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Scientific and Technical Subcommittee
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Vienna, 11–22 February 2019
Item 7 of the provisional agenda[*]
Space debris

Research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris

The present conference room paper contains submissions received by the Secretariat from:

(a) Japan on 2 November 2018, and includes additional pictures and figures not included in document A/AC.105/C.1/115;

(b) Thailand on 11 January 2019;

(d) International Astronautical Federation on 5 November 2018, and includes additional pictures and figures not included in document A/AC.105/C.1/115.

The document is issued without formal editing.

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[*] A/AC.105/C.1/L.373.

Japan

REPORT ON SPACE DEBRIS RELATED ACTIVITIES IN JAPAN
(FOR UNCOPUOS/STSC FEBRUARY, 2019)

1. Overview

Corresponding to request from the OOSA, Japan reports here, the debris relating activities mainly conducted in the Japan Aerospace Exploration Agency (JAXA).

Here, the following debris related activities conducted in JAXA during 2018 are selected as major progresses to introduce in the next section.

(0) The 36th annual meeting of Inter-Agency Space Debris Coordination Committee (IADC)

(1) Conjunction Assessment (CA) results and research on core technology for Space Situational Awareness (SSA)

(2) Research on technology to observe LEO and GEO objects and determine their orbits

(3) In-situ Micro-Debris Measurement System

(4) Protection from impact of micro-debris

(5) Propellant tank easy to demise during re-entry

(6) Active debris removal

2. Status

2.0 The 36th annual meeting of Inter-Agency Space Debris Coordination Committee (IADC)

The 36th annual meeting of IADC was held in June at Tsukuba, Japan. More than one hundred technical experts from 11 agencies participated in this meeting. JAXA organized and hosted this meeting. Major topics in the meeting were:

Fig. 0 Group Photo at the meeting

1. IADC Statement on Large Constellations of Satellites in Low Earth Orbit

   IADC has already released the statement which has only qualitative considerations on large constellations, because there were limited research results on impact of large constellations on space debris environment at that time. In this meeting, the simulation results on large constellations performed by IADC members was shown and IADC members reached a consensus that large constellations have negative impact on space debris environment. Thus, update of the statement including more limiting conditions with numerical figures is being prepared among IADC members.

2. IADC Space Debris Mitigation Guidelines.

   The guidelines were released in 2002 and revised in 2007. Currently, many nations or international entities begin to prescribe quantitative conditions on space debris mitigation for their standards whereas the guidelines had to adopt a lot of qualitative expressions. Therefore, IADC began discussion to update the guidelines with numerical figures in order to build more concrete common understandings among members.

2.1 Conjunction Assessment (CA) results and research on core technology for Space Situational Awareness (SSA)

JAXA receives conjunction notifications from Combined Space Operations Center (CSpOC). As of August 2018, the number of meetings was 131 to consider a collision avoidance manoeuvre (CAM) based on the notifications, and JAXA has executed 26 collision avoidance manoeuvres for low earth orbit (LEO) spacecraft since 2009.

Core technology for space situational awareness (SSA)

JAXA determines the orbit of space objects using radar sensor at Kamisaibara Space Guard Center (KSGC) and optical sensor at Bisei Space Guard Center (BSGC), predicts close approaches using the latest orbit ephemerides of JAXA satellites, and calculates probability of collision. Also, JAXA evaluates the criteria for CA and CAM through our experiences. In the evaluations, the trends of each conjunction condition and of prediction errors due to perturbations (e.g. uncertainty in air drag) are analysed.

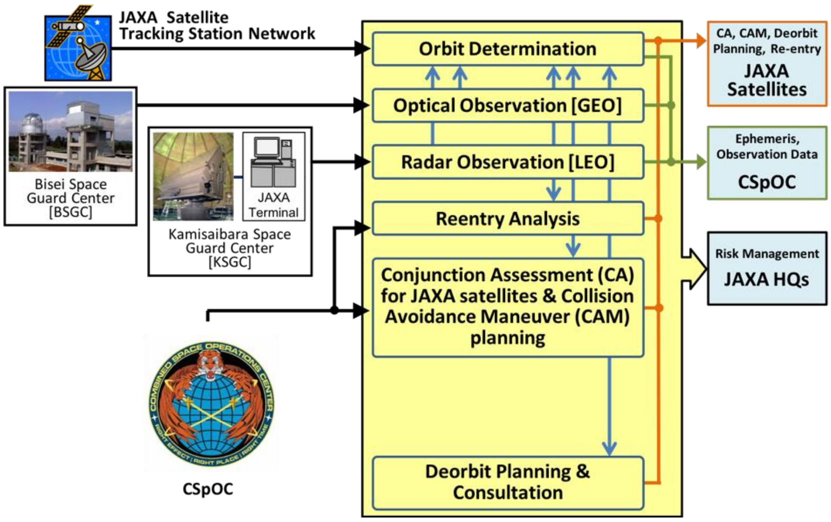

Fig. 1 Activity for the SSA in JAXA

3.0 Research on technology to observe LEO and GEO objects and determine their orbits

Generally, the observation of LEO objects is mainly conducted by radar system, but JAXA has been challenging to apply the optical system to reduce the cost for both construction and operation. A large CMOS sensor for LEO observation was developed (Fig.-2). Analysing the data from the CMOS sensor with the FPGA-based image-processing technologies developed in JAXA enable us to detect 10cm or less LEO objects. An optical observation network to reduce the load of collision avoidance was considered using real weather data of NOAA. In order to increase the observation opportunities of LEO and GEO objects, a remote observation site in Australia (Fig.-3) was established in addition to the Mt. Nyukasa observatory in Japan. Two 25cm telescopes and one 18cm telescope are available for various objectives.

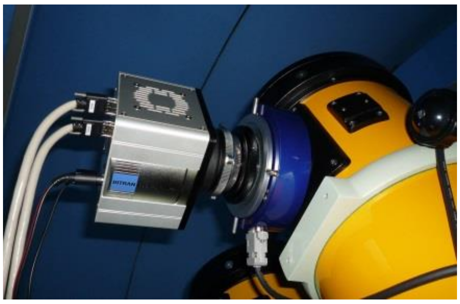

Fig.-2 The CMOS sensor manufactured by Bitran which can detect 10cm LEO objects analysing the data with FPGA-based image-processing technologies.

Fig.-3 The remote observation site in Australia. The left figure shows the sliding roof where all the observation devices are installed. Two 25cm telescopes (the right figure) and one 18cm telescope are available for various objectives.

