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MASTER THESIS

Space Debris Preventive Measures

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ΣΧΟΛΗ ΘΕΤΙΚΩΝ ΕΠΙΣΤΗΜΩΝ

ΤΜΗΜΑ ΠΛΗΡΟΦΟΡΙΚΗΣ ΚΑΙ ΤΗΛΕΠΙΚΟΙΝΩΝΙΩΝ

ΔΙΑΤΜΗΜΑΤΙΚΟ ΠΡΟΓΡΑΜΜΑ ΜΕΤΑΠΤΥΧΙΑΚΩΝ ΣΠΟΥΔΩΝ

ΔΙΑΣΤΗΜΙΚΕΣ ΤΕΧΝΟΛΟΓΙΕΣ, ΕΦΑΡΜΟΓΕΣ και ΥΠΗΡΕΣΙΕΣ - STAR.

ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

Μέτρα Πρόληψης Διαστημικών Συντριμμιών

Νικόλαος Σ. Ρέστας

Επιβλέπων: Αλέξανδρος Κολοβός, Αναπληρωτής Καθηγητής

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ABSTRACT

The existence of space debris is now a fact and has sounded the alarm to the global community. In order to move it away from the field of space, the corresponding attention has been drawn to prevention and removal strategies. This work focuses on prevention strategies, as removal strategies are a new subject. Specifically, the paper refers to the preventive measures from the year 1981 when the aeronautical space and aeronautical service published the first study, and we reach to this day including the rules and standards of the UN and the Inter Agency Space Debris Coordination Committee. Concluding, it is also important to recognize and present the current situation - behavior of the great powers.

SUBJECT AREA: Space Debris Mitigation

KEYWORDS: Space Debris, preventive measures, rules and standards, field of space, global community

ΠΕΡΙΛΗΨΗ

Η ύπαρξη των διαστημικών συντριμμιών στο χώρο του διαστήματος είναι γεγονός και η σημαντική αύξηση τους έχει σημάνει συναγερμό στη παγκόσμια κοινότητα. Προκειμένου αυτά να απομακρυνθούν από το πεδίο του διαστήματος έχουν εφαρμοστεί στρατηγικές πρόληψης αλλά και απομάκρυνσης. Η εργασία αυτή επικεντρώνεται στις στρατηγικές πρόληψης καθώς οι στρατηγικές απομάκρυνσης είναι ένα πιο σύγχρονο αντικείμενο. Συγκεκριμένα γίνεται αναφορά στα προληπτικά μέτρα τα οποία ξεκίνησαν το 1981 όπου η αμερικανική Αεροναυτική Υπηρεσία διαστήματος και αεροναυτικής δημοσίευσε τη πρώτη μελέτη. Από την άλλη φτάνει στο σήμερα, συμπεριλαμβάνοντας τους κανόνες και τα πρότυπα του ΟΗΕ και της υπηρεσίας Inter Agency Space Debris Coordination Committee. Κλείνοντας παρουσιάζεται και η τωρινή κατάσταση – συμπεριφορά των μεγάλων διαστημικών δυνάμεων.

ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ: Μετριασμός διαστημικών αποβλήτων

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: Διαστημικά συντρίμμια, προληπτικά μέτρα, κανόνες πρότυπα, διαστημικό πεδίο, παγκόσμια κοινότητα

I dedicate this thesis to my family.

ACKNOWLEDGMENTS

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PREFACE

Space debris is a reality nowadays and it has raised the alarm for all nations involved in space activities. Having been produced since the beginning of the space age until 2022, their number has already become alarmingly large, so large, in fact, that it threatens space missions. Major space powers, mainly, as well as other international organizations, that have realized the seriousness of the situation, are trying to mitigate the situation by promoting standards and norms for international cooperation in order to deal with the problem.

This dissertation takes a chronological review of all preventive measures that have been proposed since 1981, when the first report on space debris was published, and goes up to 2022. The structure of the dissertation is described below.

The first chapter introduces the definition and environment of space debris. There is information on the definition of space debris, what kind of objects are space debris and information about the environment they belong to.

The second chapter presents how space debris is produced. Ways, methods, and events that, when not taken into account, can cause space debris, are also presented. In this chapter it is realized that while the human factor plays a role in the production of debris, it is not the only one.

In the third chapter there is an introduction to the risks created by space debris. In essence, with this chapter, the importance of immediate mitigation measures is understood, because they pose a risk not only to the lives of the astronauts, but also to life on Earth.

The following chapters (four, five, six, and seven) refer to the review of measures taken starting in 1981. In these chapters there is information on preventive mitigation measures by organizations such as NASA, ESA, the European Union, United Nations and the Inter - Agency Committee Space Debris Coordination Committee also included. Finally, these chapters present standards and rules concerning the equipment of spaceships, global cooperation and peace between nations.

Lastly, the eighth chapter is the chapter that brings the discussion back to the harsh reality. Despite the mitigation measures taken for space debris and world peace, the eighth chapter presents what is really going on by demonstrating how the great powers act and the challenges these actions cause and ninth chapter presents the conclusion of this thesis.

1. DEFINITIONS AND THE ENVIRONMENT OF SPACE DEBRIS

1.1 Introduction

Man has a natural tendency to explore the world around him. Starting from the land, he proceeded to the sea and then to the whole Earth. Over time, the development of technology has helped man to take important steps in his development. Having made upward progress, man could and did extend into space. Since the 1950s, humanity entered the field of space. Problems did not take long to appear as the technological achievements of man began to accumulate in space and create so-called space debris. This section aims to define what space debris is and the environment it encounters.

1.2 Definitions of space debris

The English term Space debris can be rendered in many ways in Greek. There have been various suggestions such as space junk, space debris, space waste. The term that will be given weight is debris because it is used in official documents of the European Union. However, in order not to repeat the same term, references are also made to junk or waste.

Another problem which has a universal dimension is that until today there is no legally binding definition of space debris[1]. For this reason, different types of definitions are required in the international literature.

The Office of Technology Assessment, US Congress uses the following definition: Space debris [1] is pieces of various objects that come from human activities and are no longer in use. These pieces can be of various sizes [2]from very large satellite systems to very small pieces of satellites. Space debris is dangerous to humans as well as to space activities because they can move around the Earth in various orbits at extremely high speeds, so fast that they reach 4 to 7 kilometers per second. Considering these speeds in the event of a collision, the damage they will cause if they come into contact with an object, will be catastrophic.

According to Article 1(c) of the International Body for the Protection of the Environment from Damage Caused by Space Debris, of the International Law Union, the term space debris is man-made objects in outer space, other than active or other useful satellites, when no change is expected in these circumstances in the foreseeable future[2] [3].

The Inter-Agency Space Debris Coordinating Committee (IADC) defines in the "Guidelines for the Limitation of Space Debris" space debris as all anthropogenic objects, including debris and all elements that are in near-Earth orbit or re-enter the Earth's

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[1] Charalambos Panagiotopoulos, "Liability from Space Debris", Department of International Studies, Graduate Program, 'International Legal Studies', Academic Year: 2014-2015 School of Law, National and Kapodistrian University of Athens, 2015, ttps :// pergamos . lib . wow . gr / uoa / dl / frontend / file / lib / default / data /2838965/ theFile

[2]ILA International Instrument on the Protection of the Environment from Damage Caused by Space Debris, Final Report to the Sixty-sixth ILA Conference, 305-325 (1994)

atmosphere and are non-functional.[3] This definition is adopted only for "the convenience of readers", without claiming general application[4] [3].

The International Academy of Astronautics proposed, in its "Position Paper" on space debris, to include any man-made object in Earth orbit that is non-functional, without reasonable expectation of acquiring or regaining its intended function, including fragments and its parts[5] [3]

Another definition is that used by the Committee on the Peaceful Uses of Outer Space (COPUOS). Space debris is all human-like objects including fragments and parts thereof, whether or not their owners can be identified, in surrounding orbit or re-entering the dense layers of the atmosphere that are non-functional without reasonable expectation of being able to obtain or regain their intended functions or any other functions for which they are or may be authorized.

On the subject, considering that there is no legally binding international term for space debris, no more weight will be given. The fact of the lack of agreement on such a critical issue highlights the lack of common understanding of the parties involved.

The main space debris [1], [2]encountered by humans in space are shown in the following table after connecting various studies.

Table 1: List of space debris.

Deactivated spaceships.
Various rocket stages.
Fragments of rockets, spaceships and their other machines.
Paint flakes.
Particles from human constructions.
Space rocket separation devices.
Space rocket covers.
Exhaust particles from engines.
Various exhaust engines.

[3]5 Inter-Agency Space Debris Coordination Committee, IADC Space Debris Mitigation Guidelines, 3.1, 5 (2002). THE definition is repeated in the document where includes their basics definitions : Inter-Agency Space Debris Coordination Committee, Key Definitions of the Inter-Agency Space Debris Coordination Committee (IADC) (2013).

[4]Inter-Agency Space Debris Coordination Committee, IADC Space Debris Mitigation Guidelines, 3, 5 (2002).

[5]International Academy of Astronautics, Position Paper on Orbital Debris, Prepared by an ad hoc Expert Group on Safety, Rescue and Quality, 7 (1993)

In a few words, it is shown that the same materials used for space missions, with the end of which, change their role from being useful to becoming dangerous and toxic both for humans and for the space environment. The following figure shows in graph form the percentage occupied by space debris at the beginning of the problem. This study was conducted on December 8, 1989 under the title "Orbital Debris: A Space Environmental Problem." Clearly, these numbers have not remained the same.

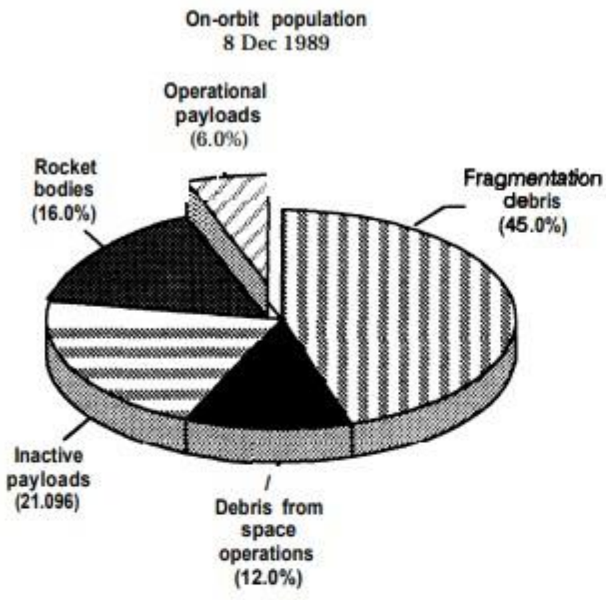

Figure 1: Percentage of space debris.[6]

The figure above [1] shows the percentages of space debris. Through this, it is observed that the space debris that comes from the operational payloads is the smallest percentage with only (6%), while the debris of the space technologies is the largest part, i.e. (45%). Then the intermediate percentages coming from the rocket stages (16.0%), the non-active payloads of the rockets (21.096%) as well as the space debris generated during space missions (12.0%) are also displayed.

According to figures released in January 2019 by the European Space Agency, Space Debris Office, the number of debris objects estimated to be in orbit is:

Table 1: Number of Space debris.[7]

Number of objects >10 cm	34.000
Number of objects from 1cm to 10cm	900.000
Number of objects< 1cm	130 million

[6] US Congress, Office of Technology Assessment, Orbiting Debris: A Space Environmental Problem-Background Paper, OTA-BP-ISC-72 Washington, DC: US Government Printing Office, September 1990. http://ota.fas.org/reports/ 9033.pdf

[7] Astroscale: https://astroscale.com/space-debris_/

1.3 Space debris environment

In this subsection, the environment of space debris, along with various statistics from studies that have been done on their number are presented. Previously, reference was made to objects that are not in use by humans. Of course, as it is known, humanity has managed to integrate satellite systems into various orbits around the Earth. These orbits presented below [1]:

- LEO (Low Earth Orbits) [8]– Low Altitude Orbits: The characteristics of these orbits have to do with their low altitude. They start from 200 kilometers and reach up to 2000 kilometers from the Earth. At this height, many micro-satellites related to telecommunications have been placed, so that they rotate fast enough (e.g., project Iridium). Even the International Space Station is in this orbit. Space debris in this type of orbit causes several concerns because these orbits are the most used for space activities. About 39% of the space debris resulting from breakups of rocket systems is found in these orbits. It should be emphasized that already since 1990, their population was increasing. Finally, it should be noted that several space debris ends up in these orbits from other larger ones due to their decomposition [1].

- MEO (Medium Earth Orbits) [9]– Medium Altitude Orbits: Orbits of this kind are used by humans for navigation mainly but also for telecommunications. For this reason, satellite systems have been installed. The height at which these orbits vary is from 2000 to 350000 kilometers from the Earth's surface. These orbits may not be used as often as the lower altitude orbits, but the ever-increasing number of space systems entering them is sure to lead to a potential space debris problem [1]. The so-called helium-modern orbits are now of particular concern because the systems placed in them (navigation systems) have a long lifecycle.

- GEO (Geostationary Earth Orbits) [10]: Geostatic orbits: They are the orbits of high altitude in which man has placed geostationary satellites. Geostationary satellites are responsible for satellite channels on Earth and telecommunications, so they are vital. The characteristic feature of the systems that are in these orbits is that they move with the same angular velocity of the Earth. These orbits are at an altitude of 360,000 kilometers. Due to the great distance from Earth, undetectable systems may also be contained (about 2000) [1] Non-active systems are also a strong risk. Due to the gravitational forces, they develop speed in the direction of the Earth. Of course, analysts argue that during the lifetime of such a system, the probability of a collision is 0.1%. Other studies claim, however, that if measures are not taken to mitigate them annually

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[8]ESA type of orbits: https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits

[9]ESA type of orbits: https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits

[10]ESA type of orbits: https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits

there will be an increase equal to 5%. Practically, this means that a satellite in these orbits will have a 40% chance of being hit by some space debris [1].

Based on the data presented above, the major problem called space debris is found mainly in low-altitude orbits, because it is easier to place satellites at low altitudes. In fact, what should be noted is that the organization US - SPACECOM [11], as stated by the standard of F Alby , D Alwes , L Anselmo , H Baccini , C Bonnal , R Crowther , W Flury , R Jehn , H Klinkrad , C Portelli , R Tremayne Smith entitled "The European Standard for Space Debris Safety and Mitigation", [4]has observed more than 8000 pieces of space debris of just over 10 cm in size. Even smaller space debris with sizes reaching millimeters have also been found in the low orbit types. Observations are made with radar stations. The ever-increasing number has led organizations such as NASA and ESA to address the impacts of collisions. The following images show the trajectories of space debris to highlight the magnitude of the problem [4].

