprises the increasingly pervasive and continually changing impacts (both quantitative and qualitative) of space-derived products, services and knowledge on economy and society.

The space economy is larger than the traditional space sector (e.g., rockets and satellites). It also involves new services and product providers (e.g., geographic

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[2] ISIC Rev.4 release in August 2008.

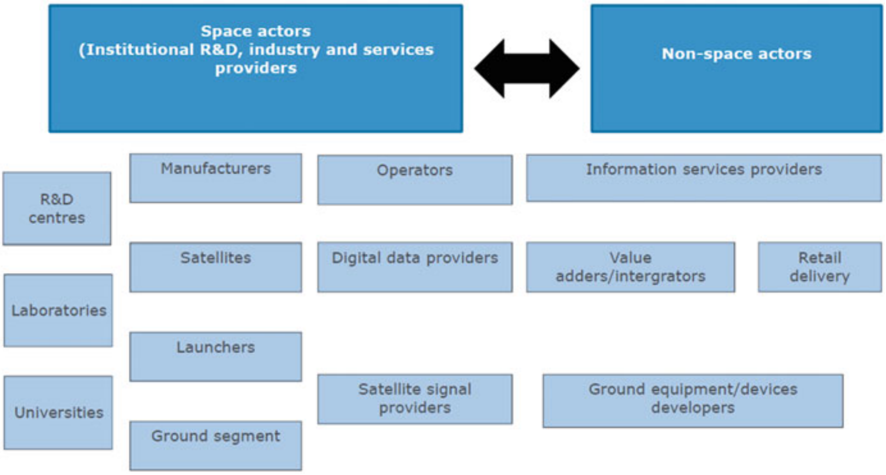

**Fig. 56.1** The space economy's simplified value chain (Source: OECD 2011)

information systems developers, navigation equipment sellers) which are using space systems' capacities to create new products. However the unique capabilities offered by satellites (i.e., ubiquitous data, communications links, imagery) represent often only small, albeit essential, components of those new products and services (Figs. 56.1 and 56.2). Investments in manufacturing of satellites for earth observation, navigation, and telecommunication result tens of multiples in the downsteam sector. Integrated application of various space technologies and often ground and airborne infrastructures broaden the space economy spectrum through value-added services sector.

Worldwide national space budgets have continued to grow in 2011 and 2012. The total for the global space economy in 2012 was $304.31 billion (€225.41 billion)[3] in government budgets and commercial revenue, an increase of 6.7 % from the 2011 total of $285.33 billion (€211.35 billion) and an increase of 37 % since 2007. The majority of the increase in 2012 is attributable to commercial growth: commercial infrastructure and support industries increased 11 %, while commercial space products and services increased 6.5 %. Global positioning system (GPS) devices and chipsets and direct-to-home (DTH) television were particularly important to this growth. Overall governmental spending increased by 1.3 %, although changes varied significantly from country to country, with India, the Russian Federation, and Brazil all growing more than 20 % for a second year in a row. Many other space agencies, including those of the USA and Europe, saw relatively little change from previous years (Space Foundation 2013) (Fig. 56.3).

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[3] Exchange rate: €1 = $1.35 (November 2013).

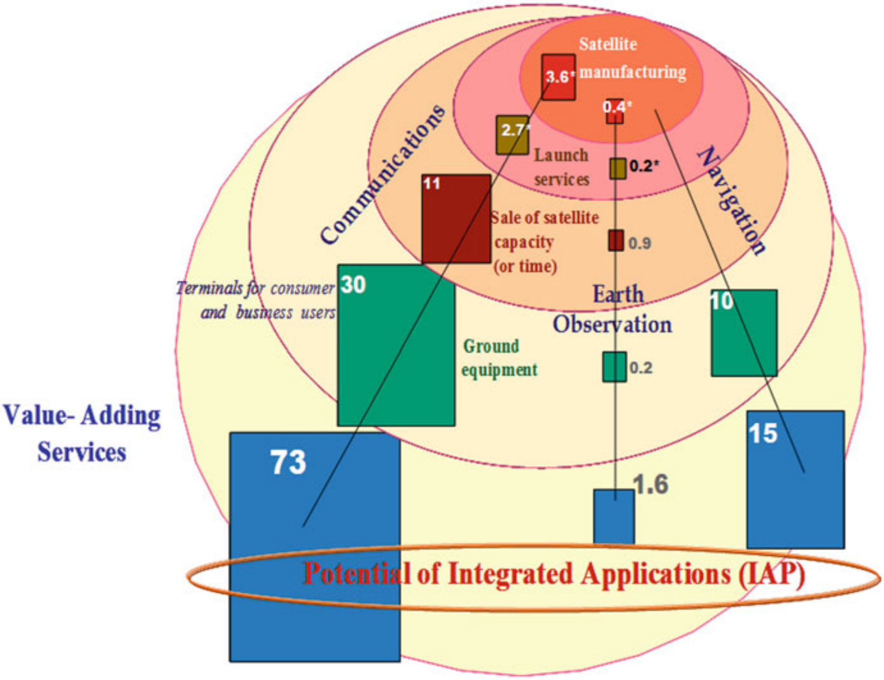

**Fig. 56.2** The space economy's evolving value chain (Adapted from source: Euroconsult and ESA LTP)

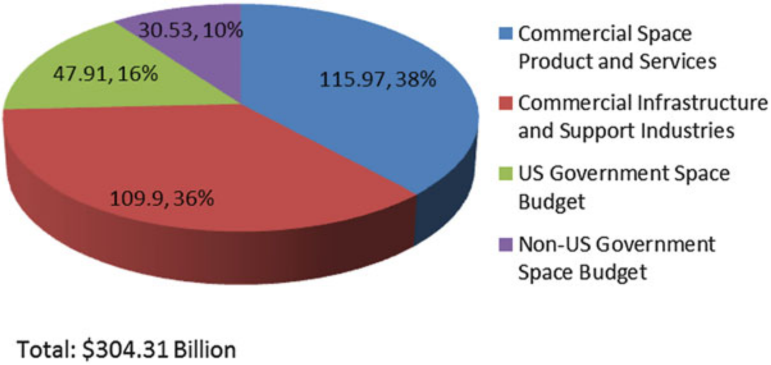

**Fig. 56.3** Global space activity (Source: Space Foundation 2013)

## 56.3 The Institutional Space Sector

In 2011, according to the 2012 Space Report, the total world governmental expenditure, including that of intergovernmental organizations, on space programs amounted to $72.77 billion (€53.9 billion), a figure which shows a nominal