3.1 Protection from impact of micro-debris

The amount of micro-debris (less than 1 mm in diameter) increased in low earth orbit. The impact of micro-debris can inflict critical damage on a satellite because its impact velocity is 10 km/s on average.

To assess debris impact on a satellite, JAXA has developed a debris impact risk assessment tool named "TURANDOT". TURANDOT analyses debris impact risks against three-dimensional model of a spacecraft.

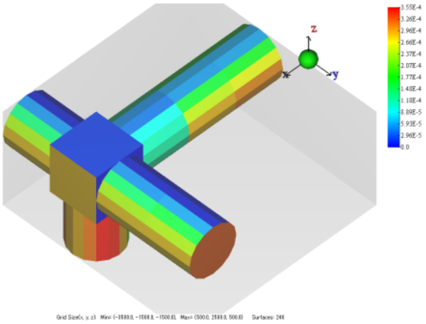

Fig.-7 an example of out from TURANDOT

3.2 Propellant tank easy to demise during re-entry

A propellant tank is usually made of titanium alloy which is superior because of light weight and good chemical compatibility with propellant. But its melting point is so high that such a propellant tank would not demise during re-entry, and it would pose the risks of ground casualty.

Since 2010, JAXA conducted research to develop an aluminium-lined, carbon composite overwrapped tank with a lower melting temperature. As a feasibility study JAXA conducted fundamental tests including a liner material aluminium compatibility test with hydrazine propellant and an arc heating test.

After the manufacturing and test of shorter size EM#1 tank, manufacturing of full size EM#2 tank was conducted. The shape of EM#2 tank is same as the nominal tank which includes PMD. Using this EM#2 tank, proof pressure test, vibration test (with wet and dry condition), external leak test, pressure cycle test, and burst pressure test were conducted and all of them showed good results. Following the EM#2 tank, PM manufacturing and testing are planned.

This composite propellant tank has shorter delivery period and lower cost compared to a titanium propellant tank. However, about the demisability during atmospheric re-entry, additional study and test are ongoing.

Fig.-8 EM#2 tank

3.3 Active Debris Removal

JAXA has organized and structured a research program which aims at realization of the low-cost Active Debris Removal (ADR) mission. As shown in Fig. 11, The ADR key-technology R&D has three major themes: non-cooperative rendezvous, capture technology for non-cooperative targets, and de-orbiting technology to remove massive intact space debris. JAXA is cooperating with Japanese private companies aiming to realize low-cost ADR as a business and working to provide these essential key-technologies for the purpose.

An electrodynamic tether (EDT) is a prospective candidate for the de-orbit propulsion for ADR because it can contribute to down-sizing the overall system and thus lowering the cost. To demonstrate some essential technologies for the EDT, JAXA planned and conducted the KITE mission, which is an on-orbit experiment of the EDT on the H-II transfer vehicle 6 (HTV-6) in 2017. Although tether deployment was unsuccessful, the field emission cathode (FEC), which is an essential part for the EDT system shown in Fig. 12, was operated well and effective on-orbit data were obtained for further EDT development.

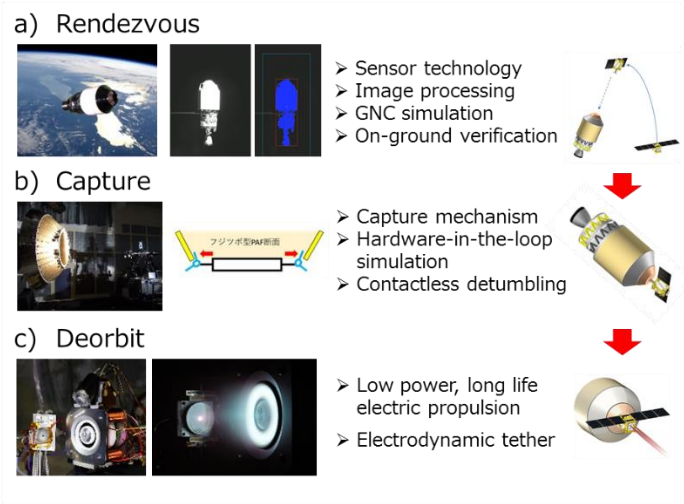

Fig.-11 Active Debris Removal research activities

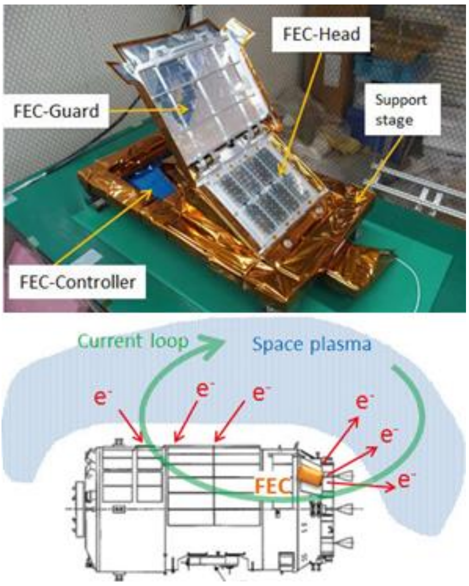

Fig.-12 FEC for KITE experiment (above) and illustration of established current loop via ambient space plasma (bottom)

Thailand

SPACE DEBRIS MITIGATION AND RESEARCH DEVELOPMENT

This report summarized the mitigation activities of the mission operated in 2018 and space debris research development framework.

1. Thailand space debris

The collision of a satellite is not only damage or end mission early but also it leads to generate a new number of space debris that can threaten to other active satellites. Today, Thailand has 4 satellites that de-orbited, THAICOM (Thailand Communication Satellite) 1 THAICOM 2, THAICOM 3 and TM-Sat (Thai Micro-SATellite) or Thaipat.

2. Mission

Thailand has operated communication satellites and earth observation satellite over decades. In term of collision risk with space objects, Thailand cooperated with Joint Space Operations Center (JSpOC) to share the orbital data of our mission for more accurate collision warning message. For the more safety of our missions, Thailand is a member of Space Data Association (SDA) to enhance the accuracy and effectiveness of the screening close approaches for the mission. All efforts purposes to reduce the collision risk of space debris that causes to raise the space debris population.

3. Research and development

3.1. Flight dynamics software (EMERALD)

Thailand, by Geo-Informatics and Space Technology Development Agency (GISTDA), developed a satellite orbit analysis and determination processing system called "EMERALD" in 2017. The main purpose of the development basically was to support mission planning and analysis.

