9. Implications of new trends in small satellite development

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9.1. Introduction

Space-borne Earth observation has become a valuable tool for sustainable management and global environmental monitoring because of its unique capability to acquire measurements of various environmental data over large areas of the Earth's surface. The important need for Earth observation missions in order to improve the related data is perhaps most clearly seen in the great number of current initiatives for international co-operation in the field of environment monitoring, in which measurements from Earth observation (EO) satellites are an essential element. This is especially true in cases where we need to acquire, analyse and use data to document the condition of the Earth's resources and environment on a long-term (or permanent) basis.

For example, in 2008 the Group on Earth Observations (GEO), which currently numbers some 74 participating countries, the European Commission (EC) and 51 other organisations, developed concrete plans for its Global Earth Observation System of Systems. Also in 2008, the European Union's Space Council continued to advance Europe's Space Policy, reaffirming the need for the rapid implementation of the Global Monitoring for Environment and Security (GMES) programme.

From a space-based remote sensing point of view, the only way to implement flexible space systems in the service of security and prosperity is to pursue activities aimed at developing and operating cost-effective EO missions to monitor the relevant geophysical phenomena on a global scale.

The following sections deal with general facts and trends in the field of small satellite missions for EO purposes. Special attention is given to the potential spatial, spectral, and temporal resolution of small satellite based systems. The capabilities of small satellites in terms of spatial and spectral resolution are close to what larger satellites can provide. Moreover, satellite constellations give small satellites the unique possibility of providing good daily coverage of the globe and/or allowing observation of various dynamic phenomena through their ability to increase their temporal resolution.

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New trends in micro-satellite development include building distributed space systems with a variety of features. The capabilities of both distributed space systems and single micro-satellites have implications for the technical and regulatory aspects of space system development and use. The technical implications concern data rates and volumes, launch services, ground station concepts and space debris-avoiding strategies. Regulatory aspects include registration policy, frequency allocation procedures for the inter-satellite and space-ground communication and space debris problems mitigating policy. Increased awareness of these implications can give competent authorities dealing with regulatory issues the possibility of developing a top-down concept for future requirements.

The current situation and new trends in small satellite development are very much in line with the increasing importance of space-based remote sensing, since we have to face a growing world population and decreasing resources while at the same time asking for an ever increasing number of cost-effective space systems to provide good quality and timely information.

9.2. Small satellite missions: facts and trends

9.2.1. General facts

Small and cost-effective missions are powerful tools to react flexibly to information requirements with space-borne solutions. Small satellite missions can be conducted relatively quickly and inexpensively and provide increased opportunity for access to space. The spacecraft bus and instruments can be based either on optimized off-the-shelf systems with little or no requirement for new technology, or on new high-technology systems. Thus a new class of advanced small satellites, including autonomously operated "intelligent" satellites, may be created to open new fields of applications for scientific purposes as well as operational, public and commercial services. Further milestones in the area of small satellite EO missions are the availability and improvement of small launchers, the development of small ground station networks connected to rapid and cost-effective data distribution methods, and cost-effective management and quality assurance procedures.

For about two decades, small satellites using off-the-shelf technologies for missions focused on specific physical phenomena have been seen as an opportunity for countries with a modest research budget and little or no experience in space technology to enter the field of space-borne EO and its applications. Small satellite technology is a major means of bringing within the reach of every country the opportunity to operate EO missions and to utilise the acquired data effectively and at a low cost, as well as to develop and build application-driven missions. It provides the opportunity to independently conduct or participate in EO missions using small, affordable satellites and associated launches, ground stations, data distributions structures, and space system management approaches.