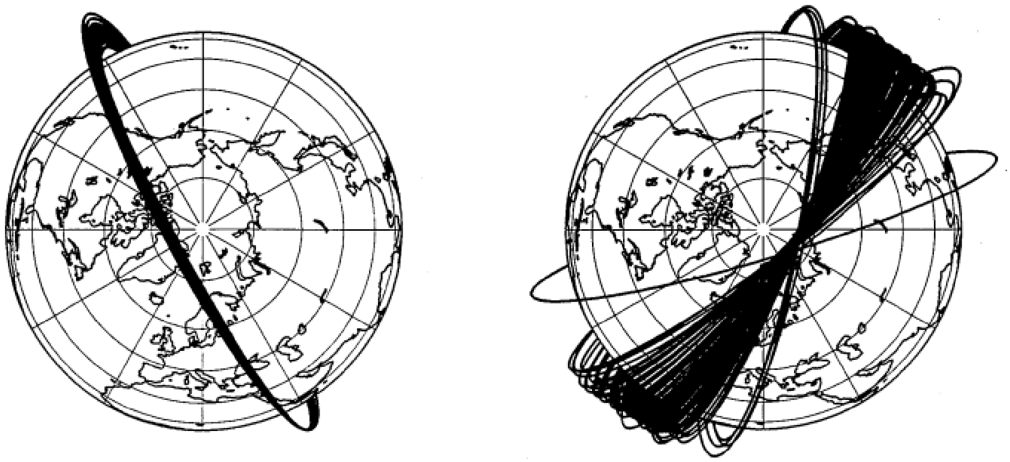

Figure 2: Space Debris orbits.[12]

[11]US-SPACECOM: https://www.spacecom.mil/

[12] Space Policy, Will Space Run out of Space? The orbital Debris Problem and its mitigation, article 'Mitteilungender TU Braunschweig', Carolo-wilhelmina, vol 14, Page 95-105, May 1998. Will space run out of space? The orbital debris problem and its mitigation - ScienceDirect

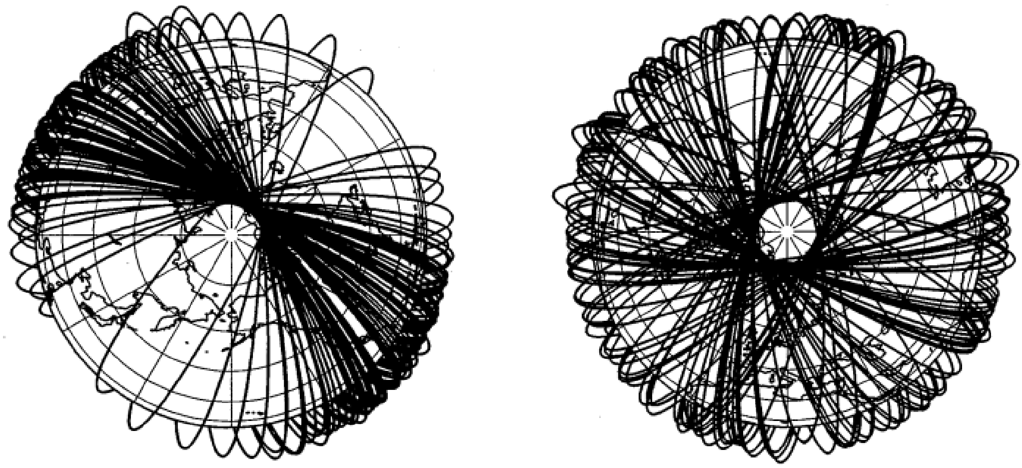

Figure 3: Space debris after variation.[13]

Figure 2 [4]shows the course of space debris when it appears and the course it takes over a period of 3 months. Their increasing number, certain changes they can undergo and also the passage of time give the result of figure 3. As it can be seen, it is completely different from that of figure 2. Therefore, it is concluded that the more the problem of space debris is neglected the worse it becomes in the future. The large amount of space debris has led to studies of areas that are safe like Loretta 's study Hall entitled "The history of space debris" [5]These areas are indicated in the next image according to a study carried out in 2004 where the main object was to find European safety measures to mitigate space debris.

[13] Space Policy, Will Space Run out of Space? The orbital Debris Problem and its mitigation, article 'Mitteilungender TU Braunschweig', Carolo-wilhelmina, vol 14, Page 95-105, May 1998. [Will space run out of space? The orbital debris problem and its mitigation - ScienceDirect]

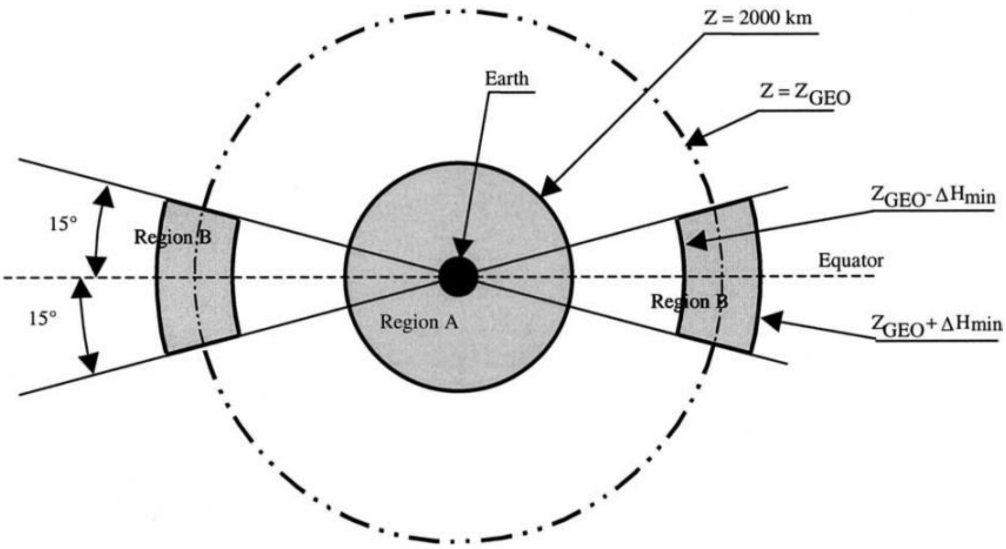

Figure 4: Safe areas.[14]

Identical to the image above, one area is in zone A which extends in altitude (2000 km) and areas B which reach geostationary orbit with the following characteristics (42,164 km). Looking at figure 4, it is immediately apparent that the safe areas in relation to the total space around the planet are extremely small. The next image shows how space debris changes after an explosion [4]according to a study entitled "Will space run out of Space?" The Orbital Debris Problem and Its Mitigation".

[14] F.Alby, D.Alwes, L.Anselmo, H.Baccini, C.Bonnal, R.Crowther, W.Flury, R.Jehn, H.Klinkrad, C.Portelli, R.Tremayne-Smith, The European Space Debris Safety and Mitigation Standard, Advances in Space Researcher, Darmstadt Germany, vol 34, Page 1260 - 1263, 10.106/j.asr.2003.08.043 , August 2001. Microsoft Word - 3sdc_paper_cro (esa.int)

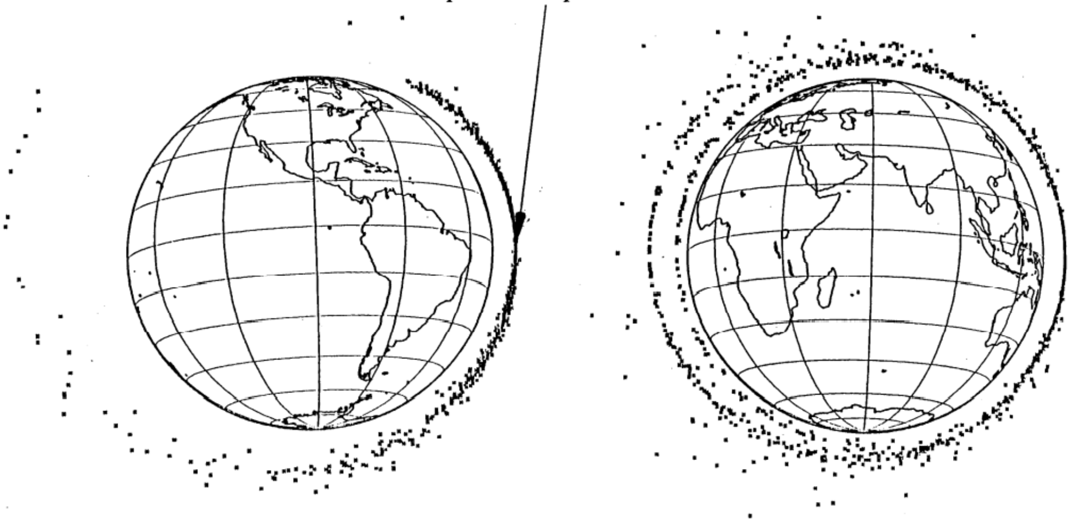

Figure 5: Space Debris after explosion.[15]

Based on the first chapter of this thesis, space debris varies in size. Nevertheless, with the increase in their population, they can become extremely dangerous due to their high velocities. Apart from the dangers they pose to space missions and humans themselves, they may well spell the end of space missions in the future if the necessary mitigation measures are not taken. As the problem remains until today the various definitions for space debris shows that this matter has not taken seriously yet. In my opinion in order to face the problem national organizations must take this problem seriously and make more restricted standards especially for the Low Earth Orbits.

[15]Space Policy, Will Space Run out of Space? The orbital Debris Problem and its mitigation, article 'Mitteilungender TU Braunschweig', Carolo-wilhelmina, vol 14, Page 95-105, May 1998. Will space run out of space? The orbital debris problem and its mitigation - ScienceDirect

2. HOW DID SPACE DEBRIS COME ABOUT?

2.1 Introduction

In this chapter, the sources of space debris that feed space will be analyzed. As it turns out, they can be divided into two categories. The first category is the human factor. Man is directly connected to space debris. The second source is the space environment. This may not be directly related to the human factor but because of the human technologies that exist in space they can be affected by space weather. Thus, in this section, an extensive description of the causes, as well as additional research results from NASA regarding incidents that occurred and contributed to the production of such debris will be presented. Finally, it is worth noting that because space debris is increasing rapidly, important organizations such as NASA, ESA, IADC, UNCOPUOS monitor the trajectories of the debris.

2.2 Human factor

Starting from the history of space [6]someone would notice that humanity began to deal dynamically with the field of space since the Soviet Union launched the Sputnik - 1[16] satellite into space in 1957. This act triggered other launches from the West. The ever-increasing launches of satellites led to the birth of space debris. With a more detailed look, the problem started after the launch of the US Vanguard - 1[17] satellite that took place in 1958 into MEO orbit. The transmission of this satellite stopped after 6 years of operation and is still inactive in space. Then in 1959 another 2 Vanguard satellites were launched by the USA, but they are also considered space debris [6]However, apart from launches, space debris can be produced as follows: from accidents (accidental debris), from missions (Mission related - debris) and finally from the weapons tests that take place in space (International acts creating debris).

Debris associated with space missions [6]can be generated during the operation of satellite systems. In fact, the debris which grows from them can vary in size from very small to very large. The case is that this debris constitutes only 12% of that recorded. The release of missile parts can also create debris. During the release of a stage of a rocket mechanism, small and large aluminum oxide particles are ejected at low speeds into space and can remain for up to 2 weeks. Still the upper tier of rocket systems contains balloons which, when exploded, launch various particles. Shields and other rocket parts can be found in space. Finally, this category also includes the various objects used by astronauts and which can be lost in space during a space mission [6].

The debris that is the result of accidents is also part of the space. It is common that a collision between satellites has occurred, and space debris has been produced. Some accidents that have happened in the past are shown below [7]:

- In December 1991, the Russian satellite Cosmos 1934 collided with parts of the Cosmos 926 satellite. This collision was noticed in 2005, leaving a lot of debris floating.

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[16]Nasa.gov – sputnik1: https://www.nasa.gov/multimedia/imagegallery/image_feature_924.html

[17]Vanguard 1: https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1958-002B

- On July 24, 1996, a French satellite collided with components from the French Ariane rocket.
- On February 17, 2005, an American rocket collided with a Chinese spacecraft orbiting in space.
- February 10, 2009 an Iridium type satellite collided with an inactive Russian type military satellite Cosmos 2251. This collision resulted mainly in hundreds of detectable size space debris.
- In 2007 China conducted a collision to destroy one of its own Fengyun - JC spacecraft (using an anti-satellite weapon). This collision littered space with over 2,000 pieces of detectable space debris, while an estimated 35,000 microscopic pieces of debris were produced.

There have been other accidents in space from time to time. Based on a study carried out by NASA in 2010 [2] entitled "Space Debris: Causes Types Effects and Management" the worst incidents of collisions that have occurred are presented here. The fields on the vertical axis refer to the names of the systems, while on the horizontal axis there is information about (the owner, the number of debris, the amount of debris in orbit, the year of the breakup, the altitude at which it occurred and the cause of the breakup).

Common name	Owner	International designator	Cataloged debris*	Debris in orbit*	Year of breakup	Altitude of breakup	Cause of breakup
Fengyun-1C	China	199-025A	3218	2989	2007	850km	Intentional collision
Cosmos 2251	Russia	1993-036A	1559	1371	2009	790	Accidental collision
STEP 2 Rocket Body	USA	1994-029B	710	58	1996	625	Accidental collision
Iridium 33	USA	1997-051C	567	487	2009	790	Accidental collision
Cosmos 2421	Russia	2006-025A	509	0	2008	410	Unknown
SPOT 1 Rocket Body	France	1986-091C	492	32	1986	805	Accidental collision
OV 2-1/LCS 2 Rocket Body	USA	1965-082DM	473	35	1965	740	Accidental collision
Nimbus 4 Rocket Body	USA	1970-025C	375	245	1970	1075	Accidental collision
TES Rocket Body	India	2001-049D	370	111	2001	670	Accidental collision
CBERS 1Rocket Body	China	1999-057C	343	178	2000	740	Accidental collision
Total			8616	5506			

Figure 6: Worst collisions by NASA.[18]

Sometimes space debris can create by satellite anomalies. These anomalies have been studying by the In-space Servicing, Assembly and Manufacturing (ISAM), in order to increase the on-orbit maneuverability, anomaly recovery and lead to a new generation of satellites that can help in debris removal. In the next figure is presented example of common Satellite anomalies [8] by a study of Alec J. Cavaciuti, Joseph H. Heying, and Joshua Davis with title “IN-SPACE SERVICING, ASSEMBLY, AND MANUFACTURING FOR THE NEW SPACE ECONOMY”.

[18]Habimana Sylvestre, VR Ramakrishna Parama , Space Debris: Reasons, types, impacts and Management, Indian Journal of Radio and Space Physics, Vol 46, March 2017. [(PDF) Space debris: Reasons, types, impacts and management | Sylvestre Habimana - Academia.edu]

Intelsat-28 May 2011	Intelsat-28's West C-band antenna reflector failed to deploy. This critical anomaly resulted in a $146 million insurance claim and a significant loss of capability.[13] A servicing spacecraft with robotic arms could have approached Intelsat-28 and repaired the antenna, potentially restoring the spacecraft's full operational capacity.
SES-14 January 2018	Société Européenne des Satellites (SES) launched SES-14 on Ariane 5 and experienced a launch anomaly that affected the spacecraft's trajectory. The spacecraft's on-board propulsion system performed an impromptu burn, preserving the intended trajectory to GEO, but limiting propellant for standard orbital operations and reserves.[14] A servicer spacecraft with refueling capabilities could refuel SES-14 and mitigate the impacts of the unplanned propellant burn.
Intelsat-29e July 2019	Intelsat-29e suffered a voltage anomaly followed by a communication system failure, resulting in satellite loss three years into its 15-year design life. The total loss is estimated to have cost Intelsat $382 million, an amount that could have been reduced if an OOS architecture with repairing capabilities existed.[15]
SXM7 January 2021	Sirius XM's SXM7 experienced a technical failure during on-orbit checkout less than two months after launch, resulting in the loss of the $220 million spacecraft. OOS inspection could have assisted in a quicker and more accurate diagnosis of spacecraft anomalies and subsequent on-orbit repair.[16]

Figure 7: Satellite anomalies.[19]

At a later stage there are also the debris created by weapons tests in space, as stated by the study of J M Hutagalung C. _ I Tobing, J. _ Debastri, R T Amanda titled “Space Debris as an Environmental Threat and the Requirement of Indonesia's Prevention Regulation” [6]. Between 1968 and 1985 there are anti-satellite tests (ASAT) in space by the major powers the USA and the Soviet Union. The latter repeatedly conducted tests with a co-orbital satellite approaching the same orbit as its prey. In September 1985, the US conducted a test of ASAT anti-satellite weapons against the Solwind craft P -78 at an altitude of about 525 km. A year later in September 1986, the Delta 180 payload was struck by a Delta -2 rocket body in a planned 220 km altitude collision.

