Chapter 1
Introduction

Why Space Services Are Now Vital to Global Society

Fifty years ago at the dawn of the space age, space sciences, space exploration and space applications were in their infancy. For the most part, little was known about how space might be used to achieve practical purposes and little was known about the conditions or possible use of outer space above the stratosphere. Explorer I revealed that there were the Van Allen Belts that protected the Earth from extreme Solar Storms. Early Bird in 1965 realized Arthur C. Clarke's vision of communications satellites in geosynchronous orbit and proved that a practical space industry was not only possible but highly profitable as well. Today a half century later the world is dramatically different. There are a number of videos on line known under the generic title "A Day without Satellites". These video presentations reveal many of the various ways we are today dependent on satellite networks. These videos show how we depend on satellites for air traffic control, including takeoffs and landings, for banking transactions, for credit card validation, for Internet synchronization, for television distribution, for global business communications, for a wide variety of military networking and missile targeting, for weather forecasting, for extreme storm warnings and recovery, for oil and mineral exploration, for fishing, for search and rescue and dozens of other vital services. Space systems have gone from being an exotic and new enterprise to a vital infrastructure that is central to our daily lives.

Space systems have become so very vital, that if we were suddenly denied access to our space-based infrastructure for weather forecasting and warning, for space-based navigation and timing, for civil and military communications, and for remote sensing and surveillance from space we would be in danger. We would suffer almost immediately—economically, militarily, and socially. Many of our transportation and our communications systems would go down along with our weather and rescue services and defense systems. Internet would lost its synchronization,

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credit card validation would no longer work, we would not be alerted to major storm systems, air traffic control, shipping navigation, and trucking routing services would be lost.

Unfortunately as our space-based systems have become more and more common, other factors have served to make our satellites more at risk. One risk is that of extreme solar flares and coronal mass ejections. These concerns are addressed in another book in this series entitled *Orbital Debris and Other Space Hazards*. This current book, however, returns in more detail to the problem of orbital space debris and new efforts to develop active debris removal capabilities. [Joseph N. Pelton]

The Inter-Agency Space Debris Coordination Committee (IADC) and the UN Committee on the Peaceful Uses of Outer Space (COPUOS) have developed guidelines to help reduce the creation of new space debris and aid defunct spacecraft and upper stage rockets to naturally de-orbit. Yet these guidelines are currently advisory and non-binding. These procedures, in short, are not sufficient to ensure that orbital debris build up will not continue to increase with potentially catastrophic consequences in the longer term.

Overview of the Problem

Currently there is about six metric tons of space debris in earth orbit and about 45 % of that is in low-earth orbit and polar orbits where the threat of collisions continues to increase. This process can lead to an escalating cascade of more and more debris. Today we are very much at risk of such a cascading build-up that is known as the "Kessler Syndrome". Two events in recent years have particularly contributed to orbital space debris build-up. One event was the collision of the defunct Russian Kosmos 2251 weather satellite with the Iridium 33 low earth orbit mobile communications satellite. The other was the shooting down of an old and defunct Chinese Fen Yun weather satellite by the Chinese military. Each of these events led to the creation of nearly 3,000 new tracked debris elements. Currently 22,000 of these space debris elements are being actively tracked by U.S. surveillance networks. Each of these debris elements are capable of creating major new debris, especially if they collided with another satellite or upper stage rocket. In short, without further remedial action to remove space debris from Earth orbit, the problem will continue to get worse. [NASA Office of Orbital Debris]

At some point the cascading effect of debris elements colliding with other debris elements will create deadly rings of debris that are sufficiently dense that it would not be safe to launch spacecraft into Earth orbit with a reasonable hope of not being struck by a piece of debris that would disable the satellite and the launch vehicle in such a way that they would simply add to the morass of space debris. Fortunately we are well short of this "terminal condition" that would essentially prohibit the ability to launch new operational spacecraft into Earth orbit. When Donald Kessler of NASA warned of this threat some 35 years ago, there was a minimal amount of space debris at the time. Indeed at that time the overwhelming likelihood was that natural debris from micrometeorites, meteorites, bolides, etc. constituted a much greater threat of collision with a satellite or upper stage launch vehicle. But that has now dramatically changed.