One possible approach to developing small satellite systems is to take full advantage of ongoing technological developments leading to the further miniaturisation of engineering components and the development of micro-technologies for sensors and instruments that would allow the design of dedicated, well-focused EO missions. At the extreme end of miniaturisation, the integration of micro-electromechanical systems (MEMS) with microelectronics for data processing, signal conditioning, power conditioning and communications leads to the concept of applying specific integrated micro-instruments (ASIM). These micro- and nano-technologies have led to the concept of using nano- and pico-satellites, constructed by stacking wafer-scale ASIMs together with solar cells and antennas on the exterior surface, to create space sensor webs.

The situation in the field of small satellite missions for EO has matured in the last ten years. This can be observed, for example, in the topics and quality of contributions to international conferences in Berlin, Logan, the annual International Astronautical Congress, or those organised by space agencies such as ESA or CNES. The Small Satellite Workshops of Commission I of the ISPRS's provide further evidence of the increased attention being given to this subject.

But what exactly is a small satellite? Table 4 gives some examples of how different entities define or categorise small satellites depending on their products or programmes.[808]

To end this confusion, the International Academy of Astronautics (IAA) has proposed a simplified definition.[809] This definition is reflected in Figure 11 in conjunction with additional features that are essential when discussing small satellite characteristics such as cost and response time. The performance issue is covered in subsequent sections.

Tab. 4: *Confusion of small satellite definitions.*

ESA:	Small Mini Micro	350 kg –700 kg 80 kg –350 kg 50 kg –80 kg
EADS Astrium:	miniXL Mini Micro	1000 kg –1300 kg 400 kg –700 kg 100 kg –200 kg
CNES:	Mini Micro	500 kg + P/L (Proteus) 120 kg + P/L (Myriade)

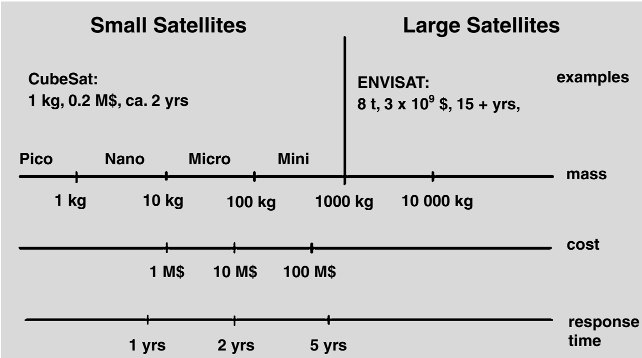


Fig. 11: *Some features of small satellites.*

The cost and response time figures should be considered as ball park figures. They are based on the usage of state-of-the-art technology by professional teams. They may deviate considerably if key technology has to be developed, or if the implementation teams are at the beginning of their learning curve. Figure 11 is complemented by two examples representing the opposite ends of the range. From the customer's point of view, the most important feature of small satellites is their performance. This aspect is covered in the following sections. From Figure 11 we can see that in broad terms, the smaller the satellite is, the less are the cost and the response time. This fact provides a strong incentive to opt for small and especially micro-satellite missions. In this paper we mainly use the term micro-satellite for satellites below a 100 kg mass (including the subsets nano-satellite, pico-satellite etc.) but this definition should also include producer dependent deviations in order to reflect the specific development and mission requirements, as well as cost and response time variables.

The advantages of small satellite missions are:

– more frequent mission opportunities and therefore faster return of science and application data
– larger variety of missions and therefore an equally greater diversification of potential users
– more rapid expansion of the technical and scientific knowledge base
– greater involvement of local and small industry.

Large satellite missions and small satellite missions are considered to be complementary rather than competitive. In some cases large satellite missions can even be a precondition for cost-effective approaches.

9.2.2. General trends

Small satellite missions are supported by several contemporary trends:[810]

- advances in electronics miniaturisation and associated performance capability;
- the recent appearance on the market of new small launchers (e.g. through the use of modified military missiles to launch small satellites);
- the possibility of "independence" in space (small satellites can provide an affordable way for many countries to achieve Earth Observation and a defence capability in space without relying on inputs from major space-faring nations);
- the ongoing reduction of mission complexity and costs associated with management and meeting safety regulations etc.;
- the development of small ground station networks connected to rapid and cost-effective data distribution methods.