In 1990, outer space contained 7% of recorded space debris. Today there are other major powers testing anti-satellite tests in space. In 2007, China launched a ballistic missile aimed at destroying one of its own Fengyum- 1 C satellites. This collision created more than 3000 pieces of debris. Through the monitoring carried out, it was established that within 10 days the fragments from the explosion had spread throughout space and in a

[19] Alec J. Cavaciuti, Joseph H. Heying, and Joshua Davis, “IN-SPACE SERVICING, ASSEMBLY, AND MANUFACTURING FOR THE NEW SPACE ECONOMY ”, CENTER FOR SPACE POLICY AND STRATEGY, July 2022, https://csps.aerospace.org/sites/default/files/2022-07/Cavaciuti-Davis-Heying_ISAM_20220715.pdf

period of just 3 years the space debris had surrounded the Earth. The space debris was at an altitude of 175 kilometers [6]. Finally, there is also a table [2]of various anti-satellite tests that have been carried out in general and the debris caused by them. In the image, the vertical axis shows the weapons tests, while the horizontal axis shows the number of times they occurred, the number of recorded debris, and the amount of debris in orbit.

Class of breakups	No. of events	No. debris cataloged	No. debris in orbit
Phase 1: Soviet ASAT	7	545	296
Phase 2: Soviet ASAT	3	189	154
P-78 Breakup	1	-	-
D-180 test	1	18	0
Total	12	1,037	488

Figure 8: Table with anti-satellite tests.[20]

It is worth noting that a contemporary anti-satellite test conducted by the India[21] in 2019 and from the collision the number of objects larger than 1cm is about 6587 and larger than 0.1cm is about 7.22 x 100000. The impact of other debris fragments with the fragments of the Indian anti-satellite test leads to secondary space debris.

Having mentioned all the sources of space debris, the countries that are mainly responsible are the big powers USA, China, Russia as stated by Habimana 's study Sylvestre , V R Ramakrishna Parama entitled "Space Debris: Causes Types Effects and Management" [2] with the percentage that all 3 together are responsible for 95% of space debris.

Table 2: Space debris by country.[22]

Country	Rate

[20]Habimana Sylvestre, VR Ramakrishna Parama , Space Debris: Reasons, types, impacts and Management, Indian Journal of Radio and Space Physics, Vol 46, March 2017. (PDF) Space debris: Reasons, types, impacts and management | Sylvestre Habimana - Academia.edu

[21] Y. Jiang, "Debris cloud of India anti-satellite test to Microsat-R satellite", August 2020, https://reader.elsevier.com/reader/sd/pii/S2405844020315358?token=07FC2177AFCC4A060B41DA037B7263911AFE4C76B95AFE84508CBDB92B439D6BD1D55B26D49354D6F8300F9C4064B0EE&originRegion=eu-west-1&originCreation=20220727135015

[22] Habimana Sylvestre, VR Ramakrishna Parama , Space Debris: Reasons, types, impacts and Management, Indian Journal of Radio and Space Physics, Vol 46, March 2017. (PDF) Space debris: Reasons, types, impacts and management | Sylvestre Habimana - Academia.edu

USA	27.5%
Russia	25.5%
China	42%

Towards the end, the amount of debris in space and how the number increases by date starting from 1957 to 1989, according to the figure below [1] is of great interest. Specifically, the y -axis shows the cumulative number of space debris, while the x -axis shows the dates. In the lower part of the figure (bottom lines) the growth trends are shown separately for each space debris, while the top growth lines refer to their annual recording.

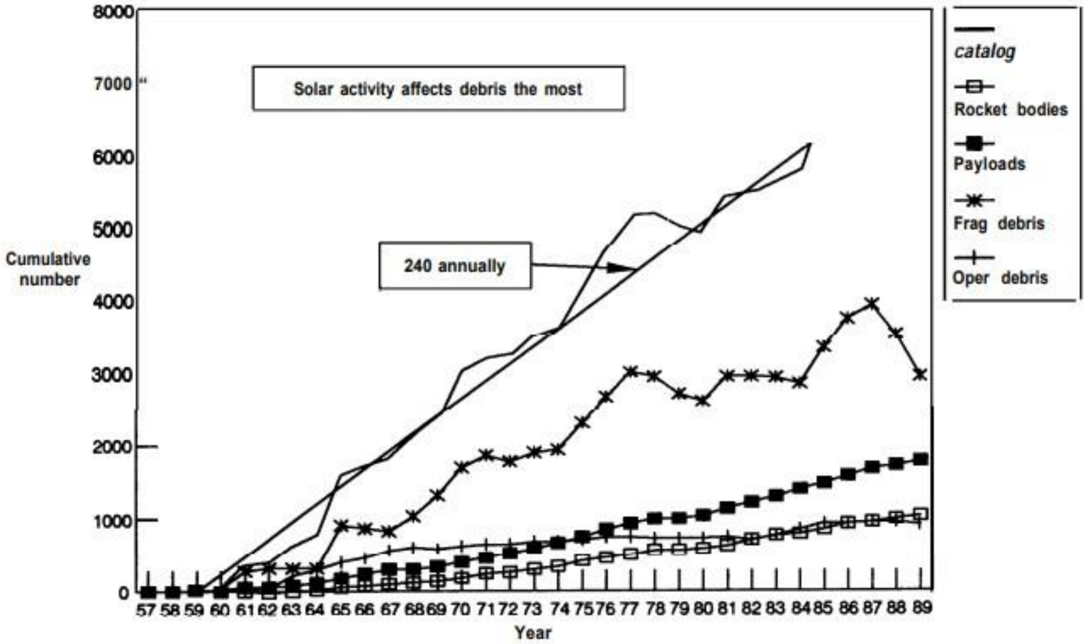

Figure 9: Space debris per year.[23]

The interest in space debris continues in the curves of 2000, until it reaches the year 2010 [6]. This image is from a study titled "The History of Space Debris" and its purpose is to show the increasing trend of space debris, as well as the types of space debris.

[23] US Congress, Office of Technology Assessment, Orbiting Debris: A Space Environmental Problem-Background Paper, OTA-BP-ISC-72 Washington, DC: US Government Printing Office, September 1990. http://ota.fas.org/reports/ 9033.pdf

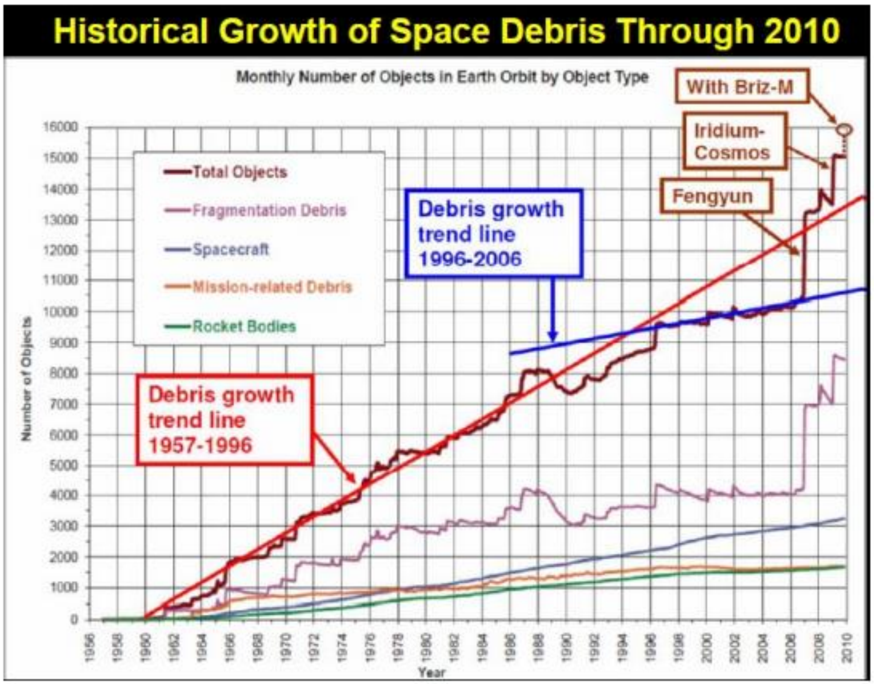

Figure 10: Space debris per year.[24]

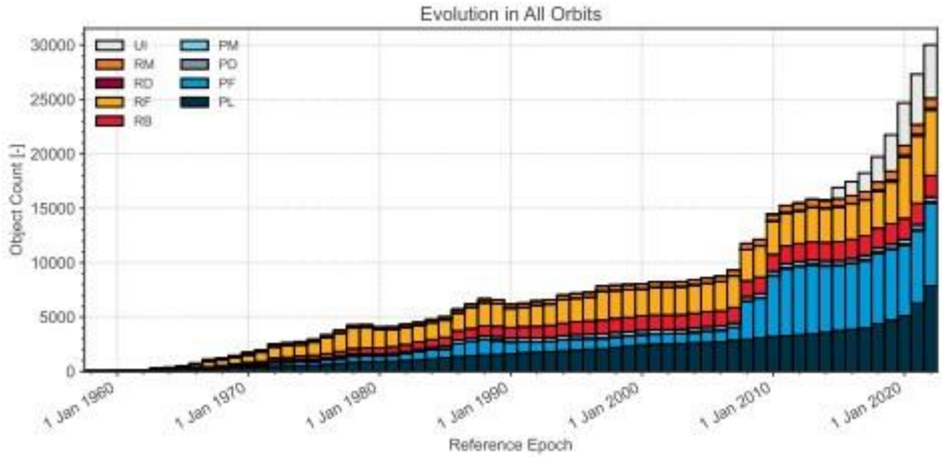

Figure 11: Space Debris by ESA.[25]

What is concluded is that when the activities in space began, the production of space debris began as well. This increasing tendency on such activities resulted in giving the impetus to the major powers to proceed with preventive strategies.

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[24]Loretta Hall, The history of Space Debris, Space Traffic Management Conference, Jim Henderson Welcome Center, Embry-Riddle Aeronautical University - Daytona Beach, September 2014. https://commons.erau.edu/cgi/viewcontent.cgi?article= 1000&context =stm

[25] ESA Space Debris Office, "ESA'S annual Space environmental report", Issue 6.0, GEN-DB-LOG-00288-OPS-SD, April 2022. https :// www . sdo . esoc . esa . int / environment _ report / Space _ Environment _ Report _ latest . pdf

The most common space debris is mainly rocket bodies, rocket payloads as well as various fragments. The next image below presents the results of a study under the title "Will space run out of Space? The Orbital Debris Problem and Its Mitigation", carried out by the competent United Nation Committee responsible for the peaceful use of outer space (COPUOS) [4] in 1998. These results offer a 100-year prediction about the future production of space debris. The y -axis shows space debris larger than one centimeter, while the x -axis shows the dates.

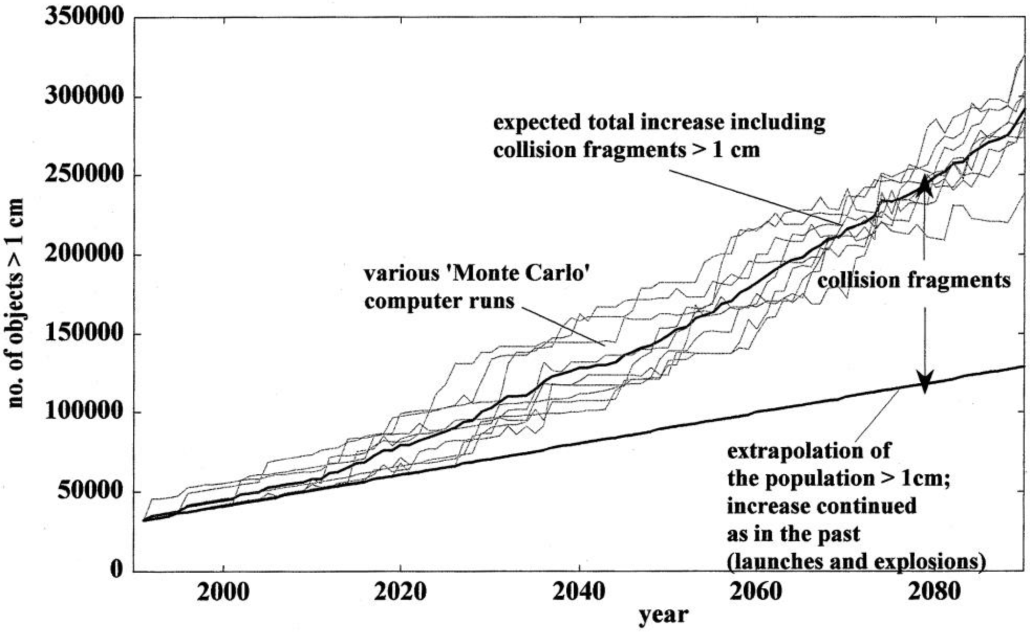

Figure 12: Forecast of Space debris by date.[26]

2.3 Separation procedures

Another source of space debris production, and in fact the most frequent one, is the separation processes or the explosions that the rocket systems may undergo [1]. Since early 1961, the 25 separations that have occurred alone have resulted in over 100 recorded space objects. Separation processes carried out by spacecraft not only manage to create space debris but also spread it out into the rest of space. Spacecraft and space systems in general can undergo separation procedures for various reasons.

The most important of these are 1) Damages that may occur in the electrical systems of satellite technologies 2) Damages that may be sustained by the propulsion systems of rocket systems 3) Deliberate actions in order to cause the disintegration of space technologies 4) Space weather due to the radiation that it emits, may cause damage to the systems of space technologies. 5) Unknown causes that may affect the systems and walls of the spacecraft. The next image shows the torque of a satellite moving around the Earth which can lead to a cloud of space debris [1]as stated by the study titled "Orbital Debris: A Space Environmental Problem". Initially the satellite moves around the Earth in

[26] Space Policy, Will Space Run out of Space? The orbital Debris Problem and its mitigation, article 'Mitteilungender TU Braunschweig', Carolo-wilhelmina, vol 14, Page 95-105, May 1998. [Will space run out of space? The orbital debris problem and its mitigation - ScienceDirect]

a fixed orbit. In the event of a collision, debris will be produced. Over time they will move in an annular orbit around the Earth. The dispersion of the debris cloud is a function of many factors such as the altitude and initial inclination of the satellite.