The operators of satellite networks, such as Intelsat (where the author was employed at the time) took the much more serious risks to its satellites that might be created by solar flares, coronal mass ejections, and natural cosmic debris. Thus many unsafe and indeed thoughtless practices that contributed to human-caused orbital debris continued largely unabated. This meant the on-going use of explosive bolts for the separation of staged launch vehicles, no specific efforts to de-orbit upper stages of launch vehicles, no exhaustion and expelling of fuels or explosives stored in spacecraft or upper stages of launch vehicles that could subsequently explode, and other such dangerous practices. Many space scientists continued to assume that natural objects and cosmic weather conditions would continue to be the greater risk factor for operational spacecraft. Over the decades from the 1980s, 1990s, 2000s, and now the 2010s the amount of human-launched materials has continued increase. In 1994 the UN Committee on the Peaceful Uses of Outer Space took up this problem in a serious way. This also led to a collaborative process among a number of the space agencies which became seriously engaged in trying to develop guidelines to minimize the increase of further space debris.

Several events in 2007, 2008 and 2009, however, served to escalate concerns about orbital space debris. These incidents raised concerns to a much higher level of urgency on the world stage. The first act occurred on January 11, 2007. This event was the intentional launch of a Chinese missile to destroy an obsolete polar-orbiting Chinese weather satellite, the Fen Yun 1C. A missile using an anti-satellite (ASAT) system was launched from near the China's Xichang Space Centre on 11 January and reached its target at an altitude of 865 km (or 537 miles). This unexpected event created a dangerous new ring of debris with about 3,000 trackable space debris objects. Because this event occurred at such a high altitude these debris elements will stay in orbit for a very long time. The U.S. subsequently did another anti-satellite test firing on February 21, 2008 but this intercepted a re-entering spy satellite that contained some 500 kg of noxious hydrazine fuel and thus this action was claimed to be a safety measure. All of the debris elements from this very low altitude and incoming trajectory de-orbited within 24 h of the missile hit. The key thing to note from these two events is that the higher the altitude of the missile intercept the greater the nature of the problem. This is because the debris stays in orbit much longer if created in a higher orbit. Simply put, the pull of gravity decreases in magnitude at higher and higher elevations and thus orbital decay takes much more time. [Chinese Anti-Satellite Test]

It was the Kosmos-Iridium collision in 2009 again shocked world opinion and triggered new efforts to control the build-up of human-generated space debris. On February 10, 2009, just before 1700 Universal Time (at zero degree meridian) that a very high speed and explosive collision occurred. This involved the Iridium 33 mobile communications spacecraft and the Russian Kosmos 2251 defunct weather satellite. This collision occurred at an altitude of 789 km (or 490 miles) at a location high over Siberia. This spectacular event just like the Chinese missile interception generated thousands of pieces of newly tracked space debris. Below are

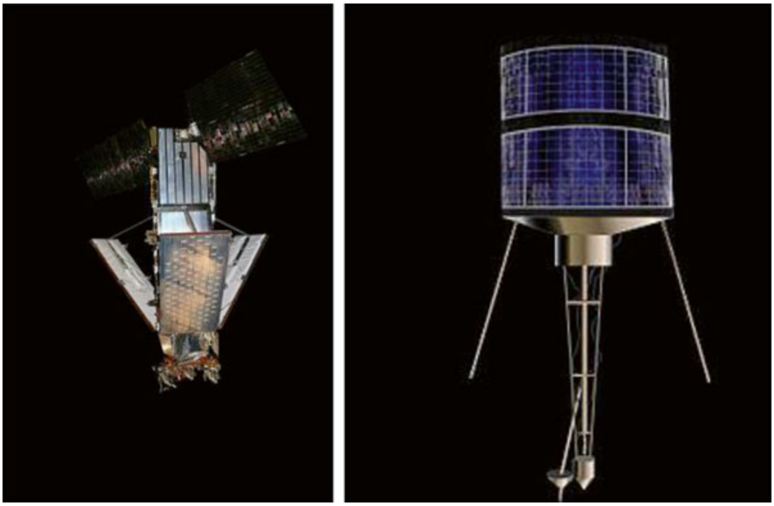

Fig. 1.1 The Iridium 33 satellite and a Russian weather satellites like the Kosmos 2251 (Graphics Courtesy of Iridium and Roscosmos)

