IISL-01-IISL.4.04

THE IMPACT OF ORBITAL DEBRIS ON COMMERCIAL SPACE SYSTEMS

Tare C. Brisibe*
Regulatory Information Officer, INMARSAT Limited, London, United Kingdom
E-mail: Tare_Brisibe@inmarsat.com

Isabel Pessoa-Lopes
Moderator of the UN PSA – SGAC
Policy, Law and Commercialisation of Space Working Group
and
Principal Consultant, SPACE RISKS
E-mail: ipl@spacerisks.com

ABSTRACT

Space debris is increasingly becoming an important factor when considering the exploration, exploitation and environmental protection of outer space. Deliberations are currently being conducted at the national and international levels intended to implement appropriate and affordable measures to minimize the potential risk and financial loss that space debris may cause to orbital space assets. Several initiatives have focused on establishing a technical basis for addressing the complex attributes of space debris involving: debris measurement; data compilation; modelling and analysis of debris environment; risk assessment and mitigation measures. Legal consultations have identified *inter alia*, inadequacies in the current international legal framework governing activities in outer space that give rise to several issues including registration, liability and insurance, especially in the light of increasing commercially oriented space systems. This paper analyses aspects of space debris, which are inextricably interwoven with and influence the evolving legal framework aimed at minimizing the deterioration of specific orbital locations. Emphasis will be placed on a number of commercial issues.

INTRODUCTION

Three months after the launch of Sputnik 1 in 1975, the satellite ceased transmissions, re-entered the atmosphere and burnt up in the earth's atmosphere. Thus began the creation of space debris that has become a major but generally neglected problem with regards to space exploration. Since Sputnik, large numbers of space exploration projects have resulted in the formation of a large belt of debris that poses a potential source of danger to other operational spacecraft. Thousands of individual hardware items or objects have been placed in various space orbits, varying in size

* This paper is written in the co-authors personal capacity and does not necessarily represent the views of INMARSAT Limited.

from a few cubic centimetres to complete space laboratories weighing many tonnes with some of these items or objects having on-board nuclear reactors. Whilst most items tend to disintegrate and burn up entirely on re-entry into the Earth's atmosphere, it is also possible for pieces of considerable size and weight to reach the surface of the Earth.

TECHNICAL CONSIDERATIONS

It is estimated[*] that since 1957 approximately 26,000 objects have been launched into space out of which 17,000 have returned to Earth. Of the remaining 9,000 man-made objects, only 700 are in operation. Other objects accounting for space debris are non-operational satellites, discarded upper stages from launch vehicles, tools and equipment lost or forgotten by astronauts as well as fragments resulting from explosions. Space debris poses a threat because these fragments can be moving at very high speeds capable of releasing tremendous forces upon impact.

Sources of Space Debris

Space debris can be generated from various sources that include: in orbit impacts, break-ups, launch vehicle failures, intentional explosions, discarded rocket stages and deterioration, among others. The major contributor to the orbital debris background has always been object break-up. Satellite break-ups can be due to collision, electrical system malfunction, accidental detonation, propulsion system malfunction, deliberate or even unknown causes. Break-up of launch vehicles upper stages are linked to the uncontrolled mixing of propellants and rupture of tanks. The majority of break-ups have been due to explosions and most of the small pieces of debris are from explosions in near-Earth orbit. Nevertheless, scientists have acknowledged the problem of space debris for nearly two decades and have since developed methods of tracking the orbits of debris.

Debris Measuring

Remote sensing of space debris from ground-based measurements may fall into either or both of two categories, *viz*: radar and/or optical[‡]. Debris measurements can also be obtained via retrieved surfaces and impact detection[δ], or be space-based.

Because debris in geostationary orbit ("GEO") all move in the same direction (equatorial orbit) and at similar speeds, collisions at this altitude are less destructive. Objects in GEO are very far away from Earth and have much more stable orbits than in low Earth orbit ("LEO"). The implications of this fact are that the debris in GEO are potentially 'more permanent' and have a longer hazardous lifetime. The debris situation in GEO appears to be of at least two orders of magnitude less severe than that in LEO. Thus, current collision risks in GEO are lower than in LEO but due to the long residence-time of fragments in GEO in comparison to LEO the environmental consequences of a collision become greater.