EMERALD was modified to monitor and predict the re-entry location and date of the Chinese space station (Tiangong-1) in 2018. China Manned Space Agency (CMSA) government officially announced that Tiangong-1 re-entry at the central region of South Pacific about 7:15 a.m. (local time in Thailand) which was close to EMERALD prediction. To prepare the worst scenario if Tiangong-1 falling in Thailand, GISTDA also cooperated with related government agencies to draw the 1st draft of the space debris disaster plan, which describes the responsibility and actions of each related agencies from monitoring to mitigation operations. Fortunately, the re-entry falling area was on the central region of the south pacific.

3.2. Space surveillance awareness system

Thailand, by Geo-Informatics and Space Technology Development Agency (GISTDA), started conducting the research and developed space surveillance awareness system in 2018. It consisted of 2 main operations: space surveillance system and risk assessment and tracking system as shown in **Fig.1** The developing technologies of the system have enhancing capabilities to detect new space debris, catalogues debris object, determines and prediction their orbits that is necessary to alert the collision risk from space debris and asteroid. The full implementation of the fundamental of the system is expected within 5-7 years. The strategy to achieve the ultimate goal in the short period is the cooperation both Thailand government agencies and international space agencies to exchange and share information that leads to achieving to develop the technological capability that can preserve the near-Earth region for future generations.

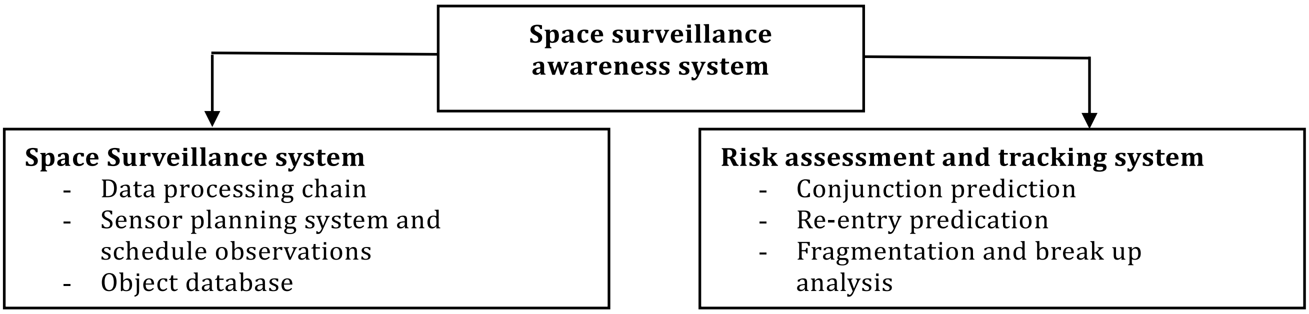

Fig.1 Space surveillance awareness system.

International Astronautical Federation

ENSURING FUTURE SUSTAINABILITY OF SPACE OPERATIONS: THE ORBITAL DEBRIS QUESTION

An ever-growing orbital population

The first ever launch to orbit, Sputnik 1 on 4 October 1957, opened the field to all the space applications that we enjoy today. Our daily lives depend more and more on such applications which turn out to be compulsory, strategical, for climate, telecommunications, localization, security and defence, science and exploration.

They also represent a very important economical domain, with millions of jobs throughout the world and trillions of Euros in corresponding activities.

However, one has to realize that the flight of Sputnik 1 also marked the very first step of the orbital pollution: on the very same orbit as the 82 kg satellite was the main stage which brought it to orbit, the 6.5 tons Semiorka Block A, and a small 100 kg fairing which protected Sputnik during the atmospheric ascent.[1] Thus, nearly 99 per cent of the mass injected into orbit had no useful function there. Sputnik emitted its beep-beep during 21 days, but spent a total of 92 days in orbit before re-entering atmosphere: it means that the satellite had no useful function during three quarters of its orbital life. This “dead” satellite, its main rocket stage, and the protective cap were all “artificial, orbital, non-functional objects”, which is the definition of an orbital debris.

Since 1957, the number and mass of objects in orbit has drastically increased.

It is obviously a sign of good health of the space sector and the near explosion of the number of associated applications, but it also questions the long term sustainability of our orbital operations. The mass of objects in orbit has increased linearly since 1957, reaching nearly 8,000 tons nowadays (Figure 1 left) and the number of catalogued objects (large enough to be followed from ground, typically 10 cm in Low Earth Orbits or 1 m close to Geostationary Orbit[2]) has reached now 20,000 (Figure 1 right).[3] Such strong increases may look surprising, as the number of successful orbital launches has drastically decreased compared to the cold war period (140 successful launches in 1967, 52 in 2005), and as the regulations aiming at controlling the orbital population increase have been set in place at international level starting in 1995, more than 20 years ago.

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[1] Chertok, “Rockets and People”, NASA SP-2011-4110.

[2] Public catalogue from USSPACECOM JSpOC: www.space-track.org.

[3] NASA Orbital Debris Quarterly News Vol. 22 Issue 1 Feb. 2018.

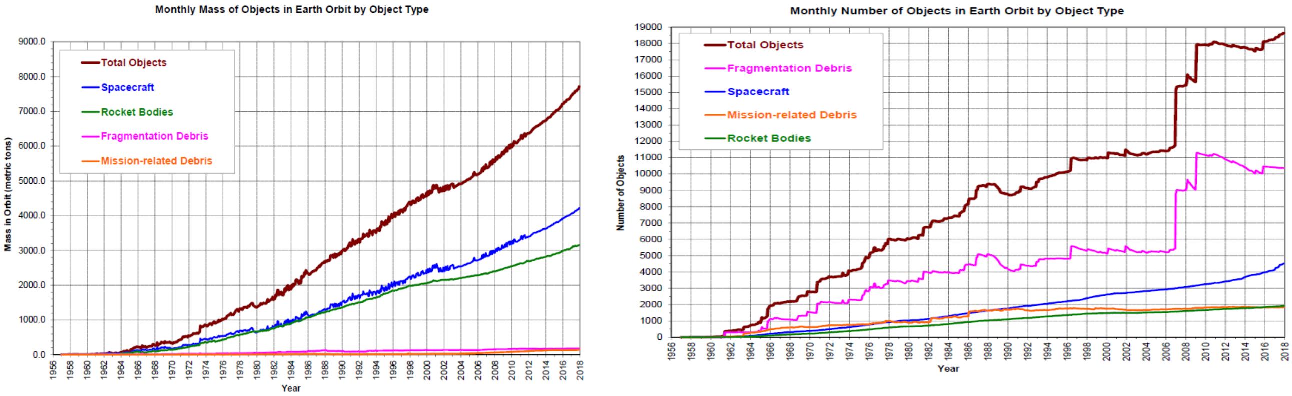

Figure 1: Evolution of the mass and number of cataloged objects versus time (NASA 2018)