In addition, the trend to smaller satellites has been and is still supported by improvements in diverse fields of technology, such as optics, mechanics and materials, electronics, signal processing, communication and navigation, in addition to microelectronics. Mass, volume and power consumption of spacecraft and their instruments have followed the trend to miniaturisation, at the same time allowing for a significant increase in performance. These trends can be observed for passive optical space borne systems as well as for active microwave systems, such as S.A.R. (Synthetic Aperture Radar) systems. They all benefit from overall technology improvements.

9.3. Status and prospects

The focus of this section is mainly on micro-satellites. The capabilities of micro-satellites are shown with respect to their spatial, spectral and temporal features and limitations. The new trend in micro-satellites leads us to the development of distributed space systems and their potential. The knowledge and vision behind this trend is a useful basis for deriving its technical and regulatory implications.

9.3.1. Capabilities of micro-satellites – optical payloads

9.3.1.1. Spatial resolution

The first civil space-borne Earth surface imager was launched in 1972 on the ERTS (Earth Resources Technology Satellite) spacecraft later renamed

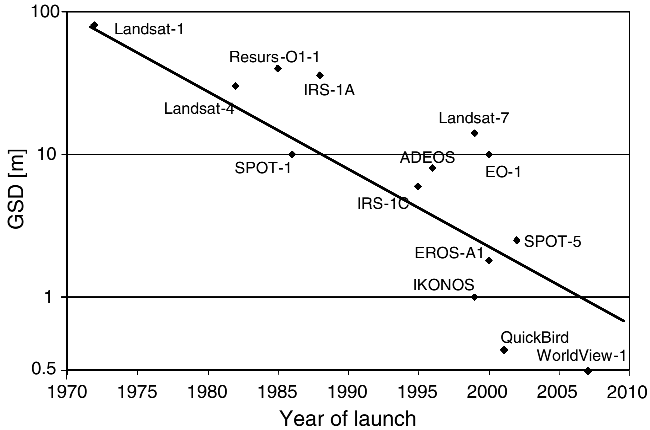


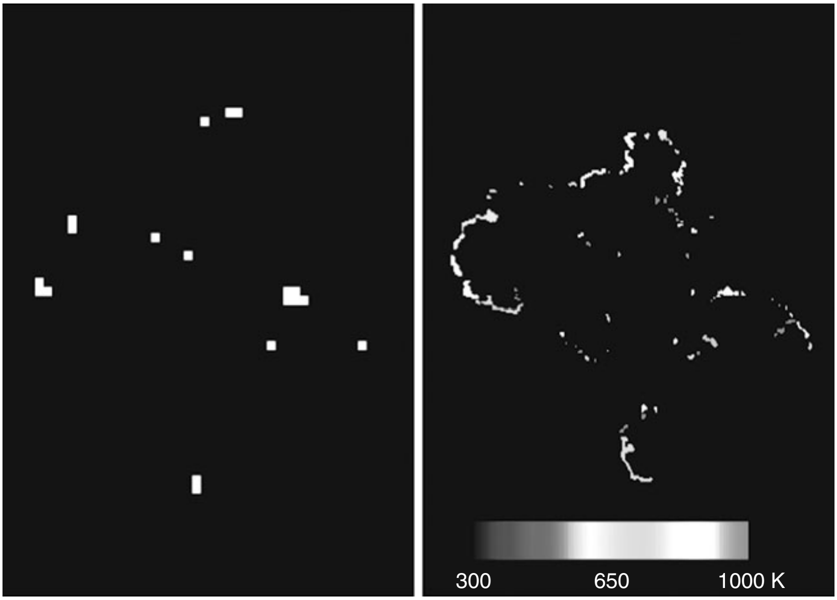
Fig. 12: *Some civil Earth surface Imagers to show the trend of ground resolution (source: GSD).*