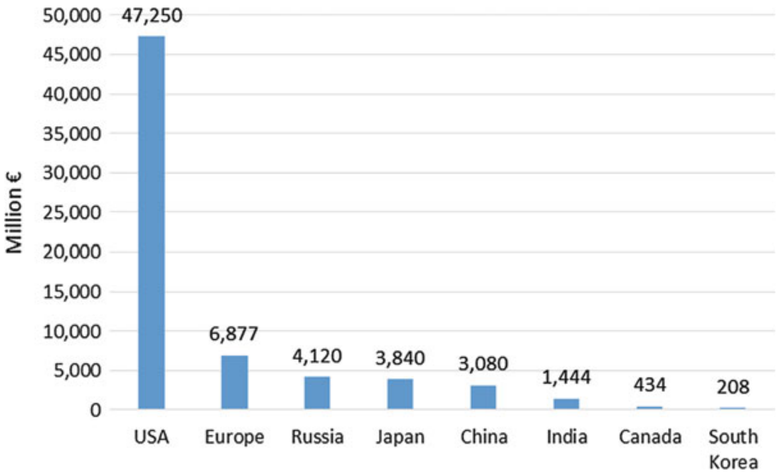

**Fig. 56.4** Public Space Budgets (2011) (Eurostat: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=gba_nabsfin07&lang=en; IMF: http://www.imf.org/external/ns/cs.aspx?id=28)

decrease of 6 % compared to 2010. This space spending is comprised of $44.92 billion (€33.27 billion) in civil expenditures (61.7 % of the total) and $27.85 billion (€20.62 billion) in defense expenditures (38.3 %) (Space Foundation 2012, p. 58).[4] On the other hand, the Euroconsult Report lists 2011 civil space expenditures to amount to $40.3 billion (€29.85 billion), whereas its estimates for government expenditures for defense space programs amount to about $30 billion (€22.22 billion).[5] Consequently, the ratio of defense expenditure relative to civil expenditure has gone down compared to last year, where the ratio was $37 billion (€27.40) in civil expenditures (or 52 % of the total) and $34 billion (€25.18 billion) in defense expenditures (or 48 %). Based on the Space Report 2012, of the estimated $27.85 billion (€ 20.62) of defense-related space expenditure worldwide, $26.46 billion (€19.6 billion) was spent by the USA, representing a share of 95 % and indicating a significant percentage increase compared to the previous year. These funds came from inter alia, the Department of Defense (DoD), the National Reconnaissance Office (NRO), and the National Geospatial-Intelligence Agency (NGA). It should be noted that a degree of uncertainty exists regarding expenditures on defense space activities (e.g., US Defense Advanced Research Project Agency) as not all relevant funding is made public. However, it is clear that the activity in the USA is a driving force in worldwide space activity, particularly in the defense area. Figure 56.4 shows the public space budgets in the USA, Europe, the Russian Federation, Japan, China, India, and South Korea (Fig. 56.5).

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[4] The amount was calculated by subtracting the total military expenditure on space from the total world governmental expenditure on space (see infra footnote).

[5] Euroconsult Report 2012.

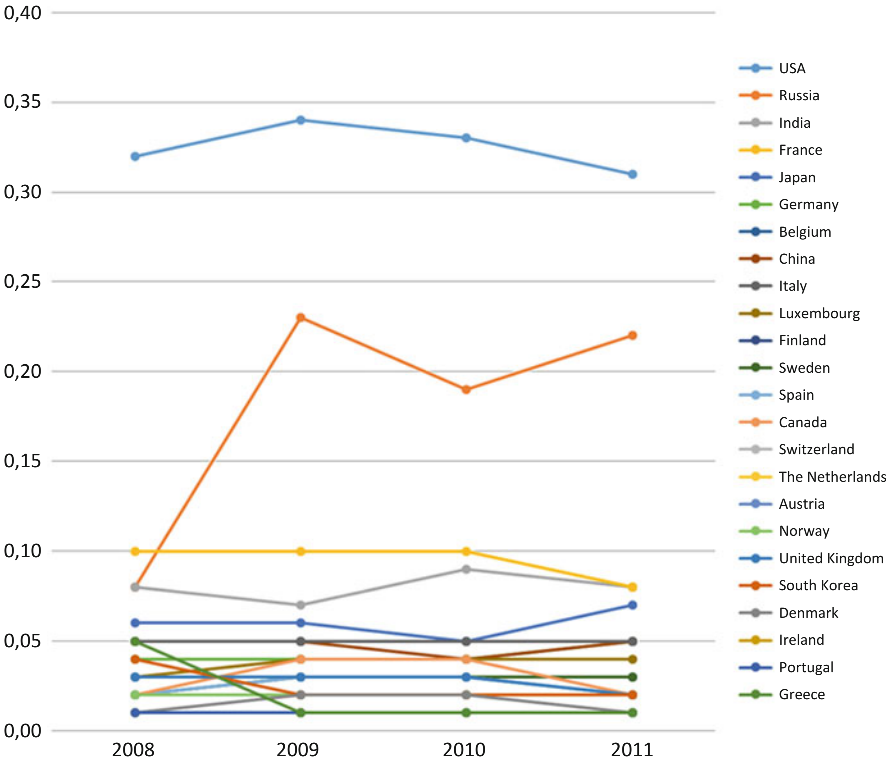

**Fig. 56.5** Public space budgets as a share of nominal GDP – trend 2008–2011 (military excluded) (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=gba_nabsfin07&lang=en) (The most visible trend is the increase of the public space budget of Russia from 0.08 % of the GDP in 2008 to 0.22 % of the GDP in 2011. The decrease of the Greek space budget from 0.05 % of the GDP in 2008 to 0.01 % in 2011 is also remarkable)

The ordering of the various states according to their space expenditure has been maintained similar to that of 2010, with China being an exception advancing its position in 2011. The USA has maintained its lead position with the largest budget among states, directing $20.79 billion (€15.4 billion) towards civil expenditure, and $26.46 billion (€19.6 billion) towards defense expenditure. The low estimate of Russia's budget must be put into perspective, as it does not factor in the intensive military activity entailing regular classified launches or the scientific programs. China's national space budget reached $3.08 billion (€2.28 billion) and overtook France's budget of $2.27 billion (€1.68) in 2011. Already in 2010, China had started to overtake France's 2010 budget of $2.5 billion (€1.85 billion) with a budget of $2.4 billion (€1.77 billion). India has managed to maintain its position as having the 7th largest space budget, surpassing Italy's budget by a significant margin. The European Space Agency (ESA), as an international organization composed of 20 Member States, had a 2011 budget of €3.994 billion ($5.80 billion)

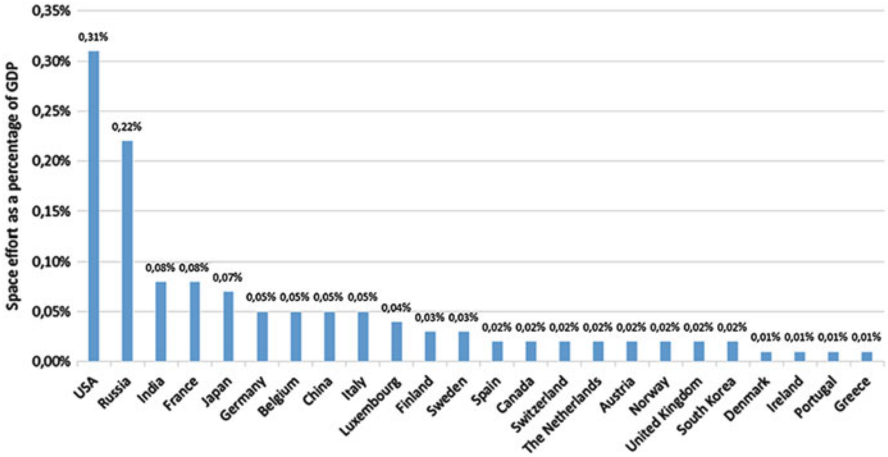

**Fig. 56.6** Public space budgets as a share of nominal GDP in 2011 (Source: Euroconsult/IMF) (Eurostat: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=gba_nabsfin07&lang=en; IMF: http://www.imf.org/external/ns/cs.aspx?id=28)

an increase of 6.7 % above its 2010 budget of €3.745 billion ($4.60 billion). As a joint investment of the 20 Member States, the five biggest contributors are France 18.8 %, Germany 17.9 %, Italy 9.5 %, UK 6.6 %, and Spain 5.1 %. The Space Report 2012 notes a slight decrease of 8.7 % in Japan's space budget amounting to ¥309.4 billion ($3.84 billion) when compared to ¥339 billion in 2010. Japan's budget contributes to reducing the world concentration of space expenditure among the USA, European countries, ESA, and the Russian Federation, to 80.4 % in 2011 from 82 % in 2010. When measuring the concrete effort of countries in the space sector, it is necessary to put the figures into perspective in regard to Gross Domestic Product (GDP) (Fig. 56.6). However, considering the absolute numbers alone will paint only a partial picture since comparisons between countries with different economic conditions (e.g., price or wage levels) can be misleading.