Out of the 20,000 catalogued objects registered today, some 1,700 are active satellites; the other ones are space debris, representing 92 per cent of the orbital population (Figure 2 gives the distribution of catalogued objects). These debris are mostly found in Low Earth Orbits, with altitudes varying from 600 to 1,200 km, as well as in the vicinity of the Geostationary orbit at 35,800 km. Half of the catalogued debris are integer elements, dead satellites, upper stages left in orbit or leftovers from space operations; the other half is constituted of fragments of any sizes, residues from collisions or explosions in orbit.

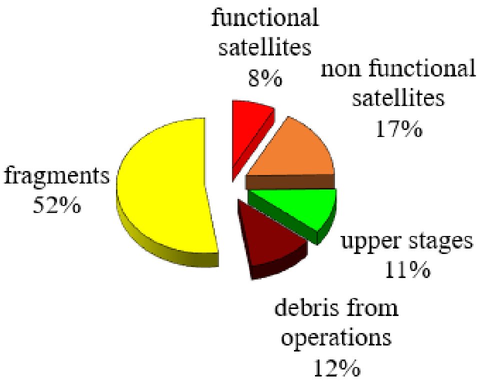

Figure 2: Distribution of catalogued objects (Space-Track 2018)

In addition to these catalogued, large, objects, some 750,000 objects larger than 1 cm, and more than 170 million larger than 1 mm, also orbit the Earth.[4]

These figures may appear impressive, but one has to keep in mind that Space if infinitely wide above our heads; the 8,000 tons' artificial orbital objects, equivalent to the mass of the Eiffel Tower, are spread all around the space surrounding Earth; corresponding density is excessively small, reaching a maximum of 0.1 object per million cubic km in the most densely populated region.

Nevertheless, these objects have three very distinctive characteristics: once an object is in orbit, it generally remains there for a long time; for instance, a satellite placed at 1,000 km altitude will remain there for 1,000 or 2,000 years.[5] Meanwhile, it travels at orbital velocity, close to 8 km/s or 30,000 km/h; such a velocity, integrated over thousands of years, induces in-fine a significant collision risk. Last, any object placed into Low Earth Orbit is bound to fall back to Earth, potentially inducing casualty risks.

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[4] ESA MASTER model, 2009.

[5] Refer for instance to CNES tool STELA, https://logiciels.cnes.fr/fr/content/stela.

Orbital debris raise two major problems

Uncontrolled atmospheric re-entry of large space objects poses a risk to populations.

During re-entry, debris are fragmented by the very high dynamic pressure, proportional to the square of the velocity, then these fragments are submitted to very high thermal fluxes, proportional to the cube of the velocity, due to the friction of air molecules which tend to melt and sublimate materials. Unfortunately, this fusion is generally incomplete and some 10 to 20 per cent of the total mass of the debris may survive re-entry, depending on its conception. Refractory materials, such as Titanium, Carbon or some varieties of Steel, do not melt during re-entry and impact the surface of the globe.

Hopefully, Earth is covered with 71 per cent water, the rest being composed mostly of large desert areas (densely populated zones only represent 3 per cent of the surface), so the risk to populations remain low.

As an order of magnitude, one considers that a large satellite or launcher stage renters randomly into the atmosphere one a week,[6] inducing a risk of 1 chance out of 10,000 to hurt someone. As per today, there has never been any identified victim, despite numerous examples of large debris found near inhabited zones, with some rare occurrences of minor damages on constructions.[7] It is a “Damocles sword” problem: we continue to launch large stages or satellites knowing that they will end up re-entering randomly, generating non-negligible risks to overflown populations.

Collision risk in orbit

Collisions generate different consequences: it is no longer a problem of safety, but a commercial risk associated to the damage of active satellites, useful or often fundamental in our everyday life.

One can identify several different potential risks.

A collision between a small debris, un-catalogued, and an active satellite can cause the functional loss of the spacecraft. Indeed, the kinetic energy released during a collision being extremely high (a collision with a 1 mm debris has an energy of 1 kJ, equivalent to a bowling ball launched at 100 km/h), an impact even small can kill a satellite, for instance if hitting the On-Board-Computer. Several studies on that topic have shown that the probability of losing a satellite due to a collision is in the order of magnitude of 5 per cent: space debris are currently the first cause of satellites losses in orbit.[8] [9] As by definition such small debris is uncatalogued, therefore “invisible”, there is no way to prevent such collisions.

Collisions among large objects are very seldom, taking place every 5 to 8 years depending on models, but they generate a large number of new debris, and can therefore increase significantly the global risk in orbit. This regeneration effect following collisions raises the risk of an uncontrolled increase of the number of debris; this phenomenon, known as the Kessler Syndrome, theorized as early as 1978,[10] could lead to an un-controllable situation, even if we stopped any space activity in the future. As an example, the collision between the two satellites Iridium 33 and Kosmos 2251 in February 2009 has generated over 2,200 large catalogued debris, and a myriad of smaller ones.

Simulations led by NASA, then by 7 agencies from IADC (Inter Agencies Space-Debris Coordination Committee), show that even if we stop completely any space

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[6] In average, 88 re-entries of satellites or upper stage per year since 2008; www.space-track.org

[7] http://eclipsetours.com/paul-maley/space-debris/.

[8] FP7-SPACE-2010-1 P²ROTECTn ONERA, TAS et al. https://cordis.europa.eu/result/rcn/238326_en.html.

[9] FP7-SPACE-2010-1 REVUS, Astrium et al., 6th European Conference on Space Debris, ESA SP-723, ISBN 978-92-9221-287-2, 2013.