Landsat-1. The MMS (Multispectral Scanner System) instrument provided a spatial resolution of 80 m and a swath width of 185 km. With Landsat-4 a more sophisticated multi-spectral imaging sensor was launched in 1982 – the TM (Thematic Mapper) with a spatial resolution of 30 m. There are numerous sensors of different types (mechanical scanners, push-broom scanners, matrix systems) from many countries, including Brazil, China, Argentina, France, India, Thailand, South Africa, Korea, UK, and Germany.[811] Due to the immense improvements in several fields of technology, such as optics, mechanics and materials, electronics, pattern recognition, signal processing, computer technology, communications and navigation, space borne imaging systems have now reached ground sample distances (GSD) of less than one meter. Figure 12 shows the trend of improving resolution (or decreasing GSD) of civil space-based mapping systems that have taken place since Landsat-1 in 1972.[812] The number of space-borne mapping systems indicates the need for high resolution maps to use the best available technologies.[813]

An example of the aforementioned trend is the PIC-2 camera on the small satellite EROS-B from Israel, which provides a GSD of 0.70 m.[814] On 25 April 2006, EROS-B, with a mass of 350 kg, was launched into a 500 km sun synchronous orbit (SSO) by a Russian START-1 launcher. By comparison, the 130 kg micro-satellite TopSat, developed by SSTL/UK and launched into a SSO in November 2005 onboard a KOSMOS-3M from the Pletsesk Cosmodrome, provides a GSD of 2.5 m.[815]

9.3.1.2. Spectral resolution and range

In addition to spatial resolution, spectral resolution is also increasing. An example can be seen in the hyperspectral imager CHRIS on the ESA-funded PROBA satellite.[816] CHRIS, a 14 kg/9 W hyperspectral imager, has a GSD of 18 m and provides up to 19 out of a total of 62 spectral bands in the VIS/NIR spectral range (400 – 1000 nm). PROBA, with a mass below 100 kg (which qualifies it as a micro satellite) was launched into a 600 km sun synchronous orbit (SSO) on 22 October 2001 together with the DLR/Germany micro satellite BIRD for forest fire detection and fire parameter assessment[817] and the main payload TES (India)[818] with the PSLV-C3 launcher from India. The 94 kg micro-satellite BIRD (Bi-spectral InfraRed Detection) is an example of extending the wavelength range of micro-satellite instrumentation to the thermal infrared. BIRD is equipped with two IR cameras in the wavelength ranges of about 4 μm and 9 μm and is used to demonstrate a possible approach to detection and quantitative characterization of high-temperature events like vegetation fires on the Earth's surface. A detailed description of the BIRD system is given in Brieß et al., 2003. Here we only show an example of BIRD performance. Figure 13 gives a comparison of results derived from MODIS (currently the best satellite system to detect fires) and BIRD with



MODIS: Fire map BIRD: Fire map

Fig. 13: *Fire detection by MODIS and BIRD (Australia, 5 January 2002).*

respect to the forest fire in Australia near Sydney on 5 January 2002. The difference is obvious. BIRD data are even capable of providing fire-fighting authorities with important parameters such as fire temperature, front length and front strength in kW/m.

9.3.1.3. Temporal resolution

Small satellites provide a unique opportunity for launching affordable constellations. In this respect, small satellites can do things that are not practical with large satellites. At this point, DMC (Disaster Monitoring Constellation)[819] and RapidEye[820] can serve as examples of constellations of five micro-satellites. More details are given in section 3.4. "Distributed space systems."

9.3.2. Limitations

Small satellite missions usually focus on one specific physical phenomenon to be investigated or monitored. In this context, the restrictions and limitations of small satellite missions by comparison with large complex missions are:

- In orbit lifetime restrictions because of the extended use of advanced technologies (by comparison with conventional satellite missions)
- Limited platform capacity for using instruments with high power consumption or high data rate requirements
- Size limitations and platform stability limitations that do not allow the use of large microwave antennas or long monolithic telescopes
- Restricted options for instrument combinations on a single satellite platform because of the limited size and power capabilities of small satellites.