LEO is the most crowded region with satellites and debris and is therefore a greater hazard. There are many possible orbits and higher relative velocities. LEO is also the area where Extra-vehicular activities ("EVA's") are most likely to take place and where the International Space Station will be located. Moreover, large constellations of communications satellites are scheduled for launch in the near future, so that the population of operational satellites is set to grow rapidly in the next few years.

Debris Modelling

Taking into consideration the contributions to the population of orbiting objects by several source mechanisms, various technical (short-term and long-term) models for population growth have been developed by the international community[j].

However, the debris population in LEO may grow in an accelerated manner in the future if space flight continues to be conducted as it was in the past. This was comprised of instances with the same launch and explosion frequencies, coupled with the absence of end-of-life de-orbiting of either payloads or rocket boosters. Most models agree that rapid population growth can occur in the absence of appropriate debris mitigation. The models also agree that the population level required to trigger rapid growth in a given orbital region will be achieved before rapid growth is observed. In this regard, the Re-orbiting (boosting) of GEO spacecraft into disposal orbits ('graveyard orbits') at the end of their active life is a measure already in practice[ψ], and will contribute to a sustainable debris population in GEO.

Debris Mitigation

Lack of sufficient debris mitigation efforts such as collision avoidance could eventually result in collision driven population growth. In the light of the aforementioned debris growth patterns, several mitigation policies and practices are currently under study aimed at reducing debris increase in time. These include: mission-related debris prevention, prevention of in-orbit break-ups (mainly in-orbit explosions and collisions), de-orbiting and re-orbiting of space objects (end-of-life payload disposal, rocket booster disposal).

Many spacecraft in geo-synchronous orbit are currently boosted into higher disposal orbits at the end of mission life. In the more distant future, it may be necessary to completely remove all satellites and upper stages from orbit. This removal will only be feasible if new technology is developed. Though the definition of re-orbit distance remains a subject being examined carefully by the international community.

APPLICABLE POLICY AND LAW

Having addressed the technical aspects of debris in the preceding section, this paper considers the existing international laws as well as national policies, regulations and standards, which are of direct relevance to the subject. Presently, there are no agreements offering internationally accepted definitions, albeit three[*] of the five treaties established under the auspices of the United Nations Committee on Peaceful Uses of Outer Space (UN COPUOS) set forth provisions which may be interpreted as being applicable to space debris.

In this regard, States parties are continually responsible for authorising and supervising the activities of their nationals and/or non-governmental activities in outer space[†] and bound to undertake international consultations in the event that certain activities or experiments would cause harmful interference with the activities of other States parties‡. Within the same context, the potentially hazardous consequences of orbiting debris are dealt with by provisions, which hold States potentially liable for damage caused by their activities to other States parties in airspace or outer space§. Such liability may be deemed as strict, or based on the establishment of fault, depending on where the damage is caused**. Furthermore, launching States are obliged to register space objects in an appropriate national registry and notify the UN of launched objects†† and specific details‡‡ in addition to rendering assistance to requesting States for the identification of a potentially hazardous or deleterious space object by the use of monitoring or tracking facilities.§§

From the foregoing provisions, the legal responsibility of States towards orbital debris can be implied. However in practice, applicable regulations, policies and standards have evolved in a heterogeneous fashion, giving rise to a patchwork of national and intergovernmental rules. Of note are the national regulations, policies and standards of the United States of America ("U.S."); the Federal Republic of Russia ("Russia) and the member States of the European Space Agency ("ESA").
Thus, the ESA member States under a Resolution*** adopted by its Council, *inter alia* has invited its Member States to take measures aimed at conducting efficient studies into the legal and economic aspects of space debris. It is intended that the legal and economic questions raised during the conduct of these studies would lead to the introduction of appropriate provisions in existing international agreements and commercially oriented contracts.†††
In addition to the Resolution, a draft European Space Debris Safety and Mitigation Standard‡‡‡ (ESA Standard) was established by a working group§§§. It is contended that the ESA Standard is currently under review by commercial stakeholders including insurers and satellite operators, and is to be harmonized with the activities of the Inter Agency Co-ordination Committee ("IADC"). The objectives of the said ESA Standards are: the prevention of space generation; and protection of space vehicles against existing space debris. In particular, the Standards *inter alia*, promote policies encouraging the adoption of operational techniques limiting production of debris and call for compliance with operational requirements and safety rules.