[10] Kessler, Cour-Palais, “Collision frequency of artificial satellites: The creation of a debris belt”, Journal of Geophysical Research, Volume 83, Issue A6, p. 2637-2646, 1978.

activity, the number of orbital debris would increase exponentially in the coming years. As an illustration, figure 3 presents the results of simulations led by NASA, considering "no further launches after 2006"; the long-term increase due to collisions among large objects is clear.[11]

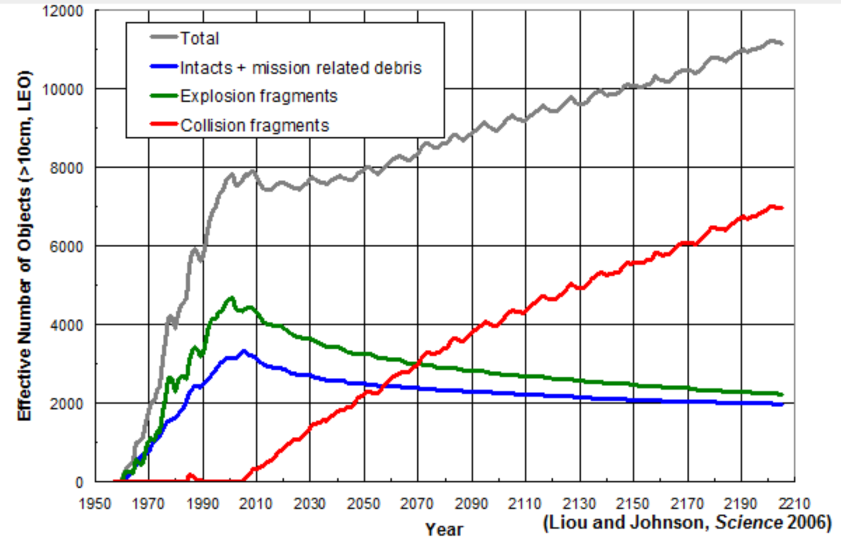

Figure 3: Expected evolution of the number of objects larger than 10 cm in Low Earth Orbits, under the assumption of "no further launches after 2006" (NASA 2006)

Measures aiming at limiting the number of orbital debris in the future and guaranteeing sustainable operations in space

An international set of requirements, efficient and well shared

The most important measure, fundamental, is to set rules at international level in order to prevent the generation of new debris during future space operations. Such recommendations, known as "space debris mitigation", can be summarized into five high level actions.

First, it is compulsory to limit the generation of debris during normal launch operations, and to avoid any voluntary destruction of satellites in orbit.

Second, one shall avoid accidental explosions in orbit by passivating all space objects left in orbit, i.e. by eliminating any stored energy such as residual propellants, tank pressurization, battery energy or stopping the inertia wheels.

Third, it is necessary to limit orbital life of space objects: it is required that satellites and launcher upper stages remain less than 25 years after their operational life in two protected zones, the Low Earth Orbits, and the vicinity of the Geostationary Orbit, as depicted in Figure 4.

The fourth measure consists in recommending to the satellite operators to do their best to prevent in-orbit collisions, when information is available with adequate precision, and when the satellite is manoeuvrable.

Last, it is recommended to minimize the risk posed to populations induced by uncontrolled atmospheric re-entries; to that extent, an operator should perform a controlled re-entry for any mission leading to a risk of hurting someone larger than 1 chance out of 10,000.

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[11] Liou, Johnson, "Risks in Space from Orbiting Debris", *Science* 20 Jan 2006: Vol. 311, Issue 5759, pp. 340-341.

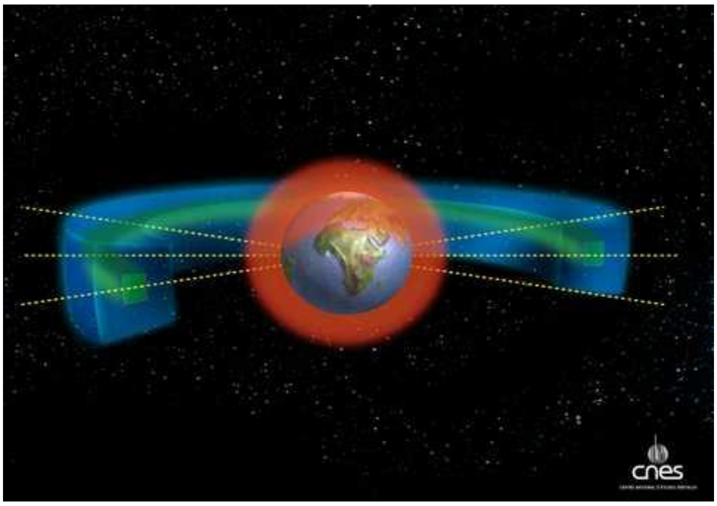

Figure 4: IADC Protected Regions (IADC 2002)

These rules can be found in numerous texts, both at national and international levels; the following list aims only at showing that such recommendations have been made for more than 20 years now.

The very first publication expressing some concern on Long Term Sustainability of Space appears to be a Japanese paper dated 1971.[12] Numerous other references then followed the initial reflections from NASA starting in 1974, then in Europe by 1987, leading to the first national standards, mainly from NASA (1995),[13] NASDA (now JAXA, in 1996)[14] and CNES (1999).[15]

The first text adopted at international level is known as « IADC Guidelines », collection of recommendations prepared by the Inter-Agency Space Debris Coordination Committee grouping the (now) 13 main space agencies, adopted unanimously in 2002, revised in 2007.[16] A similar standard at European level was finalized in 2000 and approved in June 2004.[17]

The IADC Guidelines have been adapted by the space committee of UN, the COPUOS (Committee for Peaceful Use of Outer Space), resolution adopted during a UN plenary session in 2007.[18]

France has been the first country to elaborate a real law dealing with the subject, the FSOA (French Space Operations Act, or LOS, “Loi relative aux Opérations Spatiales”), which entered into force in 2010, revised in 2017.[19]

A set of ISO standards dedicated to space debris have been published since 2011, mainly the ISO 24113 which acts as the highest-level standard;[20] this document, if it could effectively be rendered applicable to all operators and constructors, would allow an efficient slow in the increase of space pollution.

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[12] Nagatomo et al., “Some considerations on utilization control of the near Earth Space in future”, 9th ISTS, Tokyo, 1971.

[13] “NASA Safety Standard. Guidelines and Assessment Procedures for Limiting Orbital Debris”, NSS.1740.14, Aug.1995.

[14] “NASDA Space Debris Mitigation Standard”, NASDA-STD-18, March 1996.

[15] “CNES Exigences de sécurité – Débris Spatiaux”, CNES-MPM-51-00-12, June 1999.