For these reasons small satellite missions may only be considered as complementary to conventional Earth observation missions.

9.3.3. Distributed space systems

In recent decades, spacecraft mass and power have been reduced to limit costs and risks, leading to shorter development times, as well as to the possibility of flying up-to-date technologies and achieving frequent re-flight. Besides such advantages on a single spacecraft level, it must be considered that cost reduction also opens the possibility of flying multiple spacecraft systems. A system of platforms can replace a monolithic system very effectively with the advantage of substituting the concept of failure with, ideally, one of graceful degradation. In addition, a system of platforms can achieve a performance level unachievable by a monolithic approach. Although in principle the distributed system concept can be applied to both large and small spacecrafts, it is naturally suited for small and especially micro-satellites, for a number of reasons: low system cost, easy replacement of a failed satellite (both in cost and delivery time) and possibility to gradually update technologies in orbit (which is generally an issue for large space systems).

The "Nano-Satellite Constellation Mission Idea Contest"[821] shows that there are already efforts to extensively utilise the low-cost aspect of satellites in constellations. The basic idea of this international competition is to find new remote sensing applications beyond those developed just for academic use. In this way, it is expected to supplement existing remote sensing systems in their performance or application areas, and even to satisfy other applications' needs that have not been met by existing technologies and techniques. For the purposes of this competition, the term constellation covers all distributed space system options.

In thinking about distributed space systems, a distinction can be made between different systems based on the distance between the satellites and the requirements concerning the control of their distance.[822] Using this approach, the following categories can be identified:

- Constellations
- Formations
- Swarms
- Inspection and docking systems

Figure 14 shows local systems with separations of a few meters between the spacecrafts, regional separations of typically a few tens meters to several hundred kilometres, and global systems with separations of more than a thousand kilometres.[823]

The concept of formation flying of satellites is frequently confused with that of satellite constellations. In the following sections we will distinguish between these concepts using the definitions of NASA GSFC:

- A constellation is composed of two or more spacecraft in similar orbits with no active control by either to maintain a relative position.
- Formation flying involves the use of an active control scheme to maintain a relative position.

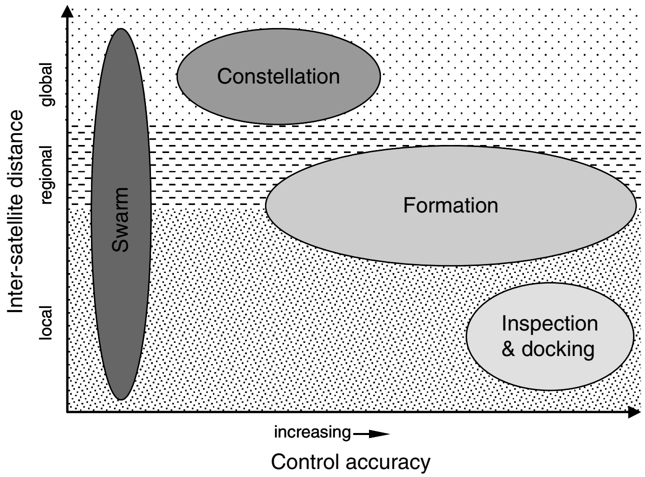


Fig. 14. *Requirements for distributed space systems.*

From the application point of view, the aim of a constellation is generally related to coverage enhancement and, therefore, to the reduction of the repetition time of observing the same ground target and consequently of the required time to achieve global coverage. In practice, a constellation consists of identical spacecrafts whose orbits are designed to adequately cover the globe (or part of it). Constellation products are just the sum of the spacecrafts' products.