The US space budget figures evince its strong engagement in the space field; however, its level of investment seems to have tapered off or even diminished slightly. As explained previously, the Russian figures must be read with caution, yet Russia's space effort has increased by 0.03 % to be 0.22 % in 2011. France's ratio relating to space efforts as a percentage of GDP has diminished to 0.08 %, with India surpassing it and Japan following behind at 0.09 % and 0.07 %, respectively. The other leading space countries in Europe continue to invest 0.05 % or less of their GDP on space activities. The USA continues to dominate the amount spent on its space budget per capita at $151.59 (€112.28) (a decrease of 2.64 % from 2010), whereas France's per capita space budget was reduced to $35.86 (€26.56) (a decrease of 11.24 %). From the values listed in the Euroconsult report, the per capita budget of Luxembourg has been calculated to be $44.00 (€32.6) (a 10.6 % increase) and Belgium's is $23.55 (€17.44) (a 10.05 % increase); these funds are heavily directed towards participation in ESA (Belgium now 4.1 % and

Luxembourg 0.3 % listed in ESA's 2012 Space Budget). Finally, Norway has not changed significantly, its per capita space budget holding steady at $21.00 (€15.55), while Japan's per capita budget has decreased by 9.9 %. While some per capita space budgets have decreased (e.g., the USA, France, UK, Canada, Japan, Spain, and South Korea) this does not necessarily indicate a trend across the board; the majority of states have experienced an uptick in per capita space funding since 2010 (including the Russian Federation, Germany, China, India, Italy, Luxembourg, Belgium). Authoritative sources conflict on the situation in India and China due in part to their socioeconomic characteristics (Tables 56.1–56.3).

Space cannot be seen in isolation from the research and development (R&D) policy. Figure 56.7 shows the civil space budget in relation to the GBAORD for R&D. The only four space powers where the civil space budget as a part of the GBAORD outreaches the OECD average (9.103 %) are the USA (13.465 %), the Russian Federation (22.14 %), France (12.175 %), and Belgium (12 %), Russia not being a member of the OECD. This shows the big impact of the American, Belgium, and French space budget on statistical statements in absolute terms. After this leading group, Argentina has the highest proportion of civil space budget in GBAORD, 7.764 %, which surmounts even the efforts of the European space powers Italy (7.409 %) and Germany (5.95 %). The OECD total for civil space-related budgets was $18.5 billion (€13.7 billion) in 2009 with few large countries dominating the total. GBAORD data are assembled by national authorities and classified by "socioeconomic" objectives on the basis of NABS 2007 (Nomenclature for the analysis and comparison of scientific programs and budgets). The advantage of this is that they are reflecting government priorities.

Figure 56.8 shows space versus other areas of R&D expenditure according to Eurostat. This shows how space ranks as a priority within a country. In 2011 the main socioeconomic objective within the EU, counting for was "general advancement of knowledge" (including R&D financed from general universities funds), followed by "industrial production and technology" and "health." At country level the socioeconomic objectives linked to "general advancement of knowledge" accounted for the largest part of GBOARD in 25 EU MS. "Exploration and exploitation of space" represented an increasingly important priority for Europe up 5.5 % from 4.9 % in 2010, to be assessed against a downhill trend in Japan (6.6 % down from 6.8 % in 2010) and in the USA (6.0 % down from 6.5 % in 2010).[6] From the countries presented Russia conserves space as its highest priority. In the European Union space comes fifth after the knowledge, industrial production and technology, health, and defense. In the USA, space ranks forth, one position higher than Europe. Their highest priority is defense followed by health and knowledge, whereas industrial production and technology are not considered as a high priority.

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[6] Note that the data refer to budget provisions and not to actual expenditure and have limitations, i.e., the exploration and exploitation of space" category excludes military space programs which are included under "defense."

**Table 56.1** Government ependitures for space programmes (Euroconsult 2013) (Note: Expenditures over $10 million only. European countries excludes ESA contributions)

| | *'07* | *'08* | *'09* | *'10* | *'11* | *'12E* |
|---|---|---|---|---|---|---|
| North America | 41,671 | 43,828 | 48,445 | 47,738 | 44,367 | 43,307 |
| CANADA | 251 | 276 | 354 | 515 | 598 | 618 |
| United States | 41,420 | 43,552 | 48,091 | 47,223 | 43,769 | 42,689 |
| Latin America | 289 | 260 | 282 | 425 | 516 | 743 |
| Brazil | 118 | 108 | 145 | 216 | 228 | 254 |
| Argentina | 87 | 69 | 96 | 106 | 130 | 146 |
| Mexico | 0 | 5 | 21 | 75 | 122 | 241 |
| Chile | 0 | 6 | 17 | 25 | 23 | 5 |
| Venezuela | 84 | 71 | 3 | 2 | 12 | 14 |
| Bolivia | 0 | 1 | 0 | 1 | 1 | 83 |
| Europe | 8,311 | 9,160 | 9,310 | 9,174 | 10,606 | 9,574 |
| ESA | 4,063 | 4,474 | 4,851 | 4,077 | 4,665 | 4,195 |
| EU | 395 | 560 | 464 | 1,276 | 1,603 | 1,679 |
| Belgium | 16 | 22 | 22 | 22 | 23 | 47 |
| Finland | 80 | 94 | 78 | 76 | 84 | 39 |
| France | 1,886 | 1,904 | 1,780 | 1,811 | 2,100 | 1,742 |
| Germany | 774 | 908 | 1,021 | 921 | 823 | 623 |
| Greece | 11 | 12 | 11 | 11 | 11 | 10 |
| Italy | 491 | 587 | 546 | 450 | 711 | 609 |
| Norway | 4 | 19 | 20 | 31 | 33 | 30 |
| Spain | 67 | 134 | 134 | 109 | 111 | 166 |
| Sweden | 50 | 42 | 34 | 34 | 31 | 27 |
| The Netherlands | 39 | 38 | 40 | 42 | 86 | 45 |
| United Kingdom | 410 | 342 | 287 | 292 | 302 | 341 |
| Romania | 25 | 24 | 22 | 22 | 23 | 21 |
| Russia & Central Asia | 2,748 | 3,665 | 5,559 | 5,961 | 6,877 | 9,114 |
| Russia | 2,560 | 3,506 | 5,439 | 5,608 | 6,417 | 8,597 |
| Kazakhstan | 125 | 92 | 55 | 109 | 261 | 242 |
| Ukraine | 63 | 63 | 52 | 214 | 96 | 108 |
| Belarus | 0 | 4 | 13 | 17 | 30 | 58 |
| Turkmenistan | 0 | 0 | 0 | 0 | 17 | 17 |
| Azerbaijan | 0 | 0 | 0 | 13 | 56 | 92 |
| Middle East & Africa | 473 | 608 | 689 | 902 | 1,022 | 976 |
| Angola | 0 | 0 | 21 | 26 | 28 | 19 |
| Algeria | 37 | 51 | 61 | 55 | 39 | 55 |
| Iran | 0 | 0 | 0 | 100 | 120 | 120 |
| Israel | 101 | 91 | 81 | 81 | 129 | 157 |
| Nigeria | 75 | 47 | 55 | 46 | 84 | 55 |
| South Africa | 7 | 99 | 53 | 109 | 99 | 85 |
| Turkey | 87 | 87 | 81 | 122 | 182 | 197 |
| UAE | 133 | 203 | 274 | 288 | 235 | 259 |
| Pakistan | 33 | 30 | 63 | 75 | 106 | 29 |