depicted an Iridium satellite and a Russian weather observation satellite similar in design to the Kosmos 2251 (Fig. 1.1).

This random collision occurred at sufficiently high velocity to create nearly 3,000 new debris elements in low earth orbit. Thus as a consequence of the Chinese anti-satellite missile firing and the Kosmos-Iridium collision the amount of tracked debris elements increased by almost 30 %. This collision was also at high enough altitude to stay in orbit for many years as well. Dr. Donald Kessler's recent calculations project an increasing collision rate.

The international community which had been working on the issue of orbital debris renewed its efforts to establish new guidelines to control the new creation of orbital debris elements. Currently there are some 22,000 objects being tracked that are at least the size of a baseball. An object the size of a baseball may not sound like much, but a chunk of metal this size and traveling at a relative speed of perhaps 32,000 km an hour (or 20,000 miles per hour) to the impacted object has the kinetic energy of a reasonably large-sized bomb. Further there are perhaps a half million pieces of debris the size of a marble and millions of pieces equivalent in size to a chip of paint. Even a chip of paint travelling at hypersonic speeds could pierce a space suit or crack a window of a space plane.

International Efforts to Develop Guidelines to Mitigate the Creation of Space Debris

A group known as the Inter-Agency Space Debris Coordination Committee (IADC) began working on what they characterized as the "Space Debris Mitigation Guidelines" in the 1990s and came up with an initial set of guidelines in 2002.

These were then developed into a refined version in 2007. In both cases these guidelines were described as being "non-binding". Even so such standards are useful. They could and should be applied in planning space missions. The objectives of these guidelines were announced to be threefold:

1. Preventing on-orbit break-ups
2. Removing spacecraft and orbital stages that have reached the end of their mission operations from the useful, densely populated orbit regions
3. Limiting the objects released during normal operations.

The UN Committee on the Peaceful Uses of Outer Space has worked in close tandem with the IADC for over a decade to come up with unanimously agreed guidelines. And, indeed in December 2007 the UN General Assembly adopted the non-binding mitigation guidelines essentially as developed within the IADC deliberative processes. These guidelines have the following seven component parts as shown in Chart 1 below. [UN Space Debris Mitigation]

Chart 1: UN General Assembly Approved Non-Binding Guidelines on Debris Mitigation

Guidelines for the Mitigation of Space Debris

Guideline 1: Limit debris released during normal operations
Guideline 2: Minimize the potential for break-ups during operational phases
Guideline 3: Limit the probability of accidental collision in orbit
Guideline 4: Avoid intentional destruction and other harmful activities
Guideline 5: Minimize potential for post-mission break-ups resulting from stored energy
Guideline 6: Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission.
Guideline 7: Limit the long-term interference of spacecraft and launch vehicle

Today the IADC continues to work on improving these guidelines and the UN COPUOS has created a Working Group on the Long Term Sustainability of Space Activities (LTSSA). Within this working group is the so-called Expert Group B that has the key assignment of addressing orbital space debris and its mitigation. This group assignment is to work on: "Space Debris, Space Operations, and Tools to Support Collaborative Space Situational Awareness". The complete list of issues that the Expert Group B is currently addressing is provided in Chart 2 below. Space operations and space situational awareness for reasons addressed later in this book are closely related to orbital space debris mitigation activities. [Expert Group B]

Chart 2: Expert Group B Tasks Currently Under Study

Expert Group B Issues Currently Under Consideration

Space debris:

- Measures to reduce the creation and proliferation of space debris
- Collection, sharing and dissemination of data on space objects
- Re-entry notifications regarding substantial space objects
- Technical developments and possibilities regarding space debris removal

Space operations:

- Collision avoidance processes and procedures
- Pre-launch and pre-manoeuvre notifications
- Common standards, best practices and guidelines

Tools to support collaborative space situational awareness:

- Registries of operators and contact information
- Data centres for the storage and exchange of information on space objects and operational information
- Information-sharing procedures
- Topics for Discussion

On-going Inadequacies of Space Debris Mitigation

Despite the progress that has been made to develop the existing guidelines for orbital debris mitigation there remains serious ongoing problems in this area. The first and most obvious deficiency is the lack of a clear and definitive definition of "orbital space debris". The Liability Convention and the Registration Convention only defines "space objects", but nowhere is the term "space debris" clearly and broadly defined in existing treaties on outer space. In brief, there is no global agreement as to what this term means. There is no specific UN or any other international agency or institution that has legal or regulatory authority for the active removal of orbital space debris. Indeed there is no proven technology that can effectively and also cost-efficiently remove debris from orbit. Further if such a technology existed (i.e. ground based directed energy systems or in-orbit mechanism that could achieve such removal), it would very likely be characterized as a "space weapon" and has significant implications for the further negotiation of space arms control. In short, despite the now agreed non-binding UN Guidelines on Space Debris Mitigation, there is a lack of technical, legal, financial, business and institutional arrangements to undertake active space debris removal. This is clearly a real issue and problem in that despite the UN Guidelines the problem of space debris continues to become worse. The risk to spacecraft positioned in low earth orbit and especially polar orbit is especially increasing. Dr. Donald Kessler, who first identified the threat now known as the "Kessler Syndrome", has projected that on-orbit collisions such as that occurred in the case of the Kosmos 2251 and the Iridium 33 will now likely occur every decade or so and thus this problem will continue to become worse and worse over time unless active orbital debris removal can serve to mitigate these collision events and thus avert debris buildup. ["Cosmic Hazards" video, Interview with Donald Kessler]

Scope of This Book

The scope of this book is to explore the technical, legal, institutional, and financial and business aspects of the orbital space debris problem. It particularly seeks to explore new initiatives and systems that can rescue the world community from the serious future consequences of this mounting problem that could possibly limited future access to outer space. As the problem of an increasing world population, urbanization and human industrialization has given rise to major environmental problems of climate change, loss of species, desertification, and water shortages, the increasing exploitation of space to meet human goals has now given rise to the problem of orbital space debris. It is not accidental that the working group of the UN Committee on the Peaceful Uses of Outer Space that is now addressing this issue is called the "Working Group on the Long Term Sustainability of Outer Space Activities."

There are many ways that this problem might be addressed. These are broadly indicated in the seven guidelines on orbital space debris mitigation that are included in Chart 1 above. The current strong trend of thought, however, is to believe that "clean" future launches will not be enough. This is because the existing 6 tons of debris now in space (45 % in low earth orbit) will continue on an occasional basis to collide and thus build up more and more debris over time.

In short, this means that active debris removal—with a focus on the largest debris elements in low earth orbit as the first priority—needs to be given priority. Space situational awareness and maneuvers to avoid collision and perhaps the use of ground or space based directed energy systems to avoid collisions (or near conjunctions) must also likely be a part of this overall strategy to preserve long-term and save access to outer space. This combined need for debris removal as well as collision avoidance is probably essential. The activation of systems to achieve debris removal will take time, new technology, financial resources, and perhaps new institutional arrangements. Changes to current international space regulations and legal provisions will also likely be required—starting with a clear definition of space debris and agreed procedures under which debris removal can be achieved. Such changes will take time and commitment of key actors to achieve such a program of action. It took, for instance, from 1994 to 2007 (or 14 years) to get the United Nations to go from actively considering the orbital debris problem to adopting the guidelines for orbital space debris mitigation.