On the other hand, formations tackle the issue of achieving a synergic use of payloads onboard different platforms, with no advantage in terms of time resolution. However, they enable additional products with respect to those offered by single spacecraft. In principle, one can imagine a formation implementing a distributed payload, with no product at all delivered by the payloads on board the single spacecrafts. The clear advantage of such an approach is the possibility of flying very large sensor apertures in space.

9.3.3.1. Swarms

While docking, formation flying and constellations are well established implementations of distributed space systems, swarms of spacecraft consisting of several, tens or thousands of satellites have not been deployed yet. Swarms of satellites can characterize for instance the local, regional or global Earth environment, making in situ measurements of the atmosphere or radiation conditions.

9.3.3.2. Inspection and docking systems

Inspection and docking involves two objects in space in close vicinity. This characteristic is typical of an inspector micro- or nano-satellite, orbiting for instance the International Space Station (ISS). Another example is ESA's Automated Transfer Vehicle (ATV) docking at the ISS. This poses very high demands on control accuracy. At a given separation of ten meters for example, the control accuracy should be better by at least a factor of ten (in this case one meter). Control is based on sensors which again need to provide a tenfold better accuracy (or 10 cm).

9.3.3.3. Constellations

To achieve global coverage of the Earth with high time resolution requires a satellite constellation. As already mentioned, small satellites provide a unique opportunity for deploying affordable constellations. In this respect, small satellites can do things that are not practical with large satellites.

DMC may serve as an example of a constellation of five small satellites. The standard spacecraft weighs 88 kg, of which 19 kg is payload. DMC has a GSD of 32 m and a swath width of 600 km (Landsat: GSD = 30 m, Swath width = 185 km). It provides daily coverage of the Earth.[824] The five satellites (AlSat-1, BILSAT-1, NigeriaSat-1, UK-DMC-1, Beijing-1) from five countries have been launched with three COSMOS launchers into the same orbit. DMC-2 is a planned follow up of DMC-1 with improved performances based on new technologies.

Another example is RapidEye, a commercial multispectral Earth observation mission of RapidEye AG of Brandenburg, Germany, that includes a constellation of five micro-satellites (launch August 2008, 150 kg each, GSD = 6.5 m).[825] The mission provides high-resolution multispectral imagery along with an operational GIS (Geographic Information System) service on a commercial basis. The objectives are to provide a range of Earth-observation products and services to the global user community.

9.3.3.4. Satellite formations

Formation flying of satellites is typically associated with a small number of spacecraft flying in a concerted way at regional inter-satellite separation distances. The mission objectives determine the accuracy requirements for their control.

A science mission using interferometry may have high control demands, whereas a formation of two satellites with different instruments can have less stringent control requirements.

Some current remote sensing missions already utilise the formation concept, such as GRACE (NASA/DLR Earth's gravity mapping mission) and NASA's A-TRAIN. A-TRAIN, basically a constellation mission with some formation aspects, integrates different payloads on board different satellites (OCO, Aqua, Aura, PARASOL, Cloudsat, and CALIPSO) whose combined data allow the study of climate change data. The formation flying aspect of the system is particularly related to CALIPSO and Cloudsat, whose time separation is controlled within 15 seconds of each other in order for both instruments to view the same cloud area at nearly the same moment. Such a formation flying requirement emerged from the scientific objective of observing the same clouds (whose lifetime is often less than 15 minutes) at different wavelengths. A-TRAIN consists of large, small (CALIPSO: 635 kg) and micro-satellites (PARASOL: 120 kg).