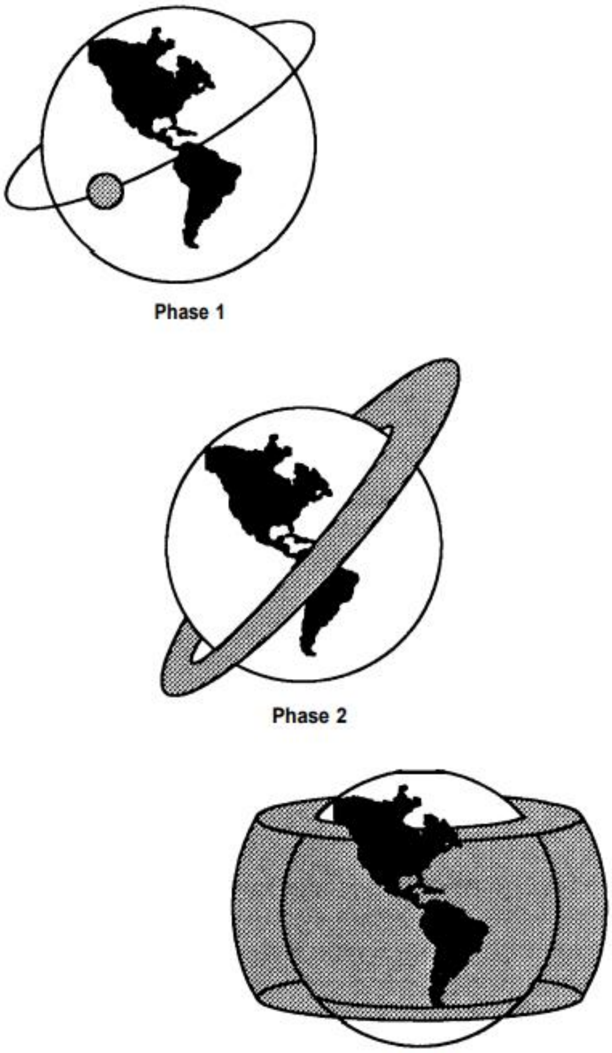

Figure 13: Space Debris cloud .[27]

2.4 Space weather

Beyond the human factor there is also space weather. The concept of space weather in space exists because of the Sun. The Sun tends to release high-energy particles into space which can affect the electrical circuits of satellite systems. These are the effects of Coronal mass ejection [28] and Solar flares[29]. High-energy particles can penetrate satellite

[27] US Congress, Office of Technology Assessment, Orbiting Debris: A Space Environmental Problem-Background Paper, OTA-BP-ISC-72 Washington, DC: US Government Printing Office, September 1990. http://ota.fas.org/reports/ 9033.pdf

[28]Coronal mass ejection: https://www.swpc.noaa.gov/phenomena/coronal-mass-ejections

[29]ESA – solar flares: https://www.esa.int/Science_Exploration/Space_Science/What_are_solar_flares

systems, disrupt their operation, and possibly destroy them. This is one of the reasons why the US Government issued a special strategic plan [9] entitled «Space Weather Operations, Research and Mitigation Working Group" concerning satellite systems to minimize their impacts from space weather.

The most recent example of satellite destruction due to space weather occurred on February 8, 2022, when Space X announced the loss of approximately 40 Starlink satellites launched on February 3. The loss was due to a geomagnetic storm that caused the Earth's atmosphere to heat up, leading to a 50% increase in atmospheric density at the Starlinks ' orbital altitude[30].

Therefore, in this section, the various sources that can supply space with debris have been listed. Sometimes humans are to blame; sometimes the space environment itself, and sometimes accidents occur from unknown causes. It is certain, however, that the greatest responsibility lies with the human factor, as it is responsible for the existence of satellite technologies in space. So in order to be reduced, it needs precaution measures during the space missions. Furthermore Nations must not release a great number of satellites in space especially in Low Earth Orbits. Organizations must have in mind all the sources that can produce space debris and follow the right standards. Anti – satellite tests must be prohibited in the space field as they can produce a huge amount of debris in space field.

[30]Starlinks: https://www.nasaspaceflight.com/2022/02/starlink-geostorm/

3. SPACE DEBRIS HAZARDS.

3.1 Introduction

Having presented in previous chapters the definition and sources of space debris, the reasons why space debris is a problem for humanity appear at this point. In this section, this major problem that has been created is highlighted, as well as the need for large organizations to lead the way for finding solutions to the problem. First, the problems created by space debris in active satellite systems, in humans, in space missions carried out in space are listed. Finally on the list, we will come across the observations - researches that are carried out. In conclusion, data from various studies that have been carried out will be presented in order to point out the visualization of the prevailing situation.

3.2 Conflicts with active systems

Regarding previous chapters in space there is a large amount of debris moving in orbits around the Earth at high speeds [1]. Their large population therefore multiplies the possibility of collision of space debris with active satellites moving around the Earth [1], [2], [4]. If the orbits of a satellite and a piece of space debris coincide, then a collision is inevitable. Due to the high speed of the space debris, new debris will be produced, and the collision will lead to its disruption or even complete destruction. In figure 12 [4]it can be observed that it is possible for the two trajectories between a body - satellite and a debris to coincide. Specifically, the geometry between two bodies that are in orbit and are about to collide is presented. The objects are at the same altitude but in different orbital phases. The figure 12 shows the equator, the trajectories of the bodies, the angle at which they will collide and their velocity vectors.

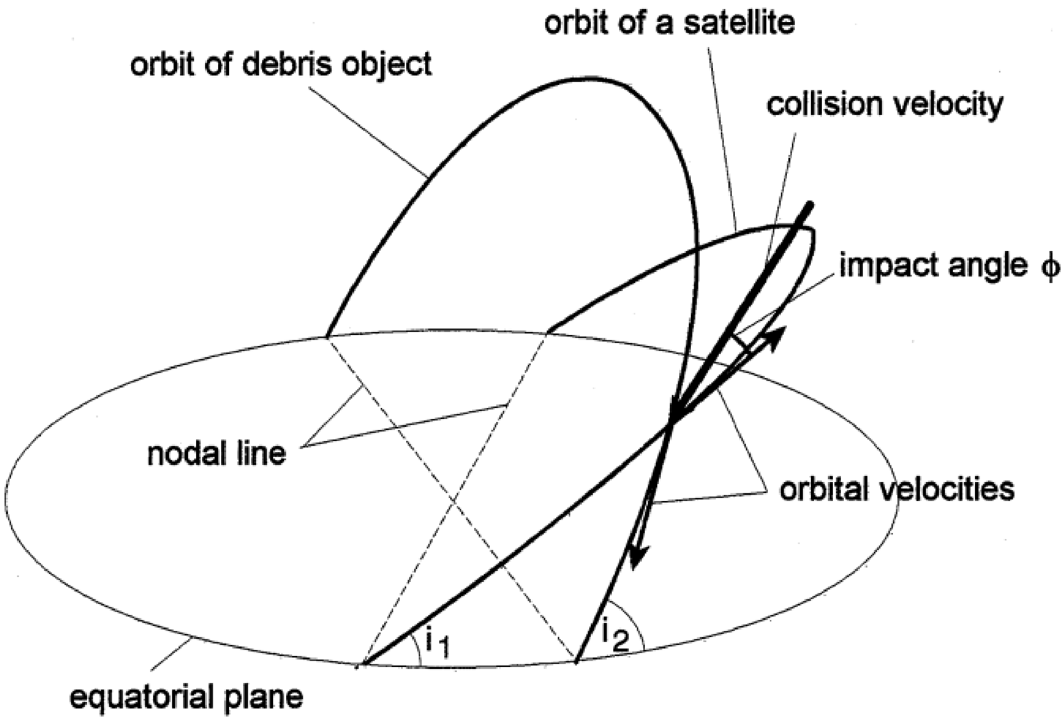

Figure 14: Collision between satellite and space debris.[31]

One such example [1]exists in the case of the Hubble telescope which was launched in 1990. In particular this telescope faces a daily chance of 1 in 100 of colliding with space debris. Another example is the re-entry of KOSMOS 954 in 1978 [1] where its fall was attributed to a collision with another body. In the case of KOSMOS 1275, it collided with a piece of space debris. Finally, there is also the release of debris from the collision between COCMOS 1818 [6] with a space debris or with various particles present in space such as pieces of asteroids endemic to space due to space weather [10]. The destruction of satellite systems is very important [7] if one considers the fact that without them humanity would not have telecommunications, Internet, satellite TV and financial transactions. Therefore, as it turns out, collisions between satellites and space debris not only lead to the malfunctioning - destruction of the systems, but also to the birth of new debris.

3.3 Contamination of the space environment

In space, rocket systems move with the help of various exhaust gases. When the time approaches and they reach the second phase during the release, various exhaust gas particles are thrown into the air space and cause pollution [1], [2]. Also, in rockets a booster is used when they want to go from low LEO to geostationary GEO orbits. The problem of pollution begins with the existence of this amplifier. During its operation billions of aluminum particles are released capable of contaminating the space environment. At this point, it is worth noting that the gases are not lost immediately after their release but

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[31] Space Policy, Will Space Run out of Space? The orbital Debris Problem and its mitigation, article 'Mitteilungender TU Braunschweig', Carolo-wilhelmina, vol 14, Page 95-105, May 1998. [Will space run out of space? The orbital debris problem and its mitigation - ScienceDirect]

remain in the space for approximately up to 2 weeks. The problems they create are great if you consider that they have a tendency to corrode the walls of spaceships as well as the astronauts' uniforms. Aluminum particles therefore pose a risk to space equipment and to the very lives of the crew of space missions.

3.4 Danger to space crews

Outer space is littered with space debris [11]either from human activities or pieces of meteorites found in space. According to a study published in 2014 by Perek Lubos titled "Space debris mitigation and prevention how to build a stronger and international regime" in space can be either large inactive objects or very small (i.e. sizes smaller than one centimeter). Oversights by the responsible Space Debris Monitoring Network (US Surveillance Network) [32]operated by the United States Space Force observes 10 cm objects, while smaller ones are usually more difficult to detect.

The network performs space surveillance, which includes the continuous detection, tracking, identification, cataloging and monitoring of man-made objects in Earth orbit, including active and inactive satellites and space debris from spent rocket bodies and their fragmentation [33].

The most dangerous space debris is that found in LEO orbits because they have velocities from 8 to 10 kilometers per second [1], [11], while in geostationary orbits – (GEO) they are usually located with velocities of 3 kilometers per second. The space missions, that the astronauts are in, are in LEO orbits since that is where the International Space Station (ISS) is located. Having a space debris in such high speeds in the event of a collision with an astronaut can penetrate his equipment [7]. There are also not a few times that there have been collisions between space debris and the ships in a space mission. The effects they can cause are shown in the next figure from a study done in 2014 by Loretta Hall entitled "The History of Space Debris". Figure 13 is from NASA [6]shows the result of space debris colliding with a window from a spacecraft.

[32]Nasa.gov – SSN: https://www.nasa.gov/mission_pages/station/news/orbital_debris.html

[33] https://www.gao.gov/products/gao-02-402rni

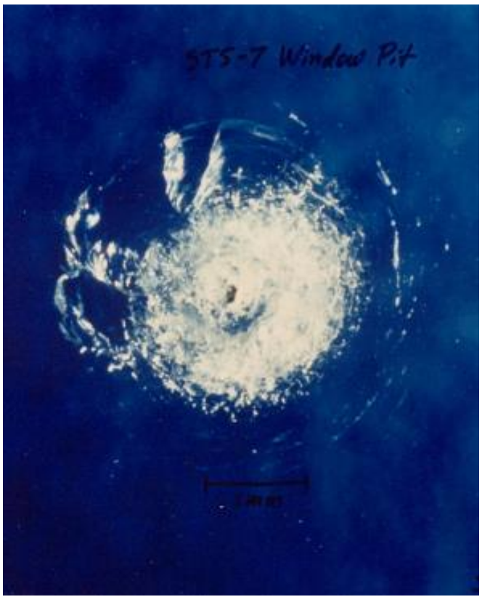

Figure 15: Collision Results .[34]

The study entitled “Orbiting Debris: A Space environment problem » published in 1990 [1]also addresses the issue of kinetic energy. In the figure below, the y -axis shows the energy in units of joules, while the x -axis shows the mass (log) of the space debris. On the right of the image, the velocities of the bodies can also be seen.

[34] Loretta Hall, The history of Space Debris, Space Traffic Management Conference, Jim Henderson Welcome Center, Embry-Riddle Aeronautical University - Daytona Beach, September 2014. https://commons.erau.edu/cgi/viewcontent.cgi?article= 1000&context =stm

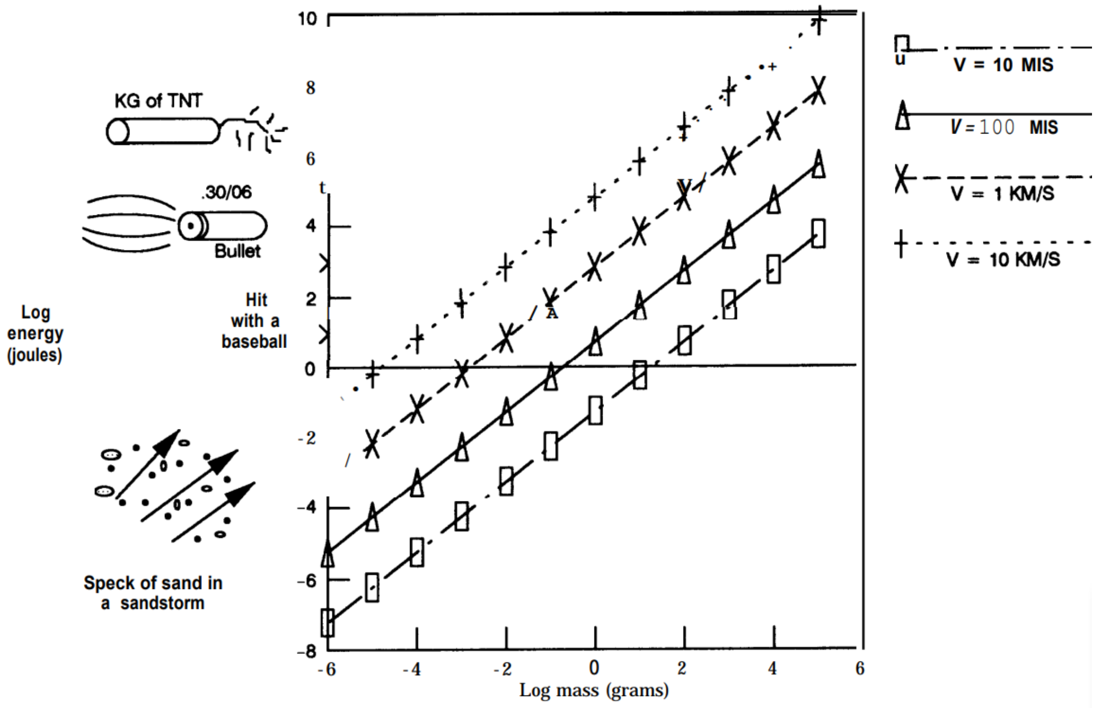

Figure 16: Kinetic energy of space debris.[35]

Therefore, it can be understood that space debris is a huge danger for space equipment and its crew, simply by realizing the large kinetic energies of the particles.

3.5 Risk in scientific research

Space debris affects not only the equipment of astronauts, satellites, but also has a great impact on scientific research [1]. In a previous subsection, the existence of the gas released during the separation of the rocket system was mentioned. These particles can confuse scientific research because they may emit a glow. They still have the ability to contaminate the particles found in the Earth's stratosphere and this in turn leads to interference in scientific research because it enhances radiation doses.