[16] “IADC Space Debris Mitigation Guidelines”, IADC-02-01, Rev.1, July 2007, https://www.iadc-online.org/.

[17] “European Code of Conduct for Space Debris Mitigation”, June 2004, Signed by ASI, BNSC, CNES, DLR, ESA.

[18] “Space debris mitigation guidelines of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space”, UNCOPUOS A/AC.105/890, Feb. 2007.

[19] “LOI n° 2008-518 du 3 juin 2008 relative aux opérations spatiales”, Revised Aug. 2017.

[20] “Space systems — Space debris mitigation requirements”, ISO-24113, May 2011.

In parallel, the UNCOPUOS established in 2010 the "Working Group on the Long-Term Sustainability (LTS) of Outer Space Activities" tasked with producing a consensus report containing voluntary best-practice guidelines for all space actors to help ensure the long-term sustainable use of outer space.[21] The approval process of the 37 guidelines, by consensus of all members, raised some hard points, and so far, 12 guidelines only have been approved.[22] However, the Working Group is still running, and once the complete compendium of UN Guidelines will be approved, it should turn out to be a very efficient tool.

Last, a dedicated charter has recently been prepared by a large number of operators, proposing guidelines more stringent than the other documents; this set of "best practices" has still a draft status, and there is no clue yet on how it could become a real regulatory document.[23]

Protection against impacts

A second measure aiming at reducing the effect of orbital population on active satellite consists in equipping them with shields. If you place a certain number of metal or Kevlar® sheets, or even dense foams, in front of a structural wall, they will shatter debris into smaller pieces, to end up as a cloud of tiny particles unable to damage the main structure without piercing it.

The potential assemblies are very diverse depending on the type of debris to be stopped, so the orbit of the shielded satellite, its orientation, and the criticality of the zones to protect. A very large number of tests are performed throughout the world, each testing an optimal combination. Ground tests are performed using light gas guns, often two-staged, propelling small metallic marbles, 1 mm in diameter, to velocities up to 12 km/s.[24]

Unfortunately, such shields have limited efficiency and can protect a wall up to impactors of 1 cm in diameter, hardly more; it means that there is a non-protectable zone from 1 to 10 cm, upper limit corresponding to the cataloguing of large debris, hence a possibility to perform collision avoidance. These shields also pose numerous problems of bulk, mass, cost, or even system problems such as thermal equilibrium of the satellite. Practically, they are currently deployed only on inhabited satellites such as the ISS, the European ATV, the Japanese HTV, or some very large American military satellites.

Collision avoidance

An efficient measure to protect operational satellite, equipped with on-board propulsion, consists in avoiding collisions with catalogued objects.

It is a very complex activity, as one needs to « propagate » the orbits of all the potentially dangerous objects over several days in order to identify possible collisions. The statistical computations are based on collision probabilities determined by the covariance matrixes of each object. Every alert triggers an analysis of the impactors trajectory, winding back in the past, and can require dedicated measurements coming from the dedicated Space Surveillance means, such as radars and telescopes; some Conjunction Data Messages are also directly provided by the JSpOC.

This process takes advantage of the existing Space Surveillance and Tracking (SST) network, mainly the US Space Surveillance Network, but also the International Scientific Optical Network (ISON), National networks, such as the French system

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[21] "The UNCOPUOS Guidelines for Long-Term Sustainability of Outer Space Activities", SWF Fact Sheet, July 2017, https://swfound.org/media/205929/swf_un_copuos_lts_guidelines_fact_sheet_july_2017.pdf.

[22] "Report of the Working Group on the Long-term Sustainability of Outer Space Activities", A/AC.105/2018/CRP.22/Rev.1, Sixty-first session, Vienna, June 2018.

[23] Oltrogge, "Announcement of GVF space industry-led endorsement of best practices for sustainable space activities", IAC-18-A6, Bremen, Oct. 2018.

[24] "IADC Protection Manual", IADC-04-03, Version 7.0, Sept. 2014, https://www.iadc-online.org/.

based on the GRAVES radar, and commercial initiatives such as the Commercial Space Operations Center (ComSpOC©) or LeoLabs.[25]

These analyses enable to identify the need to manoeuvre a satellite in order to lower the probability of a collision; as a rough order of magnitude, one considers today that each satellite will have to manoeuvre once per year to avoid collisions.

The main problem is due to the lack of accuracy of the orbital parameters of the debris, typically in the range of 100 to 1000m; this leads to an extremely high rate of false alarms, in the order of 99.99 per cent. One of the priority improvements required in the coming years consists in gaining orders of magnitude in orbital parameters accuracy[26] This could be achieved using Laser Ranging techniques, either from ground,[27] or from orbit.[28]

Just-in-time Collision Avoidance between large non-manoeuvring debris

The Collision Avoidance process described in the previous paragraph only addresses active satellite, which represent less than 20 of the very large objects in Low Earth Orbit (satellite or launcher stage); It means that it is efficient in protecting operational satellites, but has no slowing effect on the increase of orbital population due to collisions among large non-manoeuvrable objects, statistically predominant, and therefore has a limited role in Long Term Sustainability of Space Operations.

An additional measure has therefore been under study these last years, consisting at avoiding predictable collisions between large derelicts. The basic idea here is that in case of an upcoming collision event in the following couple of days (in reality, a probability of collision higher than an allowable threshold), a mission is carried out aiming at deviating very slightly the trajectory of one of the two debris to avoid the collisions, (or restore acceptable margins).

Various techniques of JCA (Just-in-time Collision Avoidance) are under study, mainly in USA and France, consisting for instance in a cloud of gas/dust/particles spread in front of the debris thanks to a sounding rocket, aiming at briefly increasing the drag and slow the debris.[29] [30] These methods are very promising as they appear to be much simpler to realize than ADR, and they would be used only in case of a highly probable collision, typically every 5 or 6 years. Other techniques, also jointly studied between USA and France, are based on orbital lasers to deviate debris using very short but intense pulses, vaporizing locally the surface of the debris and slightly modifying its velocity.[31] Proposals have even been made to master continuously the position of all the large debris, using a relatively small orbital laser to minimize the probability of collisions (Large Debris Traffic Management LDTM[32]).

Active Debris Removal

A significant measure, studied now since more than 15 years, consists in retrieving form the most crowded orbits a certain number of very large debris potentially

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[25] For a detailed description of such SST means, refer to “IAA Space Debris Situation Report – 2016”, §4, http://www.iaaweb.org/iaa/Scientific%20Activity/sg514finalreport.pdf.