(*continued*)

**Table 56.1** (continued)

| | *'07* | *'08* | *'09* | *'10* | *'11* | *'12E* |
|---|---|---|---|---|---|---|
| Asia | 4,816 | 5,925 | 6,698 | 7,124 | 8,135 | 9,293 |
| China | 1,395 | 1,924 | 2,252 | 2,546 | 2,828 | 3,432 |
| Japan | 2,172 | 2,790 | 3,075 | 2,947 | 3,546 | 3,699 |
| India | 793 | 806 | 844 | 978 | 974 | 1,259 |
| Australia | 155 | 162 | 187 | 280 | 325 | 356 |
| Malaysia | 26 | 27 | 25 | 28 | 13 | 18 |
| South Korea | 119 | 102 | 208 | 200 | 206 | 229 |
| Taiwan | 45 | 24 | 42 | 41 | 42 | 62 |
| Indonesia | 0 | 19 | 16 | 36 | 35 | 38 |
| Laos | 0 | 0 | 0 | 19 | 68 | 87 |
| Thailand | 63 | 53 | 30 | 30 | 30 | 20 |
| Vietnam | 48 | 18 | 19 | 19 | 68 | 93 |
| **Total** | **58,308** | **63,446** | **70,983** | **71,324** | **71,523** | **73,007** |

**Table 56.2** Civil government expenditures for space programmes (Euroconsult 2013)

| US$ in million | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| **North America** | **18,250** | **18,834** | **20,286** | **20,691** | **20,487** | **20,208** |
| Canada | 251 | 268 | 274 | 364 | 423 | 388 |
| United States | 17,999 | 18,566 | 20,013 | 20,327 | 20,064 | 19,820 |
| **Latin America** | **289** | **256** | **274** | **413** | **505** | **741** |
| Brazil | 118 | 108 | 145 | 216 | 228 | 254 |
| Argentina | 87 | 69 | 96 | 106 | 130 | 146 |
| Mexico | 0 | 5 | 21 | 75 | 122 | 241 |
| Chile | 0 | 3 | 9 | 13 | 11 | 3 |
| Peru | 0 | 0 | 0 | 0 | 0 | 0 |
| Venezuela | 84 | 71 | 3 | 2 | 12 | 14 |
| Bolivia | 0 | 1 | 0 | 1 | 1 | 83 |
| **Europe** | **6,846** | **7,649** | **8,090** | **7,835** | **9,312** | **8,407** |
| European Space Agency | 4,063 | 4,474 | 4,851 | 4,077 | 4,665 | 4,195 |
| European Commission | 395 | 560 | 464 | 1,276 | 1,603 | 1,679 |
| Austria | 18 | 23 | 17 | 19 | 8 | 9 |
| Belgium | 16 | 15 | 16 | 16 | 17 | 41 |
| Denmark | 0 | 0 | 0 | 0 | 0 | 0 |
| Czech Republic | 0 | 0 | 6 | 3 | 4 | 4 |
| Finland | 40 | 47 | 39 | 38 | 42 | 39 |
| France | 1,131 | 1,212 | 1,167 | 1,110 | 1,358 | 1,184 |
| Germany | 544 | 658 | 793 | 697 | 754 | 560 |
| Greece | 0 | 0 | 0 | 0 | 0 | 0 |
| Ireland | 0 | 0 | 0 | 0 | 0 | 0 |
| Italy | 362 | 415 | 499 | 352 | 566 | 421 |

(*continued*)

**Table 56.2** (continued)

| US$ in million | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 0 |
| Norway | 4 | 5 | 7 | 18 | 19 | 17 |
| Portugal | 0 | 0 | 0 | 0 | 0 | 0 |
| Spain | 26 | 49 | 57 | 51 | 55 | 57 |
| Sweden | 50 | 42 | 34 | 34 | 31 | 27 |
| Switzerland | 4 | 6 | 5 | 6 | 6 | 6 |
| The Netherlands | 39 | 38 | 40 | 42 | 86 | 39 |
| United Kingdom | 119 | 72 | 66 | 68 | 67 | 102 |
| Poland | 6 | 8 | 7 | 7 | 7 | 7 |
| Romania | 25 | 24 | 22 | 22 | 23 | 21 |
| Hungary | 1 | 1 | 1 | 1 | 1 | 1 |
| **Russia & Central Asia** | **1,468** | **1,912** | **2,839** | **3,156** | **3,742** | **5,124** |
| Russia | 1,280 | 1,753 | 2,719 | 2,804 | 3,282 | 4,607 |
| Kazakhstan | 125 | 92 | 55 | 109 | 261 | 242 |
| Uraine | 63 | 63 | 52 | 214 | 96 | 108 |
| Belarus | 0 | 4 | 13 | 17 | 30 | 58 |
| Turkmenistan | 0 | 0 | 0 | 0 | 17 | 17 |
| Azerbaijan | 0 | 0 | 0 | 13 | 56 | 92 |
| **Middle East & Africa** | **311** | **405** | **486** | **676** | **738** | **642** |
| Angola | 0 | 0 | 21 | 26 | 28 | 19 |
| Algeria | 37 | 51 | 61 | 55 | 39 | 55 |
| Egypt | 3 | 3 | 3 | 3 | 3 | 3 |
| Iran | 0 | 0 | 0 | 100 | 120 | 120 |
| Israel | 11 | 11 | 11 | 6 | 6 | 12 |
| Nigeria | 75 | 47 | 55 | 46 | 84 | 55 |
| South Africa | 7 | 99 | 53 | 109 | 99 | 85 |
| Turkey | 87 | 87 | 71 | 95 | 97 | 86 |
| UAE | 58 | 78 | 148 | 161 | 155 | 179 |
| Pakistan | 33 | 30 | 63 | 75 | 106 | 29 |
| **Asia** | **3,543** | **4,276** | **4,836** | **5,061** | **5,437** | **6,444** |
| China | 809 | 1,080 | 1,275 | 1,438 | 1,504 | 2,022 |
| Japan | 1,611 | 2,111 | 2,340 | 2,230 | 2,455 | 2,539 |
| India | 793 | 806 | 844 | 975 | 965 | 1,250 |
| Australia | 29 | 35 | 36 | 45 | 52 | 85 |
| Malaysia | 26 | 27 | 25 | 28 | 13 | 18 |
| South Korea | 119 | 102 | 208 | 200 | 206 | 229 |
| Taiwan | 45 | 24 | 42 | 41 | 42 | 62 |
| Indonesia | 0 | 19 | 16 | 36 | 35 | 38 |
| Laos | 0 | 0 | 0 | 19 | 68 | 87 |
| Thailand | 63 | 53 | 30 | 30 | 30 | 20 |
| Vietnam | 48 | 18 | 19 | 19 | 68 | 93 |
| Defense Total | 2,082 | 1,490 | 1,644 | 1,709 | 1,865 | 1,544 |