Another interference that these particles can cause is in the photography conducted for space. Looking in more detail in space, and more specifically in geostationary orbits – GEO, there are over 100,000 objects larger than one centimeter. There are many times that scientists have been led to wrong conclusions because of these particles [1]. Finally, aluminum particles make observations of space debris difficult.

3.6 In the operation of ground stations

In this sub-section reference will be made to the risk posed by space debris for the operation of ground stations. There are various sizes of space debris in space, so over time large pieces of debris become smaller and smaller. The existence of small debris

[35] US Congress, Office of Technology Assessment, Orbiting Debris: A Space Environmental Problem-Background Paper, OTA-BP-ISC-72 Washington, DC: US Government Printing Office, September 1990. http://ota.fas.org/reports/ 9033.pdf

leads to a vigilance to avoid collisions as large space debris is much easier to detect. For this reason, in case of detection of space debris the satellite systems can be driven to maneuvers to avoid collisions [6]. A study carried out in 2014, regarding 2010, reported over 100 maneuvers in a satellite to avoid collisions with space debris [6]Also in 2013, NASA recorded 29 maneuvers in some satellite systems.

In total, from 1988 until the year 2011, there were continuous checks by the US Space Agency (NASA) for possible collisions of certain space debris with the space shuttle (Space shuttle). The International Space Station (ISS) has often reached a series of maneuvers to avoid collisions. In total, the International Space Station from 1999 to 2014 has performed 19 maneuvers. 3 of them happened in the year 2014 where he had to avoid collision with 2 different spacecraft [6].

The constant maneuvering that a spacecraft must perform so as to avoid collisions is clearly a difficult task. If a maneuver is not made in time, then in this case there will probably be a collision. Another such example is the International Space Station where in 2014 it collided with some debris from the Russian satellite COSMOS 2251. The figure below is from the 2014 study entitled "The History of Space Debris" [6]and represents the Earth along with the space debris located around it (space debris is represented by the white dots). Clearly this figure must have changed today.

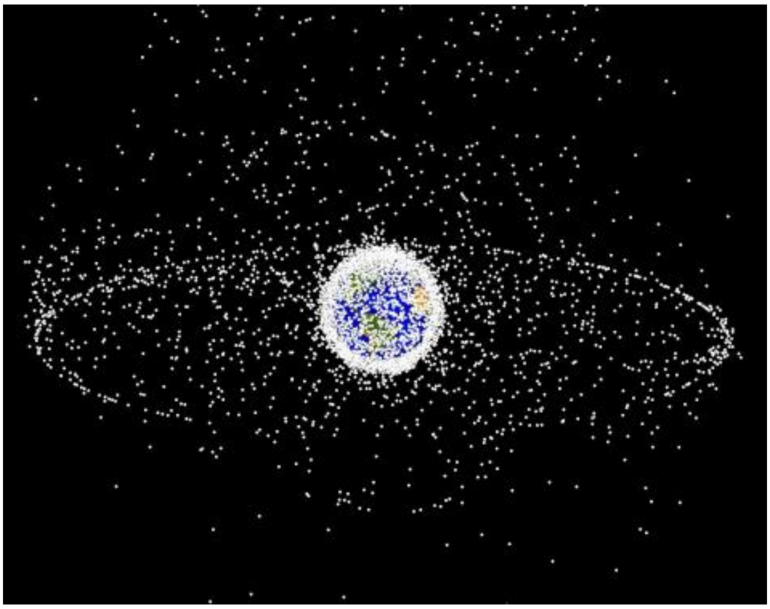

Figure 17: Earth with Space Debris.[36]

Observing this figure 15 one realizes that so much space debris is located close to the Earth (LEO) while, as they approach more outer orbits (GEO), they decrease. This is because there are more satellites in lower orbits than in geostationary orbits. The International Space Station and astronauts, in general, work in low orbits. So, it makes

[36]Loretta Hall, The history of Space Debris, Space Traffic Management Conference, Jim Henderson Welcome Center, Embry-Riddle Aeronautical University - Daytona Beach, September 2014. https://commons.erau.edu/cgi/viewcontent.cgi?article= 1000&context =stm

sense that systems in low orbits can perform many evasive maneuvers in the event of an encounter with some space debris.

3.7 In life within the Earth

In a previous point it was mentioned that space debris is a huge danger in outer space. Beyond space, they can also affect life on Earth. Small particles of space debris that escape their orbit and end up in Earth's atmosphere, usually burn up as soon as they enter it. However, they are large enough to reach the ground [6]. On average, uncontrolled re-entry of spacecraft space debris or rocket bodies weighing only 2000 kg or 4400 lbs is common. From such constructions usually 10-40% of the total construction reaches the Earth’s ground. However, most space debris ends up in the oceans.

Examples of such collisions [6]are the re-entry of the American space station Skylab into the Earth's atmosphere in 1979. On July 12, 1979, the large solar panels detached as Skylab rotated, but the main body of the station could not be completely disintegrated and upon its fall [37] it reached the ground. The total strucutre was about 84 tons. In its impact with the ground, it caused the debris to be scattered up to 200 kilometers high. In 1996 there was a fall of a missile tank in Oklahoma, America. The same had happened with the destruction of the space shuttle COLUMBIA. The space shuttle during its entry into the Earth's atmosphere was destroyed in 2003. During its fall, it did not disintegrate, and its pieces reached the ground.

In addition to the fragments of rockets, several observations concern the fragments of asteroids that are located near the Earth [10]. Several studies focus on them with enough weight being given to objects that are over 1 kilometer in diameter. These pieces, upon entering the Earth's atmosphere, may not disintegrate and reach the ground, causing serious damage to the planet. Space debris manages to reach planet Earth with the help of space weather because it affects it. An important example is the comet that fell to Earth and wiped out the dinosaurs. Because of its size, the comet did not break up and was able to reach the ground leave a trail of death and destruction to the planet and to life itself.

Finally, as mentioned in a previous subsection in space, in some cases, nuclear materials [7] are used to launch rocket systems. In the event of an accident, if they reach the Earth, they can release radioactivity in the area of their fall. An example of this category is the fall of a Soviet satellite in Northern Canada, in 1978, where it filled the ground with radioactive debris.

Although there have been incidents where pieces of satellites as well as other space debris have fallen to Earth it is nothing to worry about as most of the planet is made up of water. So, most of the space debris that ends up inside the Earth usually falls into the seas and oceans, while from the total body that will fall inside the Earth, 10-40% will reach the ground and will not disintegrate [6]. Therefore, space debris affects the entire Earth ecosystem beyond space. The following table summarizes all the above by name.

[37] Uncontrolled re-entry of satellite parts after finishing their mission in LEO, Acta Astronautica, 135 (2017) 69–75, http://dx.doi.org/10.1016/j.actaastro.2016.10.031

Table 3: Space debris hazards.

Space debris hazards.
Conflicts with active systems.
Contamination of space environment.
Danger to space crews.
Risk in scientific research.
Risk in the operation of ground stations.
Danger to life inside the Earth.

3.8 Forecast

From the date of 1957 when people began to deal with space, already the space outside the Earth seemed endless and no one believed that with all these technologies the space around the Earth would be limited by space debris [6].

Today, many agencies involved in space, whether they are public or private, such as NASA and ESA, have begun to deal with this problem [6]. Also, daily the satellites of the low orbits mainly, face the risk of collision. For this reason, space debris has become an official problem in the space community [11].

Having become an official problem, efforts to solve this phenomenon usually focus on preventive measures strategies since removal strategies are new and cost too much [11]. There are several studies for debris removal but not all of them are technologically mature. For this reason, the problem of space debris was constantly postponed. But what is certain is that now all organizations dealing with the space sector have understood the seriousness of the situation and the inability to solve this problem may mean the end of space exploration [6].

Taking all these things into consideration, space debris can cause a various amount of damage. For this reason preventive measures from COPUOS and Inter-Agency Debris Committee must be followed. The growth becomes rapidly and that’s the reason why space debris have become a serious problem to the space community.

4. PREVENTIVE MEASURES 1981 - 1999.

4.1 Introduction

The first formal study conducted on space debris was done in 1981, by NASA's Technical Committee on Space Systems [12]. With this, it was intended to highlight the nature of the threat that had not been apparent until then. Subsequently, a series of publications and studies began on this topic in order to reduce them from outer space. In this section, studies and actions carried out between 1981 and 1999 will be presented in order to prevent the phenomenon that causes more and more concern.

4.2 Prevention Procedures 1981

The first official report on space debris was made in 1981 by the United States' civilian space agency, NASA, and specifically by the Technical Department Committee on Space Systems[38] [12]. In detail, the study presented under the title "Orbital Debris. A timeline" states that "Continued production of space debris will drive the possibility of conflicts to insane levels within a decade" [39]. Therefore, the first official report calls for [12]:

- Development of space wall defenses of spacecraft to provide protection in case of impact with small objects.
- Immediate action for the further study of this phenomenon in order to have a better design of the space vehicles for the space missions and in general, of all the processes that occur in space.
- Need for universal legislation, which will be accepted by all, so that all states and organizations in the space field will comply.

The study entitled "Immediate action to prevent the serious problem" [40]in fact closes at the end emphasizing that immediate action must be taken to prevent space debris from becoming an immediate danger in the future.

In fact, in the same year, due to the use of weapons in space, the Soviet Union presented to the UN a Draft Treaty according to which the use of weapons in space would be prohibited. The main proposals were the following [14]:

- States are prohibited to install weapons in orbit.
- Any State belonging to the United Nations Organization should not encourage any such actions aimed at the use of weapons in space.

[38]Technical Committee on Space Systems: https://www.iafastro.org/about/iaf-committees/technical-committees/space-systems-committee.html

[39]David SFPortree, Joseph P. Loftus, Jr Lyndon B. Johnson, Orbital Debris: A chronology, National Aeronautics and Space Administration, NASA/TP-1999-208856, January 2009. https://ntrs.nasa.gov/api/citations /19990041784/downloads/19990041784.pdf

[40] David SFPortree, Joseph P. Loftus, Jr Lyndon B. Johnson, Orbital Debris: A chronology, National Aeronautics and Space Administration, NASA/TP-1999-208856, January 2009. https://ntrs.nasa.gov/api/citations /19990041784/downloads/19990041784.pdf

- Every state should not push for the destruction and in general the disruption of outer space.
- Any member state can add amendments to the regulations as long as they are presented and accepted by all other member states.

These proposals did not meet the needs of all countries, so no relevant decision was taken. The organization of the United Nations in the same year in 1981, having been created in the breakout of the second world war, wanted to give importance to the avoidance of war but also to world peace. For this reason, it calls on the member states to pay attention to the following proposals. [13], [15]:

- States that use nuclear weapons in outer space will be committing crimes against humanity.
- There will not be any excuse for a politician in case he decides to use nuclear weapons in outer space.

4.3 France UNITRACE / SIPA Program – 1989

As space debris became a public concern in 1989, France as a member of the United Nations proposed tracking space objects through a center to be called UNITRACE[41] [13], [16]. The center would provide data collection, recording of launches, monitoring of satellite systems while providing timely and valid information to all member states on the status of studies. France also proposed that all member states should notify each time the missile equipment they carry into space. The collection of the center's data through an association, namely International Launch Notification Center would utilize the data while at the same time being connected to the United States of America and would be responsible for the following functions [16], [17]:

- To receive notifications of launches from Member States before they occur.
- To receive notifications from the Member States about the launches that have already taken place.
- Data management.

The purpose of these proposed functions was more protective because with the correct information of each state in the event that a space object passed too close to a satellite system, major disasters could be prevented. In addition, the technological facilities (remote sensing instruments, cameras, radars, mechanically steered dishes, radio beams, low-orbit satellite system cameras) of this center will assist in the maneuvers of the satellite systems in order to prevent possible collisions with space debris. At the same time, they will provide detailed information with the aid of the Advisory Machinery [42](dispute-resolving machinery) on any issues that may arise regarding the a)

[41]Lucy Stojak, The Non-Weaponization of Outer Space, International Security Research and Outreach Program International Security Bureau, May 2002. https :// www . international . g.c. _ ca / arms - armes / assets / pdfs / stojak 2002. pdf

[42]Pericles Gasparini Alves, Prevention of an Arms Race in Outer Space: A Guide to the Discussions in the Conference on Disarmament, ISBN 92-9045-056-8, Sales No. GV.E.91.0.17, NewYork1991. https :// unidir . org / sites / default / files / publication / pdfs / prevention - of - an - arms - race - in - outer - space - a - guide - to - the - discussions - in - the - cd - en -451. pdf

identification and b) location of space objects [17]. Of course, for the best possible prevention, France proposed that the information provided by the member states should include the following additional information [17]:

- Orbital information of each satellite system.
- Information about the maneuvers that a satellite system can perform.
- Information about the energy of satellite systems in space.
- Operational data of the systems contained in each satellite system located in space.
- Information about the spacecraft such as (mass, size, lifetime of the satellite system).

In 1989, based on the study entitled "Preventing an Arms Race in Space: A Guide to Conference and Disarmament", France also proposed the creation of a satellite image processing center SIPA (Agency for the Processing of Satellite Image). Analysis of satellite images can help prevent disasters that can occur inside the Earth from space debris. The next image shows the proposed structure of this organization [17]. Through it, the role of the organization, the equipment in the visual data, the characteristics of the analysis and finally the origin of the data can be distinguished.

Principal Function	Optical Data Equipment (visible or near infra-red spectrum)	Expected Resolution	Origin of Data (civilian satellites)
- Disarmament - Crisis control - Natural disasters and development programmes	- Digital or analogue data - Photographic data (chromatic, colour, or spectral photography - Cartographic data	- 5 to 10 metres - very-high-resolution data supplied by aircraft	- previously recorded by satellites - existing weather satellites - existing or planned Earth observation satellites

Figure 18: Proposed Structure of a SIPA satellite image.[43]

The following figure shows the subsystems of the SIPA organization, their basic functions as well as some of their special techniques.

[43]Pericles Gasparini Alves, Prevention of an Arms Race in Outer Space: A Guide to the Discussions in the Conference on Disarmament, ISBN 92-9045-056-8, Sales No. GV.E.91.0.17, NewYork1991. https :// unidir . org / sites / default / files / publication / pdfs / prevention - of - an - arms - race - in - outer - space - a - guide - to - the - discussions - in - the - cd - en -451. pdf

Subsystem	General Functions	Special Technical Features
• Data Processing Subsystem (DPS)	- convert raw input into digital, photographic, or other to meet user's needs - check the validity of all scene identification parameters - determine identification parameters (processing of remote maintenance data for the preparation of calibration tables)	- conversion of photographic and carto-graphic data into usable digital data - conversion of satellite data into usable data (e.g., after correction of various radiometric and geometric errors)
• Data Management Subsystem (DMS)	- data quality control	- reproduction of data - data storage, archiving and cataloguing - data security
• Data Analysis Subsystem (DAS)	- convert non-analyzed data into information to be used by SIPA and by the users - combine manual (visual) techniques of photo interpretation and computer-assisted interpretation	- contrast accentuation - noise elimination - linear filtering - utilization of false colours - production of composite images - analysis of scenes using auxiliary cartographic or other data
• Data Dissemination Subsystem (DDS)	- disseminate restricted or unrestricted data.	- manipulate data in the form of: – permanent image: films, tracings – magnetic tapes

Figure 19: Proposed Subsystems of a satellite Image SIPA.[44]

The goals of this organization would be to collect data and prevent natural disasters that can be created by another natural disaster or by the fall of space debris into the Earth. The collection of this information could be distributed after its analysis to the other member states of the United Nations, while at the same time it could also be used to exchange information with other member states.