9.4. Implications

Since the advent of modern technologies, small satellites using off-the-shelf technologies or missions focused on specific physical phenomena have also been perceived as an opportunity for countries with a modest research budget and little or no experience in space technology development to enter the field of space-based Earth observation. Small satellite technology is a way of bringing within the reach of every country the opportunity to operate small satellite Earth observation missions and consequently of utilising relevant data effectively at low cost and developing application-driven missions. It provides the opportunity to independently conduct or participate in multilateral Earth observation missions using small, cost-effective satellites, and associated launches, ground stations, data distribution structures and space system management approaches. The actual performance parameters of small satellites, given in section 3, demonstrate that small satellites are competitive with older larger satellites with respect to their spatial, spectral and temporal resolution. Besides the increase in their number and the improvement of their performance, distributed space systems' use generates an additional operational requirement for reliable inter-satellite communications. In the following section we subdivide the implications arising from the new trends in small and especially micro-satellite development in two different groups: technical implications and regulatory implications.

9.4.1. Technical implications

9.4.1.1. Data rate and volume

Recent technological developments allow for the equipping of even micro-satellites with high spatial and spectral resolution imaging systems, a capability that demands the transmission of huge amounts of data at very high rates. Handling the high data rates is a matter of technology and transmission techniques. Both areas demonstrate significant progress. NigeriaSat-2, a 300 kg small satellite to be launched at the end of 2010 and equipped with a 2.5 m panchromatic band and four 5 m multispectral bands, is able to transmit imagery at a speed of 2×105 Mbps. NigeriaSat-2 is the first space component of the African Resources Management Constellation (ARMC), proposed by South Africa and supported by Nigeria, Algeria and Kenya. As a reference, it should be noted that the related parameters of SPOT-5 are 3000 kg, 5 m panchromatic and 10 m multispectral resolution and 2×50 Mbps downlink rate.

In monitoring EO systems the data volume can be significantly reduced by applying autonomously operating processor systems to extract the information from the sensor data. The BIRD microsatellite, with its neural network capable of producing thematic fire maps, may serve as a technology demonstration example.[826]

9.4.1.2. Access to space

During recent years there have been several small launchers from Brazil, China, Europe, Israel, Japan, Russia and the U.S. available at prices that are quite reasonable compared to the cost of a small satellite.

More commercial launch services are now available on most launch systems, many of which are new vehicles designed or modified to specifically meet international commercial market requirements. The most dramatic shift has been the market entry of Russian and Ukrainian launch systems that are operated as joint ventures with U.S. and European companies. The increasing availability of these low-cost launchers and the development of satellite dispensers have opened up the possibility of launching an entire constellation on a single launch, as individual payloads. The launch of the NASA/DLR GRACE satellites used Eurockot Launch Services, the joint venture owned by Astrium and the Russian company Khrunichev, to place two satellites in a closely controlled formation by using a dispenser. This launch was the first commercial use of the Russian SS-19 ICBM, which provides the two booster stages used by the ROCKOT launch vehicle and has a record of 150 flights. At the other end of the cost and mass spectrum, Ariane 5 has been used to launch six auxiliary payloads along with the primary Helios satellite, using its auxiliary payload adapter ASAP. This included Nanosat, Spain's first small satellite built by the country's INTA national space agency (Instituto Nacional de Técnia Aeroespacial), with a mass of less than 20 kg. In another example, the Cluster mission formed a constellation of four satellites in formation flying, by using two separate launches. Nowadays, most of the large launchers provide payload adapters to accommodate small satellites as secondary payloads.

In the U.S., new private and seed capital is currently being invested in the development of new launchers for small satellites. SpaceX of Al Segundo, California and Air-Launch of Kirkland, Washington are two examples of private enterprises providing launch services. Furthermore, DARPA and the U.S. Air Force have formed a joint venture to work on a small launch vehicle programme.

In addition to the above, space tourism has made its appearance as one of the newest and potentially most vigorous business incentives for the development of commercial small launchers. On 4 October 2004, Burt Rutan and Paul Allen built and flew the world's first private spacecraft to the edge of space, to win the 10 million dollar Ansari X PRIZE. Perhaps by looking back at the history of the early development of commercial aviation, one can have a glimpse at the future of commercial space access for the next twenty years. At the turn of the last century, air travel was relatively risky and quite expensive. As the commercial market for air transport grew, operating costs and investment risk dropped accordingly. Nowadays, air transport is so cost-effective that it is used to ship bulky agricultural goods, such as apples or flowers, half way around the world at prices that are competitive with local transport and production.