Pursuant to the provisions of the Russian Federation Law on Space Activity of 1993 ("Federal Law"), the Russian Federation has, with the aim of ensuring strategic and ecological security, prohibited the harmful contamination of outer space, which leads to unfavourable changes in the environment, including deliberate elimination of objects in space****. It should be noted that although this provision is applicable in the Russian Federation, it is safe to presume that the provisions shall govern the activities of nationals or non-governmental entities subject to Russian jurisdiction in outer space. In practice Russia has also displayed compliance with the provisions of other international legal instruments*, by adopting a set of protective measures†††† to be applied if confirmation is received of an incident involving the fall of a space object from high orbit.‡‡‡‡

Detailed National regulations[v] applicable to space debris, that also take into account the risks posed by debris to commercially operated space vehicles are those of the United States of America ("U.S."). The statutes all follow the policy thrust laid down in the Presidential Directive on National Space Policy of February 11 1988. The implementation of the Directive is evidenced by the provisions of two U.S. Government Orbital Debris Mitigation Standard practices developed in 1997, aimed at limiting orbital debris generation by launch vehicle upper stages.[§§§§]

Despite the limited regulatory steps taking by individual States such as Russia and the U.S., the International Law Association ("ILA") at its 66th Conference in Buenos Aires held in 1994, adopted a non-binding Draft International Instrument on the Protection of the Environment from Damage Caused by Space Debris[*****]. This Draft is probably the sole existing international regulation that attempts a definition of space debris to mean: "*man-made objects in outer space, other than active or otherwise useful satellites, when no change can reasonably be expected in these conditions in the foreseeable future*". The Draft constitutes a comprehensive attempt to address the range of issues on the subject, including the commercial context as it address *inter alia*: Obligations to Prevent, Inform, Consult, and Negotiate in Good Faith; Compatibility with Other Agreements; Responsibility and Liability; International Responsibility; International Liability; and Dispute Settlement. It is anticipated that treaty-making entities such as the legal sub-committee of UNCOPUOS, may refer to the said instrument in the event that space debris becomes an agenda item for this sub-committee.

COMMERCIAL IMPACT

Limiting the creation of debris through mitigation best controls risk. Unfortunately, debris mitigation usually increases mission cost. There is an ethical issue versus a legal issue based on over-riding cost considerations that is very much open to debate. However, proper disposal of equipment may well be added costs for space programs that are already on tight budgets. Some debris mitigation procedures have minimal impact on mission cost if they are specified early in the development phase. To prevent explosions, satellite components that store energy can be passivated at the end of their useful life. Batteries can be designed to reduce the risk of explosion. Passivation may entail moderate costs during the non-recurring phase of the mission. Costs during operation should be low. To prevent debris accumulation in preferred mission orbits due to collisions, satellites and other objects must be removed from the mission orbit at the end of life before collisions are likely to occur.

Although we must be cognisant of all areas in which space debris exists, LEO is of the greatest concern. Regarding satellite constellations, if a potential collision leads to the creation of a debris cloud that may result in damage to other constellation members, it may be worthwhile to perform a collision avoidance manoeuvre. The fact remains that if nothing is done, catastrophic damage to spacecraft can be expected, which will result in huge financial losses.

It is contended[β] that on average, a catastrophic collision will occur after the first half of a satellites lifetime, resulting in financial loss per unit of half the total mission costs. In the case of commercial satellites it is considered that revenue-gaining capacity can be transferred to other satellites until a replacement is launched. With a probability of 2×10^{-4} for payload destruction to occur per year in LEO which translates to 10^{-4} C_{LEO} per satellite per year. If 0.5 cm objects are considered sufficient for mission termination, then financial loss will increase about five-fold. This is contended to be the expected loss at present in LEO.

When orbital debris becomes re-entering debris, the safety of property and inhabitants on Earth is at risk, which could include radioactive fall out. Space debris threatens environmental safety in space. The insurance industry, that bears the financial brunt of accident, damages and liability claims for space activities is the foremost potential victim of this threat. Could the insurance industry be an adequate leader in space environmental protection? Apart from the insurance companies traditional role of 'compensating' injured parties for the effects of accidents and 'protecting' entities against the costs of possible damage, it has been suggested[xx] that space insurance companies could also assume a 'preventive' role to reduce the incidence of space accidents and damage by threats such as orbital debris. Through legislation, insurance strategies could encourage the space industry to continue to advance technologically without putting safety in the space environment at risk.