Finally, France, to reduce space debris, proposed a ban on nuclear weapons in space that can create debris [13], [16]. Specifically, the preventive measures, that they presented, included the following:

- General regulations for the use of weapons in outer space.
- General treaties on space law.
- Prohibition of nuclear weapons in space – detailed.
- Prohibition of weapons with a general description of outer space.

Therefore, the country of France has apparently invested in the tracking of space objects in order to prevent a possible collision between a satellite system and some space debris. It also aims to protect and monitor the planet as well as protect space.

None of the above proposals, despite having attracted the interest of the international community, were accepted because the large space countries did not wish to provide a detailed description of their activities to the smaller countries.

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[44] Pericles Gasparini Alves, Prevention of an Arms Race in Outer Space: A Guide to the Discussions in the Conference on Disarmament, ISBN 92-9045-056-8, Sales No. GV.E.91.0.17, NewYork1991. https :// unidir . org / sites / default / files / publication / pdfs / prevention - of - an - arms - race - in - outer - space - a - guide - to - the - discussions - in - the - cd - en -451. pdf

4.4 Preventive measures Study – 1990

More than 30 years of experience on the design of space systems and space missions have passed and there are methods that can help reduce space debris. Each of these methods differs in the financial department as well as in effectiveness. According to a study published in 1990 entitled "Orbital Debris: An Environmental Problem" it is preferable from an economic point of view to reduce the amount of space debris rather than to take care of the damage it causes to space systems [1].

The procedures that must be followed in order to solve the problem are divided into prevention strategies and removal strategies [1], [2]. These are 2 different philosophies because prevention strategies aim at preventing explosive devices and avoiding collisions, while removal strategies at the processes of removing space debris from outer space. As mentioned above, this diplomacy focuses only on the first dimension. According to a combination of studies, prevention strategies are as follows [1], [2]:

- Optimum design of space vehicles as well as rocket systems in order to have a low probability of explosion.

A typical example is the various propellants used in rocket systems. Batteries and electrical circuits can cause an explosion, especially from some increase in temperature. Such measures reduce the possibility of any explosion. Since 1981 [1], the American civilian space agency NASA has been concerned with such measures mainly concerning the upper stages of rocket systems. Its main purpose was to improve the upper stages so that they would not be driven into space. Similar design techniques have been adopted by Japan and the European Space Agency (ESA).

- Appropriate spacecraft design to provide resistance to atomic oxygen, solar radiation, and not to cause the spread of space debris during separation procedures.

Since the 1960s according to the study titled "Orbital Debris: An Environmental Problem» solution have been proposed to shield the walls of the spacecrafts. Fred _ Whipple, a well-known astronomer, brought forward the use of the double wall to provide protection against collisions with small particles. An example of this case is the European spaceship Giotto that passed through the tail of a comet to test the strength of the walls [1].

- Space systems should not be abandoned for a long period of time as this will lead to an increase in space debris.

All satellite systems should have a lifetime. As soon as they pass the expected limit it is good to move away from the low orbits mainly to avoid any collisions either with active systems or with the debris in the space.

4.5 Study of the United States of America – 1991

The study of space debris from the United States of America had begun since the beginning of the space age. Since the 1970s the space agency NASA has been studying the activities of space debris [18] according to the study of Joseph P. _ Loftus and Andrew E. _ Potter entitled "United States Studies in Orbital Debris". In order to achieve her goal of understanding of debris and the effect of it, she devoted herself to monitoring it and also to tests aimed at the durability of materials. NASA 's original plan was to understand how they work and come up with prevention strategies to save space missions.

The studies were mainly devoted to the following: A) Regarding the observation of space debris NASA devoted itself to the detection of particles ranging from 2 to 10 centimeters with the help of a special Haystack radar [45]. For high altitudes (geostatic orbits) NASA uses a special system called GEODSS [46]. In addition to small debris, NASA also turned its attention to exhaust products from the engines (aluminum oxides) in order to collect information on the state of the space environment [18]. B) NASA also focused on the dynamics of the environment from various conditions of use (a critical situation due to the increase in space debris). These studies will help to understand how the space environment works with space debris as well as what other situations can be created due to the large amount of debris present (debris in helio-modern orbits). C) Experiments on the durability of materials. In these tests NASA uses special cannons that shoot gas (particles with high speeds) that reach 6-7 kilometers per second [18]. D) Finally, there are the space debris management studies. These studies include techniques to minimize space debris during missions. In this category belong missile system design techniques, measures during the fission process, ways and limitations in order to ensure safety from a possible explosion in a mechanism. Finally, within all of this, the most economical solutions and techniques that can be followed are also evaluated. The next image shows a prediction from NASA according to a study done by Joseph P Loftus, Andrew E Potter titled "United States Studies in Space Debris," showing the number of objects that will be in the space field every 200 years when mitigation is done versus when it is not.

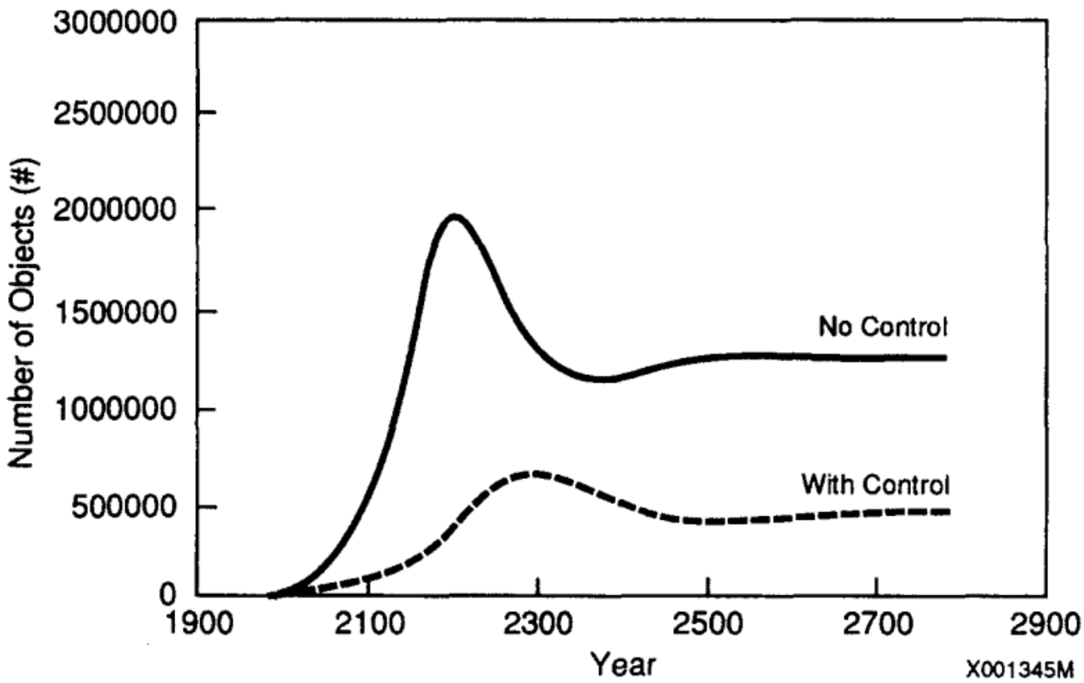

Figure 20: Number of Objects/Year by NASA [47].

[45]Haystack radars: https://ntrs.nasa.gov/api/citations/20190028719/downloads/20190028719.pdf

[46] GEODSS: https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104594/ground-based-electro-optical-deep-space-surveillance/

[47] Joseph P. Loftus, Andrew E. Potter, US Studies in Orbital Debris, Acta Astronautica, vol 24, Page 333-341, DOI 10.1026/0094-5765(91)90183-6, Great Britain, 1991. https://ui.adsabs.harvard.edu/abs/1991AcAau..24..333L/abstract

4.6 Management of outer space – 1994

Space missions increase the amount of space debris. Therefore, in 1994, the issue of space management came to the fore in order to provide a solution to the problem. According to Perek Lubos' study entitled "Space Management" [19], by the term Space Management are meant all the procedures that offer economy, safety, and completeness to space missions. Some suggestions to follow in order to use the space for logical and beneficial purposes are:

- Prevention so that there is no interference to telecommunications in space.
- Preventing materials used in space technologies from failing when they come into contact with some space debris.
- When it is deemed necessary to use separation techniques.
- Prevention of human errors in space technologies - space missions.
- Preventing failures that can happen to the spacecraft.
- Collecting and providing information about the positions of space objects located in space.
- Space to be used only for reasonable and useful purposes.
- Create an appropriate organizational structure for the above steps if not covered by existing agencies.

Preventing a material from failing is the key to making it last longer in space. Failure can occur either from a collision with some space debris or from the conditions prevailing in space. It has been said above that damage can be caused by objects as small as one centimeter traveling at a speed of 10 kilometers per second [19]. Therefore, the study of the durability of materials is an important measure for the continuity of space missions. Separation techniques can play an important role in removing satellite systems from their orbits. For example, when a satellite finishes its mission, it should be removed from its orbit. Several organizations use these techniques on geostationary satellites to ensure the geostationary zone is safe for active satellites. Another example relates to the case when a system containing nuclear energy sources must be removed. These techniques were used at sea in the air and have now been transferred to outer space offering advantages. In space missions the probability of damage must be as low as possible. Spacecraft before each mission should be checked and have a safety certificate. Therefore, at a future level there should be space standards of global scope. In order not to avoid conflicts between the space systems, a necessary part is to know the location of each object. The elements that are necessary are position, speed, and direction. These elements change over time, so special attention should be paid to them, especially after a maneuver [19]. Finally, space should be used to explore human limits. Therefore, a limitation should be given to the missions that will follow because some may not be necessary. Therefore, the conclusion is that the prevention against the growing number of space debris can provide a result.

The UN also started to discuss the issue within the COPUOS committee [48]and, its Scientific and Technical Subcommittee. In 1994, the subcommittee considered for the

[48]COPUOS, Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space: https://www.unoosa.org/pdf/publications/st_space_49E.pdf

first time issues related to space debris under a new agenda item. In particular, the subcommittee began to review scientific research on space debris, including interrelated studies, mathematical models, and other analytical work on environmental characterization of space debris.

4.7 Prevention Strategies – 1998

The study entitled "Will space run out of Space? The problem of orbital debris and its mitigation" published in 1998 dealt with prevention strategies that can be divided into 2 parts [4]: The first is about avoidance strategies and the other is about government decisions that can mitigate the space debris situation with laws and procedures. In the first case, the measures are the following:

- Avoid explosions in orbits.

A large percentage of space debris has come from explosions. Exhaust fumes should be kept away from the rocket stages. A solution to this problem is the venting of the residues [4]which is used in all European Ariane rockets [49], through a special valve that evaporates the fuel. Similar principles are followed by the United States with the Delta missiles and by Japan. This measure will significantly reduce the number of collisions, and therefore the number of fragments.

- Removing large objects from orbits.

The upper stages of the rocket systems should include fuel boosters that would allow them to maneuver in order to depart from their end-of-life orbits. In this way the orbits are emptied and there is no accumulation of satellites. Satellites that do not have special thrusters will have to be redesigned. In this case it is worth noting that the braking maneuvers while removing the satellites from their orbits need attention because they are not controlled maneuvers and special care should be taken in case the cargo reaches the Earth [4].

- Measures relating to geostationary orbits.

Geostationary satellites are in this kind of orbit playing a crucial role for life on Earth. Satellites of this class are located 36,000 kilometers above the Earth. Scientists have realized the importance of these orbits and for this reason have established the "graveyard orbit"[50] [4]. At the end of the life of the satellites with the last fuel left in them the geostationary satellites are carried 300 kilometers even further. In total this has happened to 140 satellites again according to the study titled "Will space run out? The problem of orbital debris and its mitigation" [4]. The big problem, however, is found in low-altitude orbits, as there are fragments larger than one centimeter that have come from

[49]Arianespace.com

https://www.arianespace.com/wp-content/uploads/2016/10/Ariane5-users-manual-Jun2020.pdf

[50]ESA:

https://www.esa.int/ESA_Multimedia/Images/2008/03/Mitigation_scenarios_Graveyard_orbit_300_km_above_GEO explosions and collisions, as shown in the next image. Figure 19, according to each scenario numbered 1, 2, 3, 4, the space debris resulting from explosions are distinguished in white and the debris resulting from collisions in gray. The cases concern debris with a size greater than one centimeter in the low orbits. The y -axis refers to the amount of debris while the x -axis refers to each incident.

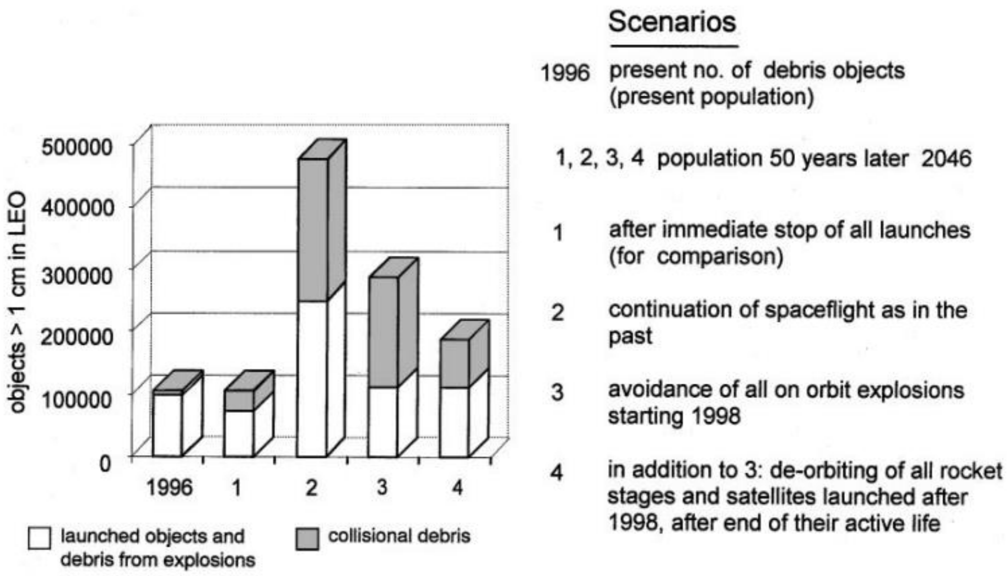

Figure 21: Effectiveness of strategies.[51]

- Government measures.

The results of the measures will not be constructive if all states do not follow a common policy.

4.8 Preventive measures by the UN Commission COPUOS – 1999

Organizations such as the United Nations and the Inter-Agency Coordinating Committee on Space Debris (IADC) are willing to find policies that will reduce the amount of space debris and will be agreed by most states [4]. The official studies on space debris as mentioned above started in 1981. While various national and transnational organizations had started to deal with space debris such as NASA, ESA the problem was also transferred to global organizations such as the UN in order to urge the member states to sail in a common line. Therefore, each member state puts forward its proposals and if these are accepted by all the others, then there is an agreement and the proposals come into force. Should a state disagree, no further action is taken.