[26] Peterson, Sorge, “Tracking Requirements for Space Traffic Management in the Presence of Proposed Large LEO Constellations”, IAC-18-A6.7.6, Bremen, Oct. 2018.

[27] Krag, “Ground-Based Laser for Tracking and Remediation – An Architectural View”, IAC-18-A6.7.1, Bremen, Oct. 2018.

[28] Mourou, Bonnal, “On-orbit laser concept and operations enabling cataloging and high resolution characterization of small debris”, Patent pending.

[29] McKnight et al., “System Engineering Analysis of Derelict Collision Prevention Options”. Acta Astronautica 89 (2013) pp 248-253.

[30] Jarry et al., “SRM plume: A candidate as space debris braking system for Just-In-Time Collision avoidance maneuver”, Acta Astronautica, under publication.

[31] Phipps, Bonnal, “A spaceborne, pulsed UV laser system for re-entering or nudging LEO debris, and re-orbiting GEO debris”, ActaAstronautica118(2016)224–236.

[32] Phipps, Bonnal, Masson, “Large Debris Traffic Management (LDTM) using lasers”, #7.6, Proceedings of the Workshop on Space Debris Modeling and Remediation, CNES-HQ, Paris, 25-27 June, 2018.

dangerous, i.e. susceptible to generate the largest number of secondary debris following a collision: such measures are known as ADR (Active Debris Removal).

This strategy follows the findings of studies made first by NASA, published in 2010,[33] then by most of the IADC delegations: if one assumes that the mitigation measures are very well complied to (no fragmentation in orbit, 25-year rule in LEO), then the retrieval of 5 to 10 properly chosen large debris from the most populated orbits would be enough to stabilize the orbital population.

A very large number of potential solutions have been proposed, studied, tested on ground or during 0g flights, and recently tested in orbit, aiming at « cleaning space ». Without being exhaustive,[34] one can subdivide these solutions following various categories.

> First, there are a few contact-less solutions, for instance using a "virtual electrostatic leash" or a laser to raise the orbit of old satellites abandoned in geostationary orbit.
>
> Numerous solutions are derived from fishing techniques, using hooks, harpoons, nets, to capture a debris then to pull it using a long tether until it re-enters in a controlled manner in the atmosphere.
>
> Several ideas baseline an increase of the drag of the debris in order to accelerate its altitude decrease, for instance using an ad-hoc chaser to equip a debris with a large airbag or a sail, increasing drastically the surface of the assembly. It is also possible to install an Electro Dynamic Tether on the debris, conducting wire which, interacting with Earth ambient magnetic field, generate Lorentz forces slowing the debris, thus reducing its orbital lifetime; these solutions have nevertheless significant drawbacks as they induce uncontrolled re-entry of the debris, thus potentially dangerous for populations.
>
> Last, more conventional solutions consist in capturing a debris with a robotic arm, with numerous variants based on tentacles or clamps holding the debris, then deorbiting it in a controlled way to atmospheric re-entry.

The technical maturity of these solutions is globally high, and numerous demonstrations have already been performed, including in orbit. The main problems are therefore not technical but rather financial, as such operations would be very expensive without clearly identifying a business plan opening the way to commercial activities. There are also numerous legal hurdles linked to the responsibility of the operations, or even military concerns, some of such operations potentially opening the way to a militarization of Space.

These questions are actively considered within several Working Groups at international level, mainly at COPUOS with the initiative LTSSA (Long Term Sustainability of Space Activities). The first Active Debris Removal activities could take place faster than feared thanks to the arrival of Space Tugs: several of these multipurpose orbital vehicles are currently under development, mainly in USA and in France, and deorbiting a large debris could be the last action of such a tug after several orbital operations, integrated as its end of life manoeuvre. Development of orbital vehicles dedicated to the de-orbiting of stranded constellation-satellites is also ongoing, witnessing the potential for a positive business plan in the ADR domain.[35]

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[33] Liou, Johnson, Hill, "Controlling the growth of future LEO debris populations with active debris removal", Acta Astronautica 66 (2010) 648—653.

[34] For a complete overview of the Remediation solutions, refer to "Space Debris Environment Remediation", IAA SG5.5, Feb. 2013, http://www.iaaweb.org/.

[35] Alary et al., "The cycler - The affordable companion for Post Mission Disposal in massive constellations"; #3.4, 5th International Workshop on Space Debris Modeling and Remediation; Paris, June 2018.

Conclusion: a preoccupying situation

Compliance to the mitigation rules is very low today

The observed level of compliance is roughly 55 per cent at global level, but this figure may be a bit optimistic as it includes all the small satellites launched at low altitude, re-entering the atmosphere rapidly. If one considers only spacecraft above 600 km altitude, the compliance level is lower than 20 per cent; if one further limits itself to satellites heavier than 100kg, the compliance level drops at 6 per cent.[36]

The mass and number of debris in orbit continues to grow without any sign of decrease. There are still numerous collisions and fragmentations in orbit every year,[37] and dozens of large objects are still released nominally during launch operations, in addition to satellites and upper stages.

Numerous studies have shown that the level of compliance to the mitigation rules should be higher than 90 per cent if one wishes to limit the growth of debris in Earth orbit. As an example, the following two charts from NASA show (left) the expected long-term evolution of the number of objects larger than 10 cm in Low Earth Orbits, considering or not proper passivation of the space objects, for different levels of Post Mission Disposal compliance to the current mitigation rules. The diagram on the right presents the expected number of catastrophic collisions in Low Earth Orbits under the same assumptions.[38]