Space platforms are being used for such fields as communications, broadcasting, remote sensing and satellite-based mobile communications, so continued the market growth is expected. As risks stabilise, insurance rates may decrease, and the capacity of the insurance market will eventually increase.

RECOMMENDATIONS

In the future, the amount of debris in orbit will depend upon whether the creation or removal rate dominates. Currently, the only mechanism for removal is orbital decay through atmospheric drag, which ultimately leads to re-entry. This mechanism is only effective in a restricted range of low Earth orbits. At higher orbits, it takes hundreds to thousands of years for objects to re-enter, and so there is no effective removal mechanism.

It is anticipated that, the number of individual intact objects launched shall be increased. The trend in space technology is moving toward smaller satellites operating cooperatively in coordinated constellations. This trend is mainly due to the revolution in commercial satellite-based communications systems, and satellite micro technology. As satellites become smaller, they will become more vulnerable to the smaller debris population. Hundreds of satellites have been proposed for operation in low Earth orbit. While functioning satellites in individual constellations will be controlled to maintain constellation geometry and hence preclude collisions among themselves, traffic will increase through each constellation due to associated operations and maintenance of their neighbours. In addition, satellite failures may eventually occur, resulting in uncontrolled satellites that drift through operating constellations.

The close proximity of satellite orbits may result in increased collision risk as well as increased risk of multiple losses if a satellite break-up occurs and forms a debris cloud with constrictions.

To prevent debris accumulation in preferred mission orbits due to collisions, satellites and other objects must be removed from the mission orbit at the end of life before collisions are likely to occur.** As space traffic increases there will be a need for stricter regulations, more innovative de-orbiting strategies, and international regulation of space. Eventually nations and companies may be required to de-orbit space assets once they are no longer functioning.

Given a set of comprehensive universally accepted guidelines, with the exclusion of technological barriers, the space debris problem could well become a problem of the past. In this context the differences between Nation States need to be set aside and replaced with a collective responsibility for actions in space in order for legislation to be effective. Considering the growing safety uncertainties and the cost implications for space activities, the insurance industry could benefit by assuming leadership to encourage the adoption of space environmental safety practices.

There is an urgent need for international standardisation. Treaties should be signed to bind all countries, organisations and companies to take measures aimed at avoiding space debris. Many different ideas have been proposed, but no major international co-operative plan has yet been put in place though there is a general consensus in the international community that optical space surveillance must be intensified.

Finally, the results of efforts dedicated to debris mitigation should increasingly be shared within the international community. These efforts could lead to the development of a common international database for space debris.

REFERENCES

[1] Proceedings of the Second European Conference on Space Debris. 1997. ESOC

[2] Third European Conference on Space Debris, 2001, ESOC

[3] *Technical Report on Space Debris*, UN, NY 1999
Index of UN Online Reports: National Research on Space Debris, Nuclear Power Sources and Other Related Subjects
http://www.oosa.unvienna.org/sd_nps_docsidx.html

[4] *Inter-Agency Space Debris Coordination Committee (IADC) Activities and Views on Reducing Space Debris From Launch Vehicles.*
Paper presented to the 38th Session of the Scientific and Technical Subcommittee of UN COPUOS, Feb. 2001

[5] *European Space Agency (ESA)*
Agenda Item 10: Space Debris
Paper presented to the 38th Session of the Scientific and Technical Subcommittee of UN COPUOS, Feb. 2001, Walter Flury

[6]. *Resolution for a European Policy on Protection of the Space Environment from Debris*
ESA/C/CXLIX/RES.6 (final)

[7] *The Financial Loss due to the Space Debris Hazard*, Nelsh, M., Kato, A., Goka, T.
Paper presented by Japan to the 38th Session of the Scientific and Technical Subcommittee of UN COPUOS, Feb. 2001
A/AC.105/C.1/2001/CRP.15, 20 Feb. 2001

[8] *Collisions between nuclear power sources and space debris*. Working Paper submitted by the Russian Federation. to the 38th Session of the Scientific and Technical Subcommittee of UN COPUOS, Feb. 2001
A/AC.105/C.1/L.246, 14 February 2001

[9] *Re-entry of Compton Gamma Ray Observatory and Launch Vehicle Debris Mitigation*, United States of America presentation to the 38th Session of the Scientific and Technical Subcommittee of UN COPUOS, Feb. 2001

[10] *The Insurance Industry and Orbital Debris*, Camboni, S.M., Napier, T.L., http://www.gbhap-us.com/fulltext/793/S960042F793.htm