One of these organizations is the United Nations, specifically the Committee on the Peaceful Uses of Outer Space (United Nations on the Peaceful Uses of Outer Space). Although the committee was created on December 13, 1958, it initially did not pay much attention to studies that had been done with space debris. The organization's awareness started later when some member states proposed to start relevant discussions in 1989. Legislations related to space debris were limited in relation to space legislation (space

[51]Space Policy, Will Space Run out of Space? The orbital Debris Problem and its mitigation, article 'Mitteilungender TU Braunschweig', Carolo-wilhelmina, vol 14, Page 95-105, May 1998. [Will space run out of space? The orbital debris problem and its mitigation - ScienceDirect]

law) [52]according to the study of J M Hutagalung, C I Tobing , J Debastri , R T Amanda titled “Space Debris as an Environmental Threat and Indonesia's Demand for Prevention Regulations” [7].

- Outer Space Treaty 1967
- Rescue Agreement 1969
- Liability Convention 1972
- Registration Convention 1975
- Moon Agreement 1979

This committee, having now become aware of the problem, decided to set rules so that the member states could keep up with a common line. The proposals established by this organization in 1999 based on the report entitled "Technical report on Space Debris" are as follows [20]:

- Limiting space debris during space missions.

About 12% of today's space debris consists of items such as fasteners, deflection weights, lens caps, and other payload mechanisms. It is worth noting that the protection services have taken mitigation actions. Belts, clamps should be tied with parent bodies. Docking mechanisms can also constitute space debris if discarded after use. At the end of missions, the tethers should be retracted to avoid collisions. Space debris such as fuel, wall paint and other bits of material released during missions must be reduced.

- Prevention of splits occurring in orbits.

36% of the components used (rocket upper stages) were abandoned at the end of the missions. Many incidents have been reported by the United States of America, the European Space Agency, Russia, and China. An important measure for the limitation is also the removal of energy sources from spacecraft (batteries, propellant fuels) that can be affected by solar radiation [20]. Collisions that occur in orbit can bring a lot of debris into space. While very rare such a phenomenon with the increase in satellite systems can prove quite disastrous.

- Launch and return of space objects.

Space systems that are in low orbits at the end of their life should be removed from their orbits to mitigate the chances of collisions. The procedures that help in this case are maneuvers, controlled entry into the Earth's atmosphere and, in general, the transfer of systems to lower altitudes. Tracking systems in orbit is an important measure. This procedure is necessary because in the event of a malfunction, either reset or removal procedures should be applied.

The measures mentioned above concern the avoidance procedures. However, in addition to these, the United Nations organization has also established measures concerning the protection of space systems. These are [20]:

- Armor

The armoring systems is also a priority of the United Nations Organization [20]. Shields can be effective against particles 0.1-1 cm in size [20]. Their small size makes it difficult to track them so there needs to be preventive measures for possible collision. Shielding

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[52]UNOOCA Space Law: https://www.unoosa.org/oosa/en/ourwork/spacelaw/index.html

materials can vary from metals to ceramics. These materials have the property as soon as they encounter the space debris to break and absorb the energy of the resulting ejection.

- Collision avoidance.

Tracking systems are unable to record all small objects in space smaller than 10 centimeters in size. However, if the objects manage to be observed, collision avoidance is possible and should be used [20].

Finally, a consolidated table with the structure of the measures followed by the United Nations organization is presented below [21]:

Table 4: UN summary table of 1999 proposals.

Aggregate Preventive measures.
Limiting debris during space missions.
Preventing splits in orbits
System reset
Armor
Collision avoidance

Since the first paper for space debris released by NASA it began the problem to be taken more seriously. From 1981 to 1999 organizations gave base in gathering information about satellites and space debris. Furthermore the COPUOS proposed standards in order to stop the space debris growth. In my opinion during this period the first step for the space debris elimination became a reality as the standards from COPUOS, the information gathering and the preventive steps shows that the space debris problem is started to gain more attention. Important actions during the period 1981-1999 for the space debris problem is COPUOS standards in 1999, the tracking actions, the prevention strategies in 1998, and the study of the United States of America 1991 and of course the management of outer space in 1994.

5. NEWER SPACE DEBRIS PREVENTION MEASURES 2000 - 2010.

5.1 Introduction

In the section, reference will be made to all the measures and standards carried out between 2000 and 2010. In particular, the standards of the European Space Agency regarding the mitigation of debris, the actions carried out by the United Nations, the standards from the organization IADC as well as new efforts by various countries and organizations will be presented. Not all efforts are the same, but the main thrust remains the same and that is to mitigate space debris in order to continue space missions.

5.2 The European Space Agency report and mathematical models 2002

In 2002 the European Space Agency published a detailed report on space debris from R. Walker, C. Martin, H. Stokes, J. Wilkinson, H. Dunnus, S. Hauptmann , P. Beltrami , P. Klinkrad entitled “Update of the ESA Space Debris Mitigation Handbook” [22]. This study mainly included all the main body around the space debris starting from their environment, their effect while finally closing with the preventive measures. Taking space debris mitigation documents from other existing NASA mitigation documents safety standard [53], Draft European Space Debris Mitigation & safety standard [54], RASA Branch Standard – Space Technology Items [55], was able to conclude to the 5 basic principles of mitigation [22]:

- Reduction of debris generated during shipments.
- Prevention of system explosions.
- Reducing segregation.
- Conflict avoidance.
- Disposal of space systems after missions.

The report placed great emphasis on disposal procedures, collision avoidance, and spacecraft protection.

Dismissal of space systems: Crowding of satellites into low-main orbits can increase the chances of collisions. Therefore, there should be a limitation on their stay time. The upper limit discussed worldwide is 25 years [22]. Such lifetime limitations could apply to future plans as well. The orbital lifetimes of space technologies as well as the upper stages can be determined by the parameters (atmospheric resistance, solar radiation pressure, lunar-solar disturbances). Maneuvers can be used when the satellite needs to lower the height of its orbit. Either chemical or electronic engines are used for maneuvers and always a) defining maneuvers according to post-mission lifetime b) defining maneuvers for different altitudes of low orbits. The next image shows for each orbit type

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[53]NASA.GOV: https://ntrs.nasa.gov/citations/19960020946

[54]F.Alby, D.Alwes, L.Anselmo, H.Baccini, C.Bonnal, R.Crowther, W.Flury, R.Jehn, H.Klinkrad, C.Portelli, R.Tremayne-Smith, The European Space Debris Safety and Mitigation Standard, Advances in Space Researcher, Darmstadt Germany, vol 34, Page 1260 - 1263, 10.106/j.asr.2003.08.043 , August 2001. Microsoft Word - 3sdc_paper_cro (esa.int)

[55]RASA BRANCH STANDARD: https://conference.sdo.esoc.esa.int/proceedings/sdc5/paper/62

the actions that set various standards based on the study titled "Update ESA 's Space Debris Mitigation Handbook."

	LEO	12hr circular MEO	GTO ($H_p < 2{,}000$km)	GEO
NASA	• Direct retrieval within 10yrs. • Re-entry within 25yrs. • Re-orbit so that: $H_p > 2{,}500$km and $H_a < 35{,}288$km.	• Re-orbit so that EITHER: a) $H_p > 2{,}500$km and $H_a < 19{,}900$km, OR b) $H_p > 20{,}500$km and $H_a < 35{,}288$km.	• Re-orbit so that: $H_p > 2{,}500$km and $H_a < 35{,}288$km.	• Re-orbit above GEO by a distance, $\Delta H1$: **300km + (1000 × A/m)km**
CNES & Draft EDMS	• Direct re-entry. • Re-entry within 25yrs. • Re-orbit so that: $H_p > 2{,}000$km and $H_a < R_{GEO} - \Delta H2$ km.	• Direct re-entry. • No requirement for disposal manoeuvre.	• Direct retrieval. • Re-entry within 25yrs. • Re-orbit so that: $H_p > 2{,}000$km and $H_a < R_{GEO} - \Delta H2$ km.	• Re-orbit above GEO by a distance, $\Delta H2$: **235km + (1000 × C_R × A/m)km**
NASDA	• Direct retrieval. • Re-entry within 25yrs. • Re-orbit so that: $H_p > 1{,}700$km (preferably 2,500km).	• Re-entry within 25yrs. • Re-orbit so that EITHER: a) $H_p > 1{,}700$km and $H_a < 19{,}900$km, OR b) $H_p > 20{,}500$km and $H_a < 35{,}288$km.	• H_a of upper stages should be reduced to $< H_{GEO}$ - 500km within 25yrs.	• Re-orbit above GEO by a distance, $\Delta H3$: **200km + (0.022 × a × C_R × A/m)km**
RASA	General requirement to reduce orbital lifetime of spacecraft or booster module after EOL.			• Re-orbit above GEO by a distance: **> 200km** (taking account of the evolution of the space vehicle from various orbital perturbations).
US Gov.	• Direct retrieval as soon as practical after EOL. • Re-entry within 25yrs. • Re-orbit so that: $H_p > 2{,}000$km and $H_a < 19{,}700$km.	• Re-orbit to one of the following disposal zones: a) $H_p > 2{,}000$km and $H_a < 19{,}700$km, b) $H_p > 20{,}700$km and $H_a < 35{,}300$km.	• Re-orbit to one of the following disposal zones: a) $H_p > 2{,}000$km and $H_a < 19{,}700$km, b) $H_p > 20{,}700$km and $H_a < 35{,}300$km, c) $H_p > 36{,}100$km.	• Re-orbit ~300km above GEO so that **$H_p > 36{,}100$km.**

Figure 22: Summary of discard options[56]

Collision Avoidance Assessment: Collision avoidance occurs when the connection of a space debris and a satellite system is to exceed a threshold value. If this happens, an evasive maneuver must be implemented. The time of encounter, warning before an event plays a decisive role, for this reason 2 avoidance strategies have been defined. A) short-term strategy (increasing the separation distance) B) medium-term strategy (increasing the separation distance along the path through several small maneuvers along the trajectory of the turns of the space system) [22].

Protection of vessels: In space there are space debris [57]with sizes smaller than 0.1 mm, 0.1-10 mm and larger than 10 mm [22]. Usually, an object of size 0.1 mm is not a danger, but in space there are clusters of such particles that cause damage to the walls. The shielding that should be present is that of multiple walls. Protection depends on many factors of the particle (mass, velocity, shape). Current technology provides protection for particles one centimeter in diameter. Shields that should be used are Whipple shields, multiple shock shields, and double bumper mesh shields. Finally, the methodology for impact risk assessment resulting from the study entitled "Update of the ESA Space Debris Mitigation manual" is highlighted. The arrows also show the sequence that must be followed [22].

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[56] R. Walker, C.Martin, H.Stokes, J.Wilkinson, H.Sdunnus, S.Hauptmann, P.Beltrami, P.Klinkrad, Update of the ESA Space Debris Mitigation Handbook, Reference QINETIQ/KI/SPACE/CR021539, July 2002. https :// nebula . esa . int / sites / default / files / neb _ study /423/ C 14471 ExS . pdf

[57]NASA.GOV: https://www.nasa.gov/mission_pages/station/news/orbital_debris.html

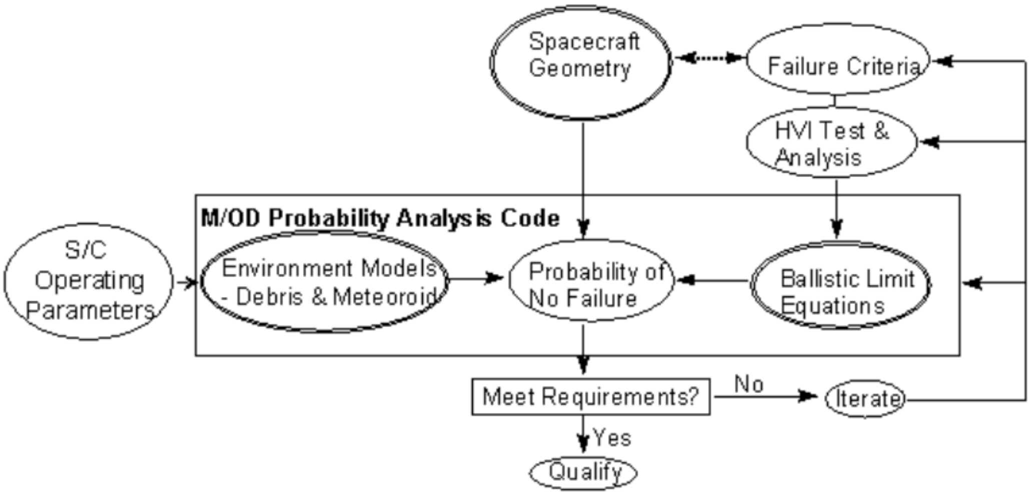

Figure 23: Risk Assessment Methodology[58].

There are models for estimating energy release. The main ones are focused [23]:

- Combustion of polydisperse sprays in weightlessness.

Due to an ignition of the residual fuel after a breakdown the mixtures in the tank are in random dispersion patterns. The release of energy during combustion does not depend on the total mass of the fuel but on the mass of the fuels entering the reaction. Therefore, the mathematical models developed make use of a probability density function and are used for particles that allow for both gas-phase and heterogeneous modes of reaction.

- Diffuse combustion of hyperbolic propellants [59]in random mixing of components during joint diaphragm piercing.

Hyperbolic gases are among the most dangerous because their flash points are very low. Their chemical reaction starts immediately when they come into contact with another propellant. Therefore, a limiting factor is the mixing rate of the propellants. Consequently, when the mixing rate is low the percentage of energy released is not considered dangerous.

- Explosion of the mixture in the propellant tanks.

Combustion of mixtures can be achieved either by ignition or by explosion. During the explosion the velocities of the particles are very high. Consequently, different dissolution scenarios are observed, and reference should be made to the maximum loading pressure of the propellants as well as its timing.

Therefore, when an explosion occurs in space it is difficult to pick up the location of the fragments in the space field. Hence, efforts are being made to develop mathematical models in order to predict the center of gravity of the particles, their velocities and their possible positions after the explosion [24].

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[58] R. Walker, C.Martin, H.Stokes, J.Wilkinson, H.Sdunnus, S.Hauptmann, P.Beltrami, P.Klinkrad, Update of the ESA Space Debris Mitigation Handbook, Reference QINETIQ/KI/SPACE/CR021539, July 2002. https :// nebula . esa . int / sites / default / files / neb _ study /423/ C 14471 ExS . pdf

[59]Hypergolic propellant is the propellant whose components react instantaneously.

5.3 Preventive Measures of the Inter Agency Debris Committee - 2002

The United Nations Organization had already begun to show interest in the issue of space debris since the beginning of 2000. Another multilateral organization called IADC (Inter Agency Debris committee)[60] [25]. This Organization consists of various organizations such as ASI, CNES, CNSA, CSA, DRL, ESA, ISRO, JAXA, KARI, NASA, ROSCOSMOS, SSAU, UKSA. The main objective of this organization was to protect the space environment at the lowest possible cost. Accordingly, it established rules and legislations so that all member states are on a common line. These measures were recognized in 2002 at the second meeting of the world congress on space in Texas, United States. The main body of the organization's rules is based on the following 4 [26]:

- Precautionary measures involving hazardous materials that pose a risk of explosions and orbital fissions.
- Removal of satellite systems at the end of their missions.
- Limiting the objects released into space.
- Avoiding conflicts.

In this way, the agency established a plan that includes a) mitigation of space debris b) risk mitigation plan c) plan related to the possible malfunctions that may occur d) disposal of space systems e) justification of each option when there are many alternatives g) compliance plan. The standards established by the organization are [26], [27]:

- Limiting space debris during missions.