Key Terms

In this book there will be a number of terms used with technical or special legal or regulatory meaning. The glossary at the end of this book should be of some assistance if particular acronyms, terms or phrases are not clear. Some particularly important terms, however, will be addressed here and now.

Orbital Space Debris is defined in the UN COPUOS Space Debris Mitigation Guidelines as follows: "Space debris is defined as all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional." Orbital Space Debris is also known as orbital debris, space junk, and space waste. It includes all defunct objects in orbit around Earth. This includes everything from spent rocket stages, old satellites, and fragments from disintegration, erosion, and collisions. Normally space operators of spacecraft or their insurers decide when a space object has reached its end of life or is considered defunct. There is a danger that they wait too long to make this judgment and there is consequently not enough fuel to remove the defunct satellite to a safe orbit or power a safe re-entry into Earth atmosphere in order to burn up.

Orbital Space Debris Mitigation is a term applied to all attempts to lessen the creation, buildup or proliferation of defunct space objects. This can include the conduct of space situational awareness and tracking, maneuver or orbital change of spacecraft to avoid collisions, pacification (or de-energizing) of in-orbit spacecraft or vehicles, or ultimately the active removal of defunct of defunct space objects. It thus covers all seven of the activities included in the Mitigation Guidelines.

Active Orbital Space Debris Removal refers to all types of actions undertaken to remove a defunct spacecraft, vehicle or space object from earth orbit at the end of life or when it has been declared defunct or hazardous. This can include a wide range of activities including the following: (1) Active firing of thrusters or deploying of passive de-orbiting systems to increase atmospheric drag at the end of life for a spacecraft, or alternatively to deorbit an upper stage launcher vehicle. (2) Efforts using some form of directed energy device (either on the ground or in space) to change the orbit of a space object so that it de-orbits. (3) It can include sending up a spacecraft, device or instrument that can directly or indirectly change the orbit of a space object so that the targeted space object leaves Earth orbit either in a short period of time or on a gradual bases—but usually with the minimum objective of meeting the currently broadly agreed "25 year rule" of deorbiting space objects after their end of life. (Note: The 25 year rule is within the IADC guidelines, but unfortunately not included in the COPUOS Guidelines.)

In-Orbit Servicing: This is the type of "on-orbit" activity where changes, modifications, repairs or upgrades might be made to spacecraft already in orbit. Currently such in-orbit servicing is primarily considered to be carried out by on-orbit robotic devices that could make changes to an orbiting spacecraft. In the future this might involve human crew carrying out servicing activities.

Space Situational Awareness: This is the process of tracking—with some precision—the orbits of all space objects in Earth orbit. Space situational awareness is typically carried out by Radar (typically VHF or S band) tracking and in some cases by optical tracking. This tracking process is primarily carried out by military systems. Such military systems have a prime concern, for tracking missile attacks, but is today carried out for many other purposes including protection of valuable space assets, and seeking to avoid collisions.

Goals and Objectives

It is the objective of this book to explain the nature of currently increasing orbital space debris problems and to report, in particular, what progress is being made with regard to active space debris mitigation and removal efforts. This means that the technical systems that are being developed for active debris removal will be explored. There will also be an analysis of the new legal, regulatory, or financial mechanisms that might be employed to further the goal of space debris reduction, mitigation and removal. In addition to this prime objective, there will be supplementary information provided with regard to in-orbit servicing and space situational awareness. Developments and improvements with regard to on-orbit or in-orbit servicing can provide useful and quite parallel technical capabilities also needed to achieve active space debris removal. Close proximity tracking and precise orbital detection is critical to servicing or active debris removal. In short without tracking exactly which orbit space debris is following, active removal would not be possible. Further techniques developed for in-orbit servicing of spacecraft (or perhaps harvesting elements of a defunct spacecraft for new purposes as proposed for the Phoenix project by DARPA) can be key to the developing of new technical systems for active orbital debris removal. Indeed it is possible that some of these space activities of the future may be accomplished on a joint or at least well-coordinated basis.

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