[11] *Draft of NASDA Orbital Debris Mitigation Standards*, Kato, A., http://www.gbhap-us.com/fulltext/793/S960022F793.htm

[12] *Satellite Launch Liability Risks*, Nesgos, P.D., (1990), Business Insurance, October 25

[13] http://www.aas.org/~light/pollution_bibliography.html

[14] http://sn-callisto.jsc.nasa.gov/mitigate/nss1740.14_1995/nss1740_14-1995.html

[15] http://www.esoc.esa.de/external/mso/debris.html

[16] http://www.aero.org/cords/sdbasics.html

[17] http://users.rowan.edu/~kozd5710/SophClinic/SpaceDebris.html

[18] Interagency (Space) Group (1995) *Report on Orbital Debris* http://www.orbitaldebris.jsc.nasa.gov/IAR/report95.html

[19] http://www.orbitaldebris.jsc.nasa.gov/

[20] http://www.esoc.esa.de/pr/pressroom/pressroom.php3?view_news=69

* http://www.esoc.esa.de/pr/pressroom/pressroom.php3?view_news=69

† Listing of radar facilities for space debris observation may be found on Reference 3, pg 6. Listing of optical facilities for space debris observation may be found on Reference 3, pg 8.

δ Examples of retrieving spacecraft and surfaces may be found in Reference 3, pg 9.

ƒ List of debris environment models may be found in Reference 3, pg 21.

ψ The former treaty based organisations INTELSAT, INMARSAT and EUTELSAT, TELESAT (Canada), the Indian Space Research Organization the Russian Federation, the Japanese NASDA adopted policies requiring their geostationary satellites to be boosted into higher orbits at the end of operational life. A similar policy is echoed in the Recommendation of May 1992 by the International Telecommunications Union.

* Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space including the Moon and Other Celestial Bodies 1967 ("Outer Space Treaty"); Convention on International Liability for Damage Caused by Space Objects 1972 ("Liability Convention"); Convention on Registration of Objects Launched into Outer Space 1975 ("Registration Convention")

† Article VI of the Outer Space Treaty

‡ Article IX of the Outer Space Treaty

§ Article VII of the Outer Space Treaty

** Article II of the Liability Convention

†† Article II of the Registration Convention

‡‡ Article IV of the Registration Convention mandates each State of registry to furnish the UN Secretary General with: a name of launching State(s); an appropriate designator of the space object or registration number; date and territory or location of launch; basic orbital parameters (nodal period; inclination; apogee; perigee) and general function of the space object

§§ Article VI of the Registration Convention

*** Resolution for a European Policy on the Protection of the space environment from Debris. Adopted by the Council of the ESA on 20 December 2000 ("ESA Resolution")

††† See Article 7 of the ESA Resolution

‡‡‡ The ESA Standards were based on: The ESA Space Debris Mitigation Book; ESA Procedures Standards and Specifications; ESA Documents and the Space DEBRIS safety Standard of French National Centre for Space Studies ("CNES").

§§§ Comprised of ESA member States, the Italian Space Agency, the British National Space Centre, the CNES and the German Space Agency

**** Article 4 paragraph 2 of the Federal Law

* The Limited Test Ban Treaty; The Convention on Early Notification of a Nuclear Accident, 1986; The Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, 1986

‡‡‡‡ Note that the measures relate specifically to space vehicles carrying nuclear power sources

V Commercial Space Launch Act (49 United States Code 70105; Commercial Space Transportation Licensing Regulations, 14 CFR Chapter II; Land Remote Sensing Policy Act of 1992 (section 202(b)(4), Title II

§§§§ The standards are applicable to U.S. Orbital stages (Athena, BA-2, Centaur, Delta, Boeing Inertial, Minotaur, Pegasus, Taurus and Titan).

They were also applied to the re-entry of the Compton Gamma Ray Observatory on 4th June 2000

***** The full text of the Instrument can be accessed at: http://www.uni-koeln.de/jur-fak/instluft/draft3.html

β See Reference 7 *Supra*

xx See Reference 8 *Supra*

** NASA's guidelines for limiting orbital debris recommend that an object not remain in its mission orbit for more than 25 years. At altitudes above 2,000 km, it is not feasible to force re-entry within 25 years using current space technology. At this time, it is generally recommended to place vehicles in disposal (or "graveyard") orbits.