**Table 56.3** Defence government expenditures for space programmes (Euroconsult 2013)

| US$ in million | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| **North America** | **23,421** | **24,994** | **28,160** | **27,047** | **23,881** | **23,099** |
| Canada | 0 | 8 | 81 | 151 | 175 | 231 |
| United States | 23,421 | 24,986 | 28,079 | 26,897 | 23,706 | 22,868 |
| **Latin America** | **0** | **4** | **9** | **13** | **12** | **3** |
| Brazil | 0 | 0 | 0 | 0 | 0 | 0 |
| Argentina | 0 | 0 | 0 | 0 | 0 | 0 |
| Mexico | 0 | 0 | 0 | 0 | 0 | 0 |
| Chile | 0 | 3 | 9 | 12 | 11 | 3 |
| Peru | 0 | 1 | 1 | 1 | 1 | 1 |
| Venezuela | 0 | 0 | 0 | 0 | 0 | 0 |
| Bolivia | 0 | 0 | 0 | 0 | 0 | 0 |
| **Europe** | **1,454** | **1,502** | **1,218** | **1,335** | **1,280** | **1,198** |
| European Space Agency | 0 | 0 | 0 | 0 | 0 | 0 |
| Europe an Commission | 0 | 0 | 0 | 0 | 0 | 0 |
| Austria | 0 | 0 | 0 | 0 | 0 | 0 |
| Belgium | 0 | 7 | 6 | 6 | 7 | 6 |
| Denmark | 0 | 0 | 0 | 0 | 0 | 3 |
| Czech Republic | 0 | 0 | 0 | 0 | 0 | 0 |
| Finland | 0 | 0 | 0 | 0 | 0 | 0 |
| France | 755 | 692 | 614 | 701 | 743 | 558 |
| Germany | 230 | 250 | 229 | 224 | 69 | 63 |
| Greece | 11 | 12 | 11 | 11 | 11 | 10 |
| Ireland | 0 | 0 | 0 | 0 | 0 | 0 |
| Italy | 128 | 172 | 48 | 99 | 146 | 187 |
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 2 |
| Norway | 0 | 15 | 13 | 13 | 14 | 13 |
| Portugal | 0 | 0 | 0 | 0 | 0 | 0 |
| Spain | 41 | 85 | 77 | 58 | 56 | 109 |
| Sweden | 0 | 0 | 0 | 0 | 0 | 0 |
| Switzerland | 0 | 0 | 0 | 0 | 0 | 0 |
| The Netherlands | 0 | 0 | 0 | 0 | 0 | 7 |
| United Kingdom | 290 | 270 | 220 | 223 | 235 | 239 |
| Poland | 0 | 0 | 0 | 0 | 0 | 0 |
| Romania | 0 | 0 | 0 | 0 | 0 | 0 |
| Hungary | 0 | 0 | 0 | 0 | 0 | 0 |
| **Russia & Central Asia** | **1,280** | **1,753** | **2,719** | **2,804** | **3,135** | **3,990** |
| Russia | 1,280 | 1,753 | 2,719 | 2,804 | 3,135 | 3,990 |
| Kazakhstan | 0 | 0 | 0 | 0 | 0 | 0 |
| Uraine | 0 | 0 | 0 | 0 | 0 | 0 |
| Belarus | 0 | 0 | 0 | 0 | 0 | 0 |
| Turkmenistan | 0 | 0 | 0 | 0 | 0 | 0 |
| Azerbaijan | 0 | 0 | 0 | 0 | 0 | 0 |
| **Middle East & Africa** | **165** | **205** | **206** | **229** | **288** | **337** |

(*continued*)

**Table 56.3** (continued)

| US$ in million | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| Angola | 0 | 0 | 0 | 0 | 0 | 0 |
| Algeria | 0 | 0 | 0 | 0 | 0 | 0 |
| Egypt | 0 | 0 | 0 | 0 | 0 | 0 |
| Iran | 0 | 0 | 0 | 0 | 0 | 0 |
| Israel | 90 | 80 | 70 | 75 | 123 | 145 |
| Nigeria | 0 | 0 | 0 | 0 | 0 | 0 |
| South Africa | 0 | 0 | 0 | 0 | 0 | 0 |
| Turkey | 0 | 0 | 10 | 27 | 85 | 112 |
| UAE | 75 | 125 | 126 | 127 | 80 | 80 |
| Pakistan | 0 | 0 | 0 | 0 | 0 | 0 |
| **Asia** | **1,272** | **1,650** | **1,863** | **2,062** | **2,696** | **2,849** |
| China | 585 | 844 | 977 | 1,108 | 1,323 | 1,410 |
| Japan | 561 | 679 | 735 | 717 | 1,091 | 1,159 |
| India | 0 | 0 | 0 | 2 | 8 | 9 |
| Autralia | 126 | 128 | 150 | 236 | 273 | 271 |
| Malaysia | 0 | 0 | 0 | 0 | 0 | 0 |
| South Korea | 0 | 0 | 0 | 0 | 0 | 0 |
| Taiwan | 0 | 0 | 0 | 0 | 0 | 0 |
| Indonesia | 0 | 0 | 0 | 0 | 0 | 0 |
| Laos | 0 | 0 | 0 | 0 | 0 | 0 |
| Thailand | 0 | 0 | 0 | 0 | 0 | 0 |
| Vietnam | 0 | 0 | 0 | 0 | 0 | 0 |
| **Defense total** | **2,082** | **1,490** | **1,644** | **1,709** | **1,865** | **1,544** |

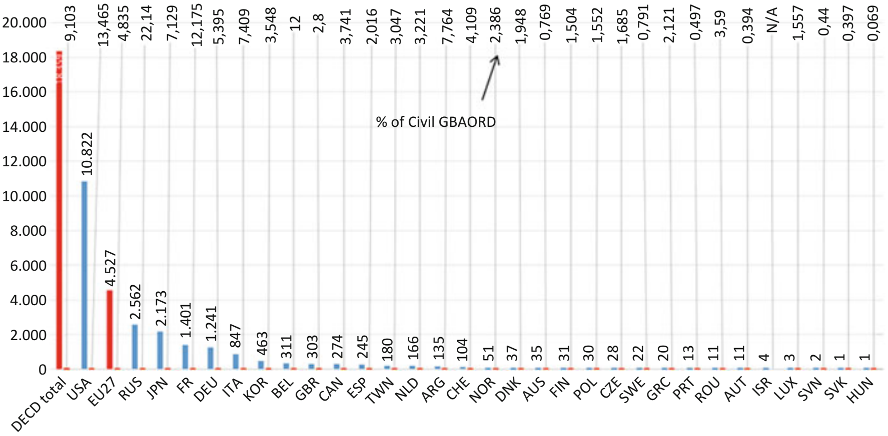

**Fig. 56.7** Civil space budget in government budget appropriations or outlays for R&D (GBAORD) (OECD 2011) (Current USD PPP million and as % of civil GBAORD, 2010 or latest year available)