Nevertheless, there are some indicators showing that there are still serious efforts to be made in order to achieve comparable results in the space transportation domain. For example:

- The establishment of the annual International Symposium for Personal and Commercial Spaceflight (ISPCS)
- The recognition of a national (U.S.) Centre of Excellence for Commercial Space Transportation by the Federal Aviation Administration (F.A.A.)
- The creation of space tourism companies and the development of related spacecrafts, like Virgin Galactic.

Having these activities in mind, it is probable that in the near future small satellite missions will no longer be strongly constrained by launch costs.

9.4.1.3. Ground systems

The classical approach of ground segments assigns the specific tasks of

- S/C monitoring & control,
- P/L data reception & archives, and
- P/L data products & distribution

to specific ground facilities communicating through complicated protocols. As the number of spacecraft increases in a constellation there would be, without a change in the operations paradigm, a concomitant increase in the costs to operate the constellation. To operate constellations of micro- and nano-satellites, the operation costs have to be low on a per satellite basis especially since some of these constellations are envisioned as consisting of tens or even hundreds of micro- or nano-satellites. Simple downscaling is not sufficient – qualitative changes combining the different tasks and facilities in networks with new features are necessary. Key words for the new ground systems are for instance

- Open systems
- Automation
- “internet” technology
- Multi-session operations
- Ground station networks
- Increasing on-board autonomy.

With respect to the last point, requirements for the space segment also need to be determined. Powerful, cheap microprocessors provide the means for increased autonomy at the individual satellite level and across the constellation. At issue, though, is developing the software to perform these operations and subsequently testing the software so that its operation can be verified before flight. Qualifying these systems for spaceflight will be a challenge that must be addressed.

9.4.2. Regulatory implications

Regulatory measures may become very severe in the future. It is time to think about these now, and not be caught by surprise. Here we just address the reasoning for and the structure of the implications. The solutions need to be provided by the authorities in charge.

9.4.2.1. Space system registration

For the increasing number of micro satellites to come, especially considering distributed space systems based on micro- and nano-satellites that may consist of tens or even hundreds of micro- or nano-satellites, current registration procedures seem to be inadequate. There seems to be a need for new approaches to deal with this development.

9.4.2.2. Transmission frequency allocation

The increasing number of high performance small satellites will be accompanied by an increasing number of data downlink channels to be allocated. At some point we need to think about sophisticated procedures to manage the available frequency slots and/or to extend the usable frequency range using new technologies and transmission techniques to be managed by a competent authority. The problem is even worse if we think about distributed space systems of micro- and nano-satellites, especially since some of these constellations, formations or swarms are envisioned as consisting of tens or even hundreds of micro- or nano-satellites thus adding the inter-satellite, intra- and inter-constellation link problem to the usual downlink requirements.

9.4.2.3. Space debris management

The huge number of future space systems in orbit (satellites and launch system components), again including those distributed space systems consisting of tens or even hundreds of micro- or nano-satellites, has implications for the space debris risk. These need to be addressed now, before we run into a much bigger problem than the one we currently face. The current space debris problem is based on the fact that at the beginning of the space age the space debris problem was simply ignored. Now we think about requesting certain end-of-life procedures for each satellite with the consequence that adequate technical features have to be implemented in the satellite. But this late reaction has more consequences: countries now emerging in space technology are starting with a handicap the space faring nations did not have. This leads to discussions about fairness and responsibility that could have been avoided if we had had vision at the very beginning instead of now being confronted with a vision and a reality of a different kind.

In order to avoid running into problems in the future that seem to suddenly emerge, using mainly technical reasoning this paper has attempted to outline possible future developments in satellite Earth observation and to derive from them the technical and regulatory implications.

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