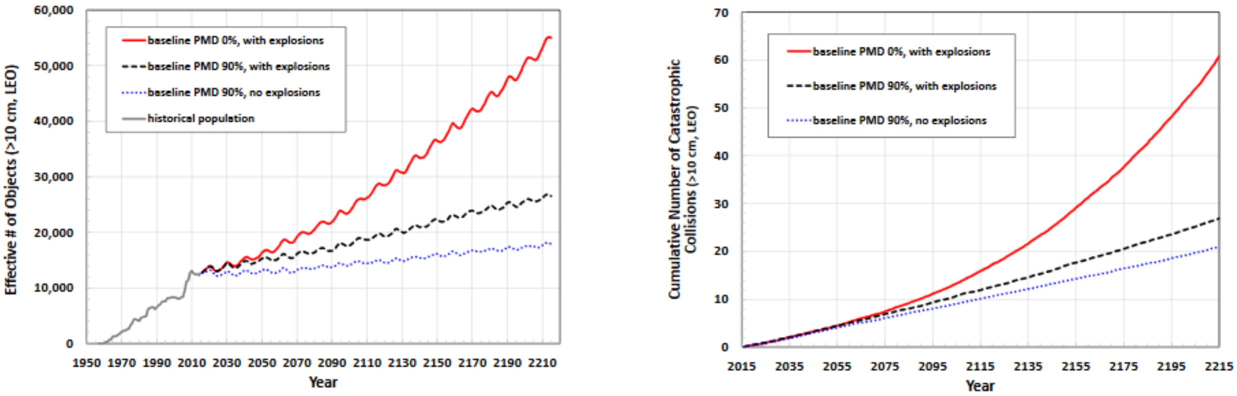

Figure 5: Predicted evolution of the number of orbital objects in LEO (left) and associated number of catastrophic collisions (right) versus time (NASA 2018)

The emergence of nano-satellites raises numerous questions.

We are currently witnessing an explosion of the number of very small satellites injected in orbit: these “cubesats” are game-changers, smart satellites taking full advantage of miniaturization, offering a large number of space applications with very low-cost development, production and launch. As a consequence, several hundreds of them are launched each year, but in most of the cases they have no propulsion, therefore no capacity to avoid collisions and to reduce their orbital lifetime; they are often launched on high altitude orbits, non-compliant with the 25-year rule. Some 430 cubesats were launched in 2017, and more than 500 per year are expected from 2018 on.[39]

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[36] Lemmens et al., “ESA’s Annual Space Environment Report”, GEN-DB-LOG-00208-OPS-GR, Apr. 2017.

[37] Among the most recent, the fragmentation of a SOZ-Unit from Proton, the 48th of its kind, occurred on May 22nd, 2018, generating some 60 cataloged debris (NASA ODQN Vol 22, Issue 3); the fragmentation of a LM-4 upper stage released 106 catalogued debris on Aug. 17th, 2018 (NASA ODQN Vol 22, Issue 3); the fragmentation of an Atlas V Centaur upper stage, probably due to a collision, released 491 debris on Aug. 30st 2018 (Agapov et al., IAC-18-A6.1.1).

[38] From Liou et al. NASA ODQN Vol 22 Issue 3, Sept. 2018.

[39] https://www.nanosats.eu/.

Additional rules are currently under definition at IADC and ISO level for satellites with no capacity to perform collision avoidance, limiting their orbital life-time to 25 years after the launch, therefore asking for a maximal altitude of some 600 km.

Large constellations

Large constellations raise a different problem: there are plans to launch such satellites (200 to 500 kg) by thousands, generally on very stable orbits. As an example, the large constellation One Web will start deploying by mid-2018 nearly 1,000 Internet satellites on a 1,200 km circular highly inclined orbit, stable for thousands of years.[40] And this may be just the beginning: Boeing has announced its own constellation with 2,900 satellites; SpaceX did the same with a first constellation of 2,800 satellites and a second one with 7,500. In total, the American FCC (Federal Communication Commission) has received requests for a total of 17,000+ new satellites to be launched in the coming ten years (let us recall here that there are only 1,700 active satellites today).[41]

Operators are often new-comers, actors from the Silicon Valley not used to space operations, but they appear to be well aware of all the space debris mitigation rules, so there are still good hopes that these massive operations on very stable orbits could lead to a controllable long-term situation, provided the international rules are strictly applied to.[42]

New radar Space Fence

A new S-bad radar called Space Fence[43] is under construction and should be operational in 2019. It should be capable of tracking objects significantly smaller than those catalogued today, potentially in the range of 5 to 3 com in diameter. This additional asset in the Space Surveillance and Tracking field is excellent news, but it means that the number of catalogued objects will raise by an order of magnitude, potentially to 200,000 objects. This will drastically increase the number of collision alerts if significant progress is not made in parallel in terms of orbital accuracy.[44]

Space Traffic Management STM

It appears obvious today that there is a growing conscience that one has to react rapidly in order to preserve future orbital activities. At international level, a lot of work is done now on Space Traffic Management, with the goal of guaranteeing Security in Outer Space, defined by ESPI as “Protection of the Space Infrastructure against natural and manmade threats or risks, ensuring sustainability of Space activities”.[45] Some researchers propose the creation of a new international entity with code-name “International Civil Space Organization” (ICSO)[46] with a very ambitious goal, ranging from the management of mitigation rules to the elaboration of Space Access fees, with coercive measures.

These initiatives are good, but they are essentially aimed at protecting operational satellites at short-term. There are hardly no proposals made today to avoid the regeneration of thousands of new debris associated to collision of non-manoeuvrable

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[40] Maclay, “OneWeb Perspectives on Responsible Design and Operational Practices for Large-Scale Activities in Low-Earth-Orbit”, Military Space Situational Awareness Conference, London, UK, April 2018.

[41] Kensinger, “FCC Large Constellation Processing Round”, 35th IADC-WG4, April 2017.

[42] Bastida-Virgili, Dolado-Perez et al., “Risk to space sustainability from large constellations of satellites”, Acta Astronautica126(2016)154–162.

[43] https://www.globalsecurity.org/space/systems/space-fence.htm.

[44] Peterson, Sorge, “Tracking Requirements for Space Traffic Management in the Presence of Proposed Large LEO Constellations”, IAC-18-A6.7.6, Bremen, Oct. 2018.

[45] “Security in Outer Space: Rising Stakes for Europe”, ESPI Report 64, Aug. 2018.

[46] Alary et al., “Toward an International Organization to handle a Sustainable Space Traffic Management – A functional approach of ICSO”, IAC-18-E3.4.10, Bremen, Oct. 2018.

large debris. As long as this potentiality is not solved, there will remain significant threats to future space operations.[47]

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To know more:

- IAA Situation Report on Space Debris – 2016 http://www.iaaweb.org/iaa/Scientific%20Activity/sg514finalreport.pdf
- IAF Symposium A6 "Orbital Debris", 10 sessions every year, http://www.iafastro.com/
- IAA Space Debris Committee activities: http://iaaweb.org/content/view/487/655/

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[47] McKnight, "Assessing Potential for Cross-Contaminating Breakup Events from LEO to MEO/GEO", IAC-18-A6.2.4, Bremen, Oct. 2018.