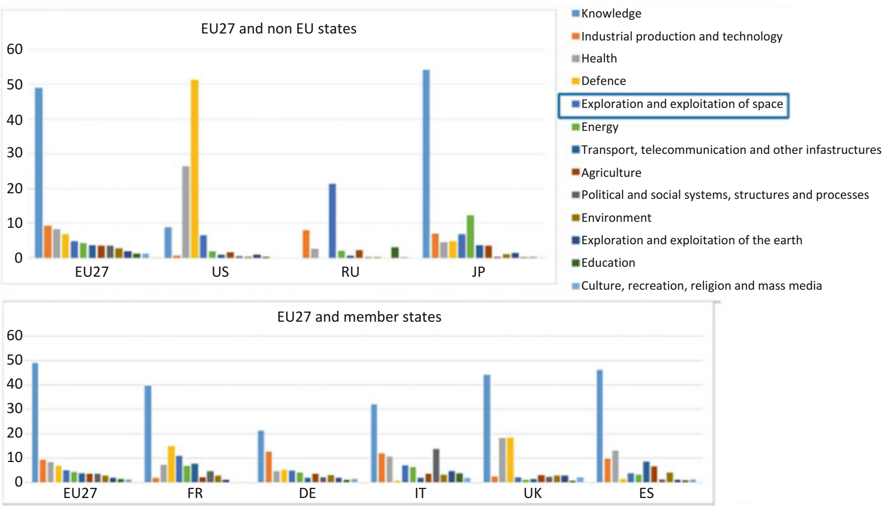

**Fig. 56.8** Space versus other objectives in R&D expenditure (Source: Eurostat 2013)

Figure 56.9 shows the evolution of the civil space budgets as a percentage of civil GBOARD for a number of selected countries. The evolution of civil space component of public R&D shows that civil space-related R&D budgets have picked in the early to mid-1990s then decreased. Since 2007 there is a stagnation/decrease with the exception of the Russian Federation, Brazil, and India.

## 56.4 The Commercial Space Sector

The 2012 Space Report provides a guide to the commercial revenue of space activities, listing the 2011 total revenue of commercial satellite services at about $110.53 billion (€81.87 billion) including activities such as telecommunications, Earth observation, and positioning services (this amount represents a 9 % increase from $101.73 billion (€75.35 billion) in 2010). The revenue of space-related commercial infrastructure including manufacturing of spacecraft and in-space platforms, launch services, as well as ground equipment is estimated to have reached around $106.46 billion (€78.85 billion) (resulting in a corresponding increase of 14 % in launch capacity compared to the deficit in 2010). The total commercial space revenue in 2011 was $216.99 billion (€160.73 billion) (Fig. 56.10).

The Russian Federation is heading the hierarchy of launches with 24, followed by China (19) and the USA (13). The leading group is closed by Europe (10). While Japan and India as established Space Powers performed 2 launches each, Iran (3) and North Korea (2) are showing efforts to close the gap (Fig. 56.11).

There are more than 50 countries in all continents that have a satellite in orbit, a figure that is the highest till today. China and India have risen as established space

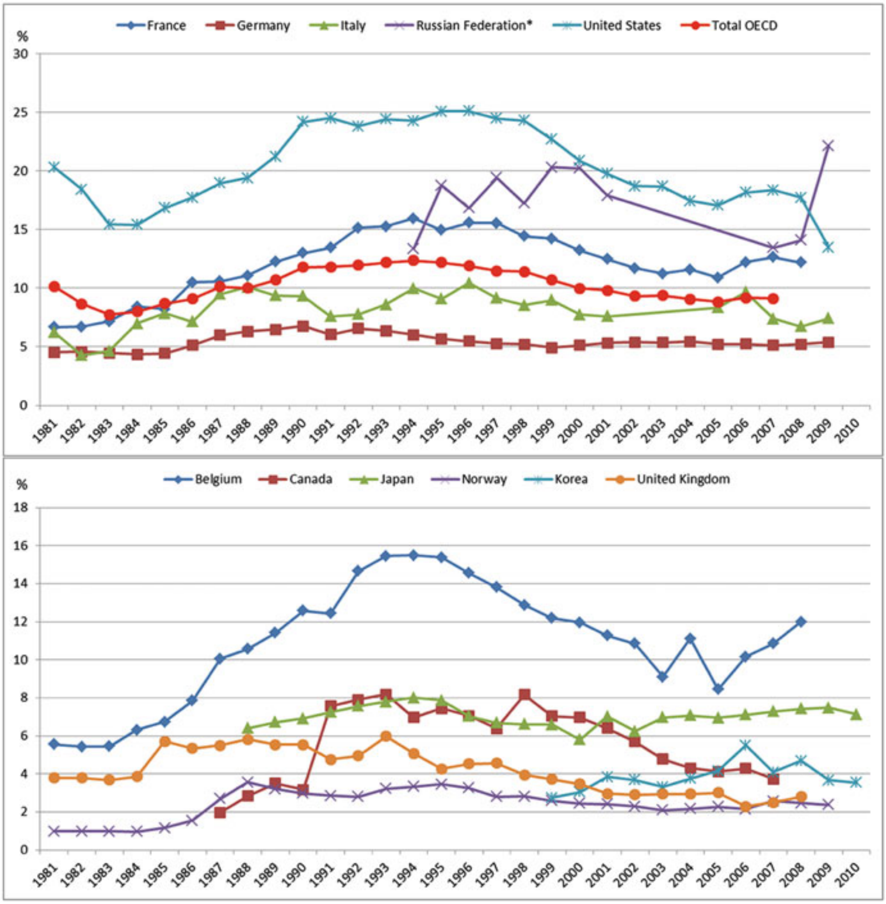

**Fig. 56.9** Civil space programs as a percentage of civil GBAORD for selected countries 1981–2010 (or latest available year) (Source: OECD (OECD 2010)

powers alongside the reemergent Russian Federation (renewed commitment in the past decade). The total space budget represents about $65.3 billion (€48.37 billion) in 2010 with the bulk of funding in G7[7] and BRIC[8] countries. Five countries have invested more than $2 billion (€1.48 billion) in 2010 – the USA, China, Japan, France, and the Russian Federation – with the USA leading the way at more than $43 billion (€31.85 billion). Almost 1,000 operational satellites are now in orbit with diverse earth observation, telecommunications, navigation, and positioning missions. In parallel to the growing importance of these down-to-earth applications, science and space exploration remain key missions of space agencies, invigorating

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[7] The USA, UK, France, Germany, Italy, Canada, and Japan.

[8] Brazil, the Russian Federation, India, and China.

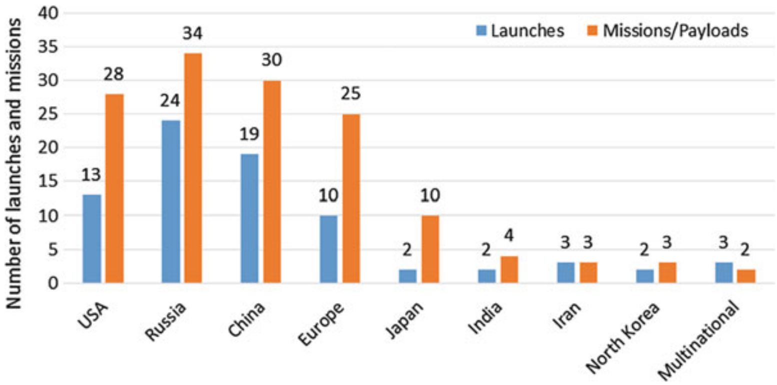

**Fig. 56.10** Major space powers' activities in 2012 (Federal Aviation Administration 2013)

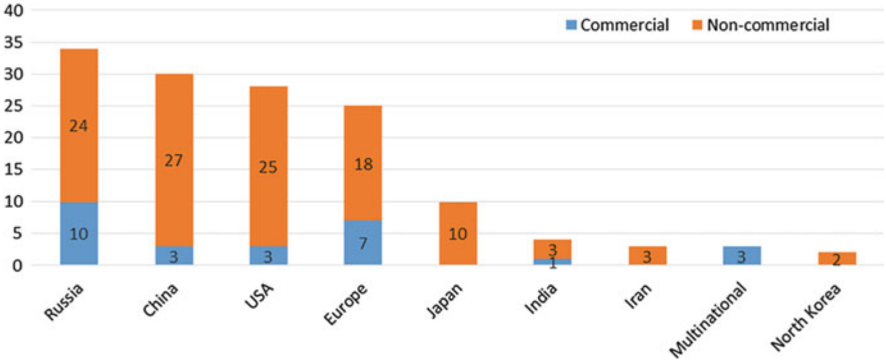

**Fig. 56.11** Payloads launched in 2012 by country and commercial status (Federal Aviation Administration 2013)

international scientific cooperation. The USA leads with more than 350 satellites in orbit, followed by the Russian Federation with 97 satellites. The new landscape of space-faring nations is the result of two trends: the ambition of many countries around the world to develop independent national space programs and the globalization of the aerospace and defense industry (Figs. 56.12 and 56.13).

## 56.5 Forecasts for Government Space Budgets and Programs

Following the continuous increase of global space budgets over the last decade, the space programs have flattened out since 2009 at about $70 billion (€51.8 billion). This ceiling point is likely to meet until the end of the current decade (Euroconsult 2013, p. 21) (Fig. 56.14).

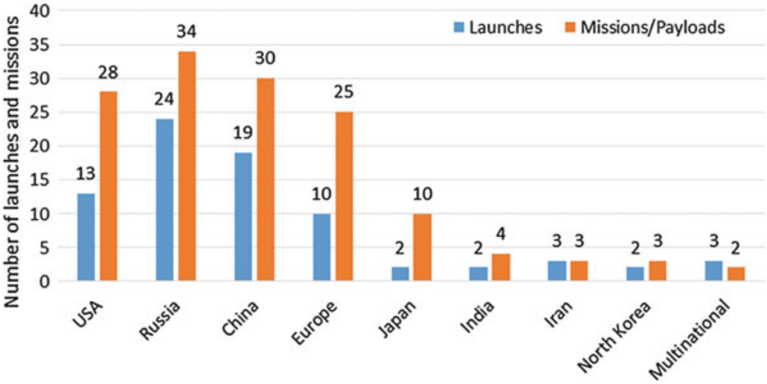

**Fig. 56.12** Major space powers' activities in 2012 (Federal Aviation Administration 2013)

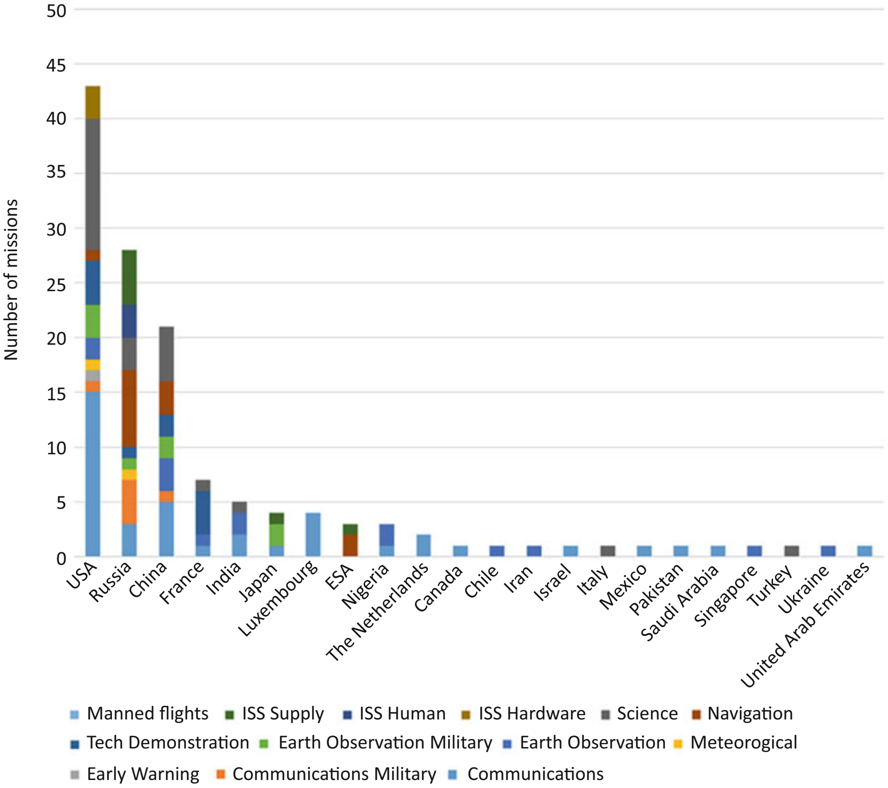

**Fig. 56.13** Types of missions launched into orbit in 2011 (Federal Aviation Administration 2013)

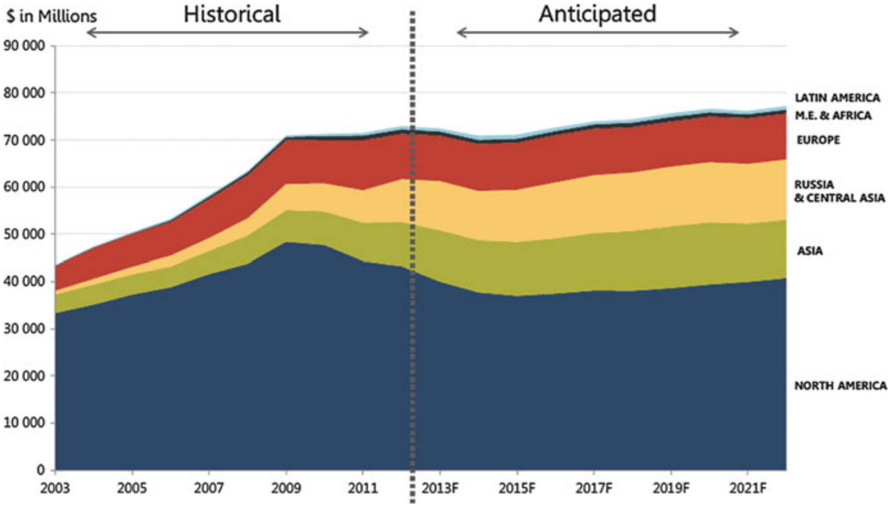

**Fig. 56.14** Forecast for government space expenditures by region (Euroconsult 2013, p. 26)

In the period between 2000 and 2009, the space budgets globally doubled mainly due to defense procurement and increase of the interest on space technologies of more countries around the world. The government gave an additional bust in the space budgets even during the 2008 economic crisis as part of stimulus to promote R&D activities in their industries. However, the massive public spending to support the economics during the economic downturn has left constrained governments in reducing public spending and prioritize in order to meet acceptable debt and deficit levels. This has led a number of countries to cut their space budget program.

The cyclic nature of government budgets has also an effect on the space budgets. In particular in the USA, budget tapering is affecting the space sector. The defense budget has driven budget growth for a decade; however the US military program is entering into a low cycle phase following the completion of its major programs. US National Aeronautics and Space Administration (NASA) has chosen to outsource part of its manned space program to the private sector. In Europe, the Euro-zone crises has left many of the countries having to cut back on their space budget, inter alia Spanish, Italian, and Greek have significantly reduced or completely cut their participation to ESA optional programs.

Governments are expected to recover a positive growth in space activities from 2016 onwards, mainly due to a clearer finance environment. It is expected that a new cycle of R&D investments will have started and governments will be ready again to invest in more ambitious projects willing to take up more risk. According to the Euroconsult report (Euroconsult 2013), the global investment funding by 2022 is expected to pass the $77 billion (€57 billion) level.

In breaking down the expectation in the civil and defense budgets, the government expenditure to civil budgets is expected to be sustained at a moderate pace of

1.2 % Compound Annual Growth Rate (CAGR)[9] until 2017 in contrast to 5 % CAGR over the last 5 years. The funding commitments in Russian Federation and Asia should more than compensate for the decline/froze spending in Europe and North America. In the time frame 2018–2022, the budget growth is expected to stabilize because most dynamic programs will have achieved significant expansion and mature space programs will slowly recover growth in their investment. The improvement of the financial situation is expected to start a new period of expansion (Euroconsult 2013, p. 22).

In the area of defense space programs, funding is expected to decrease until 2016, and for the period 2010–2015 they are expected to lose $7 billion (€5.18 billion) in particular due to the US DoD space program cuts. This related to the cycles of military procurement in the USA. In Europe, new investments will be committed in midterm for next generation system funding. The forecast is that after reaching at $26 billion (€19.259 billion) in 2016, world allocation in space defense space programs are anticipated to recover a soft 1.2 % growth on average per year to reach $28.5 billion (€21.11 billion) at the end forecast period, a budget at similar levels to the year 2007.

Regarding the regional government spending, North America is expected to remain the first region in terms of budget allocation in the next decade but with a decreasing share to the global budget spending to around 50 %. Asia is expected to overtake Europe in space budget spending and take the second position, already by the end of 2013, with $10.8 billion (€8 billion). Growth is expected to be moderate for Asia at about 2 % for the coming decade compared to the exceptional growth seen over the past decade at 11 % CAGR. This is due to the fact that their space programs will come to a maturity phase. The region is expected to reach at about $13 billion (€9.62 billion) by the end of the next decade (Euroconsult 2013, p. 22).

Europe is expected to drop from second to fourth position following after Central Asia and Commonwealth of Independent States (CIS) in world ranking in public spending, keeping budgets flat at $9 billion (€6.66 billion). Spending in Middle East and Africa is expected to maintain a constant level of $900 million (€666.66 million) as investment in satellite application programs and new generation systems. Latin America is expected to remain the last region in terms of funding, with Brazil being the regional leader.

In terms of domains of the various programs, for launch vehicles, world spending is expected to grow by 4.4 % CAGR to about $9.3 billion (€6.88 billion) by 2017. This will be driven by large procurements by US Department of Defense (DoD) and new developments in the Russian Federation, China, and Europe. The level of spending will then decrease by 2022 below $7.5 billion (€5.55 billion), when the new launchers are operational and fewer vehicles are procured by the US military. Brazil and South Korea are expected to increase their investments in contrast to the other countries for the period of 2017–2022.

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[9] Compound annual growth rate (CAGR) is the average year-over-year rate of the investment over a specified period of time.

In the area of Earth observation, programs are expected to stabilize in the coming decade with spending reaching $10.8 billion (€8 billion) by 2017 with an annual growth of below 1 % compared to 10 % in the last 5 years. New countries will enter into the market whereas the USA and Europe will experience flattening and decreasing funding in the short term. The drivers for civil funding will mostly be driven by Earth observation programs. Defense investment is forecasted to remain stable with a flat US budget and modest growth in Europe, the Russian Federation, and China to support the next generation of systems. Dual-use programs are expected to become mechanisms for cost sharing along with commercial data procurement. After 2017 global investments are expected to stabilize through investments in R&D for supporting new systems and cycles of procurement of operational systems.

The satellite communications programs are expected to see an average decline of 5 % in the next 5 years, as government spending is expected to fluctuate around $6 billion (€4.44 billion) by the end of the decade and by 2022 will be around the $5 billion (€3.70 billion) range. The US decline in military spending will not be fully compensated by Europe, the Russian Federation, and others. Public-Private Partnerships procurements might limit yearly fluctuations. Civil spending is expected to be more cyclical than in the past as they focus more on development of operational and demonstration systems rather than long-term R&D. They are expected to enter a low-investment period constrained by budgetary measures. In the second part of the decade, there should be growth with renewed R&D budgets and procurement of second generation of systems in emerging countries.

In the area of satellite navigation in the short term, a further increase is expected as the four global navigation systems (Galileo, GPS, Glonass, and Beidou) and the two regional ones (Japanesse QZSS and India's IRNSS) are still under development. Investments are expected to peak at $5.5 billion (€4.07 billion) in the second half of the decade.

In the area of science and exploration, expenditures will be by a 5-year CAGR of 4.2 % by 2017 (compared to 0 % over the past 5 years), reaching an all-time high of $6.9 billion (€5.11 billion) in 2017. Scientific programs continue to be a core element in space agencies mandates. This is expected to be maintained.

Human space flight is expected to recover from the global flat spending with a modest increase by a 5-year CAGR of 3.3 % between 2013 and 2017 due to the stable spending of the USA towards exploration system development, commercial crew development, and space operations and growing expenditure in the Russian Federation and China towards the development of next-generation transport systems and space stations. A historically high funding level over $15 billion (€11.11 billion) is expected to be reached due to existing leading space programs and new players. Indian spending is expected to increase over $500 million (€370.37 million) from 2018 to 2022 for the development of their first manned mission. It should be noted from the global spending the USA spending represented 90 % of the total in 2000 and is expected to drop to 60 % by the end of the decade. This is due to the interest of more countries in developing and maintaining human spaceflight capabilities.

In space security, investments have fluctuated following the US DoD procurement strategy, and this expected to continue for the largest part. A priority in the agenda of governments is protecting the space assets. Space security investments will also be driven by countries like the Russian Federation and new entrants in the field like Japan and Ukraine. Global spending is expected to reduce to $2.3 billion (€1.70 billion) level by 2017 and should recover by the end of the decade to $3 billion driven by procurements of next generation systems.

## 56.6 Conclusions

Accurate estimate of global space activities is a complicated task. This is due to the fact that there is lack of a standardized approach and lack of transparency in certain government space programs, such as defense-related programs. Additionally, the publication of financial figures by commercial companies is not uniform across the sector and varies in time. However, following the continuous increase of global space budgets over the last decade, the space programs have flatted out since 2009. Governments are expected to recover a positive growth in space activities from 2016 onwards due to the clearer finance environment, and a new cycle of R&D investments are expected to start with more ambitious projects. In space security the cyclic investment is mainly expected to follow the US DoD procurement strategy. The Russian Federation and new entrants in the field like Japan and Ukraine are also expected to play a role in space security investments. Space security investments are expected to be more and more focused on protecting space assets.

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