Space vehicles must be designed in such a way that their parts do not detach. A space mission that does not follow this standard should not be planned at all. The risks that may arise must also be considered. The importance of this measure results from the fact that a 7% percentage of space debris consists of covers, lids, and various payloads. Special attention 1) Pieces of metal can be released into space but in low orbits, 2) Attention to lifetime - less than 25 years, 3) necessary committee to control each action, 4) More research on paint wall coverings, 5) More study on the pros and cons of bonds.

- Limitation of possible explosions occur in orbits.

For this to happen the removal of energy sources (batteries, propellants, high pressure vessels, feedback wheels) is necessary. For this measure the organization has mentioned more detailed actions [27]such as: 1) Thorough removal of energy sources from spacecraft, 2) Batteries must be redesigned and finally the charging lines must be disabled, 3) High pressure vessels must ventilate. ATTENTION to any leaks as well as the heat systems. In the event that the spacecraft contains high pressure systems [61]and adjustable pressure vessels, you should: a) use a blow system down (tank pressure to be less than average vessel pressure), b) bladder tanks (Tank and fuel gases are separate), c) Leak design before burst[62] [28]used by many countries. 4) Attention to the

[60]IADC: https://www.iadc-home.org/what_iadc

[61] Working Group 4, Support to the IADC Space Debris Mitigation Guidelines, Inter Agency Space Debris Coordination Committee, IADC-04-06 Rev. 5.8, June 2021. IADC-04-06_Support_to_IADC_Guidelines_Rev5_8.pdf

[62]IAEA: https://www-pub.iaea.org/MTCD/Publications/PDF/te_710_web.pdf

breakdown systems, 5) Termination of the energy of the flywheels, 6) In case energy is used beyond the known techniques, a list with all the elements is necessary.

- Reducing chances for possible splits.

Before any mission planning it is necessary to have a failure plan. Continuous monitoring of systems is a necessary process as well as remedial measures.

- Avoiding intentional acts of destruction as well as other actions that are harmful. In case it is not possible, destructive actions should occur at low altitudes.
- Entry of satellite systems into protected orbits.

Moving towards the end, the satellites should transition to safe orbits that do not pose a risk to other active systems. According to a study by the organization itself, this will be done by: A) a gradual increase of the perigee

$$235 \text{ kilometers} + (1000 \times C_r \times A / m) \quad (1)$$

where Cr is a coefficient of solar radiation with a range of values from [1.2 – 1.5], A / m is the ratio of the surface to the mass of the structure. The 235 kilometers results from the 200 kilometers which is the upper altitude and the 35 kilometers the maximum descent of the spaceship. B) The eccentricity ranges at a value of 0.003. These options aim to make the spacecraft stay as long as possible in the protected areas (ideally 100 years). Figure 22 shows the minimum increase at the perigee [27].

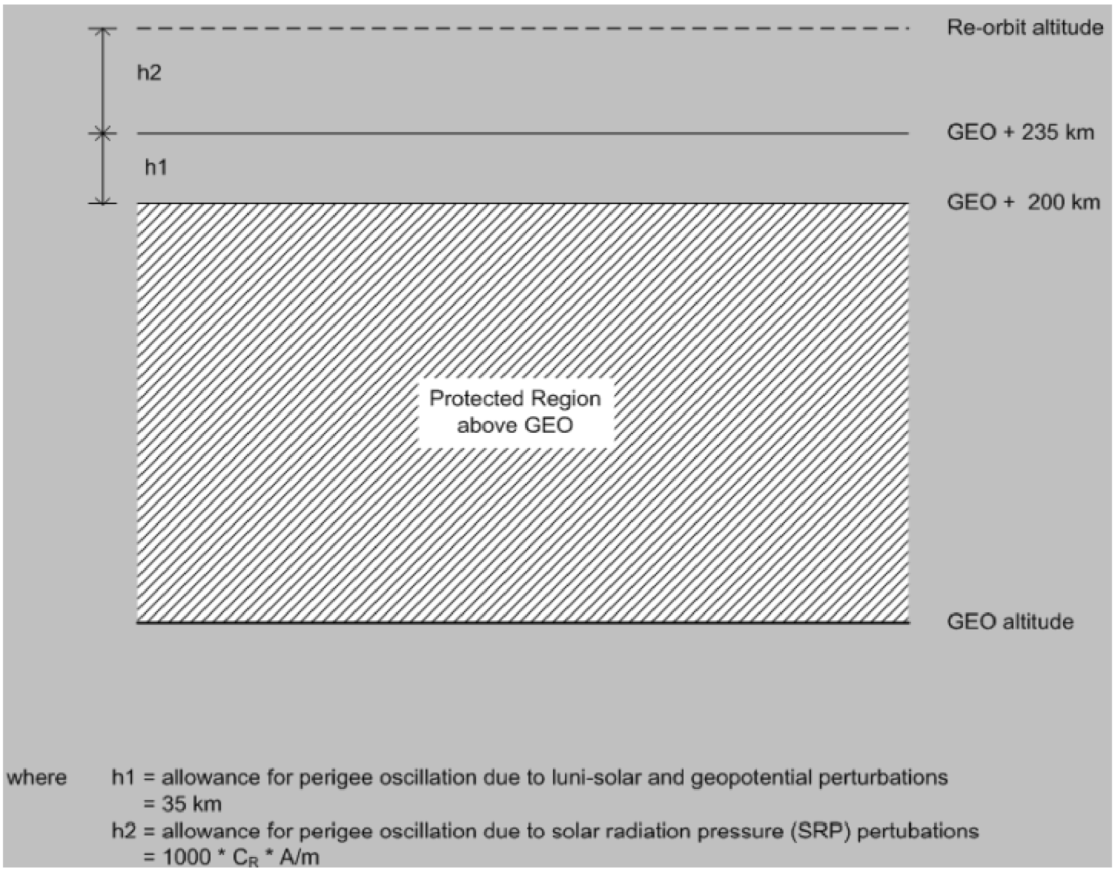

Figure 24: Increase of Perigee.[63]

In this rule there are some observations: 1) The eccentricity is not a sufficient and necessary condition to drive the spacecraft into the protected area unless its value is appropriately limited, 2) In case that the eccentricity value is less than 0.003, the protected area is not violated, 3) if the eccentricity has a value greater than 0.003, all other cases should be studied, 4) The sun can create a stable orbit due to solar pressure [27].

- Confinement of spacecraft to geosynchronous orbits.

For the above measure concerning the protection of the geostationary orbits, earlier studies had been done in 1988 [29]. The two sessions held at the ITU conference WARC ORBs [64]were related to the hazards that inactive bodies would pose to active systems in geostationary orbits.

- Maneuver the systems that pass between the low-spec orbits so that they do not interfere with existing systems.
- Special attention to the pieces that reach inside the Earth. They should not pose a risk of contamination to the environment. Activities involving this risk should be prevented and terminated immediately.
- Avoiding conflicts.

[63] Working Group 4, Support to the IADC Space Debris Mitigation Guidelines, Inter Agency Space Debris Coordination Committee, IADC-04-06 Rev. 5.8, June 2021. IADC-04-06_Support_to_IADC_Guidelines_Rev5_8.pdf

[64]ITU WARC ORB: https://www.itu.int/en/history/Pages/RadioConferences.aspx?conf=4.111

In fact, this rule includes the following actions: 1) Assessment of possible collisions from the design stage of the spacecraft, 2) Continuous monitoring throughout the mission phase, 3) If it is necessary to carry out maneuvers to avoid collisions whether crewed or not.

These regulations have been developed by the IADC to protect the space environment from space debris. There may be other regulations with minor differences, but they will all move around the same trunk.

5.4 European Debris Mitigation Preventive Measures/Measures to Strengthen an International Regime – 2004

Space debris quickly affected the entire space community. The seriousness of the situation affected members from the bodies ASI, ESA, BNSC, CNES, DRL resulting in the creation of the so-called European Community Debris Mitigation Standard Working Group [65]. This community proposes a plan by which if certain rules are followed the problem of space debris will be mitigated [5]. The measures that were given weight are the following:

- Process and Organization: To address the space debris problem it is necessary to have a design management plan and an operational plan including space debris mitigation assessment.
- Management Procedures: Refers to all rules and procedures that provide safety for space missions.
- Design requirements as well as operational requirements: In this case it is highly necessary to take all the measures related to the propellants as well as the measures related to preserving the life of the vessel in the event of a collision. Finally, measures should be taken such as the disposal at the end of the operation of a space system.
- Extra care should be given at the protected from space debris areas.

Space debris rules can have results. In addition to them, it is necessary to have a regime that will coordinate all states and organizations. The actions that should be followed are the following [11]:

- Adoption of the regulations established by the United Nations and the IADC committee.
- Integration of space debris into international space law.
- Update of all information held by the United Nations Organization.
- International collaborations between the United Nations and the Telecommunications Organization - ITU [66].

Therefore, global cooperation and the adoption of rules on space debris is what will bring results in the future of space missions.

[65] https://nebula.esa.int/sites/default/files/neb_study/423/C14471ExS.pdf

[66] ITU.INT: https://www.itu.int/en/un/Pages/un-agency.aspx

5.5 Innovations and standards 2005-2006

According to the American study by N. L Johnson titled "Orbital Debris Research in the United States", space debris poses 2 categories of hazards [30]. One case is when collisions occur between them, and the other category is collisions and the results that end up inside the Earth. These reasons led NASA to create a model called LEGEND[67] [30]with which the probability of a collision is determined as well as the consequences are predicted. Most missions have conflicts. So, it was a useful tool. Another forecast model developed by NASA was the so-called BUMBER - 2 [68]. The model combines the probability of collision with the vulnerability of the spacecraft. Thus, it gives the possible damage that the boat may suffer in the event of a collision. This model also calculates the potential damage that the vessel's heating systems may suffer. The use of the program is based on the so-called Finite Analysis Model which is a material strength program. Space debris that reaches the Earth's surface also began to pose a danger. A model developed by NASA named ORSAT [69]– Object Reentry Survival Assessment Tool predicted for a construction the possible materials that may reach the surface of the Earth given a construction [30].

In the same year, the United Nations held a conference on "Transparency and Confidence - building measures in outer space activities » [70]. In this conference, it was argued that the existence of weapons, in addition to creating space debris, also degrades international peace and trust among states. For this reason, the United Nations proposed proposals such as [31]:

- It calls on member states to establish rules and procedures for international peace and cooperation between states.

In 2006 the European Space Agency published a prevention standard for not producing space debris from D. Danesy, titled “Space Debris Mitigation Position Paper Implementation of Zero Debris Generation Zones” [32]. The standard procedure refers to the following solutions:

- Preventive measures for the spacecraft.
- Precautions for launchers.

The **preventative measures for the spacecraft** are:

- Mission planning

In order to avoid space debris, it is important to limit the lifetime of the spacecraft. An effective way of containment is to remove it from space at the end of its mission.

- Design Material design

[67]Orbital Debris LEGEND: https://orbitaldebris.jsc.nasa.gov/modeling/legend.html

[68]NASA.GOV: https://www.nasa.gov/centers/johnson/techtransfer/technology/MSC-23774-1-bumper.html

[69]Orbital Debris: https://orbitaldebris.jsc.nasa.gov/reentry/orsat.html

[70]United Nations: https://documents-dds-ny.un.org/doc/UNDOC/GEN/N05/491/56/PDF/N0549156.pdf?OpenElement

To prevent orbital decays the forms of energy storage (batteries, high pressure vessels, propellants) should be made passive. Particular attention [32] to 1) bi-propulsion systems, 2) Combined propulsion systems, 3) Ventilation pipes so they do not freeze, 4) Adoption of expansion mechanisms.

- Avoiding collisions with maneuvers.
- Removal of satellite systems after the end of their mission.

Preventive measures for launchers are:

- Use of the rules established by the United Nations Organization and by the IADC.
- Launchers' Passivation: The propellant and thruster should be discarded after using their mission.
- Limitations and lifespan of orbits. In this case the 25-year lifetime rule should be used in order to protect the orbits from space debris.
- Re-entry: The reality of this measure is different because in this case there must be great precision about the impact area.

What is certain is that the measures that have been put in place can mitigate the situation regarding space debris. However, in addition to the measures, international cooperation from all member states and the adoption of correct behavior in space missions is also needed.

5.6 Militarization of Space and Canada's Position 2007

The opportunities provided by space are social and economic, according to Wade 's study L Huntley titled "Smaller States Perspectives on the Future of Space Governance" [33]. The great powers do not take long to understand its importance and for reasons of security they tend to use weapons for global domination as well as in the air, land, and sea. Smaller but important countries such as Canada have declared their opposition to the militarization of outer space, having themselves experienced the effects of Russian nuclear debris entering their atmosphere. In 1978 a Soviet satellite powering its RADAR from a nuclear reactor crashed on Canadian soil and spewed dangerous highly enriched uranium over a wide area [71]. Although the Soviet Union never admitted guilt, Moscow paid a $3 million settlement for cleanup costs.

The cooperation of the United States of America and Canada started in the past where together they formed the North American Aerospace Defense Command - NORAD[72] [33]. In fact, Canada's position of not wanting the militarization of space and its choice to play the role of mediator between the United States and Russia so they can find a common line, made it distance itself from the United States in the past. However, their relations resumed with the construction of the International Space Station in 1984. Today, collaborating with ESA and as an active member of the United Nations organization, he supported the non-militarization of outer space [33]because, apart from undermining peace, the existence weapons can lead to the production of space debris. Still in 2007, a

[71] James Clay Moltz , Crowded orbits, Conflict and Cooperation in Space, Columbia University Press New York, 2014

[72]NORAD: https://www.norad.mil/

committee called PAROS was created by the UN[73] whose purpose was to prohibit the existence of weapons in space. In fact, in the same year, the country of Canada presented to the UN the Canadian rules of space remote sensing for the mitigation of space debris [34], [35]. They are:

- Methods of removing satellite systems and the reliability of these methods.
- To calculate the operation of the satellite systems.
- Calculation of the probability of loss of human life as well as the presentation of the solution.
- The amount of debris that will reach the surface of the Earth, the size of the impact expressed in square meters, and how the calculations were made.
- Calculation of confidence levels.
- The identification and quantity of hazardous materials – goods contained in each satellite, the quantities estimated to reach the surface of the Earth as well as how the calculations were made.
- The orbital elements and epochs of the assigned orbits for each satellite.
- An artificial report on space debris estimated to be released during space missions, from potential explosions, from collisions, and mitigation measures.

The rules for minimizing potential space debris at the end of a mission based on the Canadian manual are [34]:

- Compliance based on the rules of the International Telecommunication Union - ITU [74].
- Radio communications regulations.
- Canada's spectrum usage policies.

Finally, the rejection plans for a satellite are:

- Removal of the energy stored in the propellant tanks (propellants – batteries – feedback wheels).
- Using the remaining propellants to move the satellite system into lower orbits.
- Beware of evasive maneuvers.

5.7 ISS Preventive measures 2007

The International Space Station is the first crewed spacecraft to be developed considering the micrometeoroids and orbital debris as a high priority. NASA, ESA and JAXA designs are different but follow the same principals which are the multiple layers of an outer shell, multiple layer insulation, Kevlar, and an inner pressure shell. All these designs are used for preventive measures. The NASA'S report for the ISS with title "Final Report of the International Space Station Independent Safety Task Force", 2007 present the design requirements for micrometeoroids and orbital debris which are [36]:

- ISS catastrophic penetration probability requirement of less than 5% over the design life (15 years) of the ISS program. This equates to a probability of no critical penetration of 0.95.

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[73] PAROS: https://www.nti.org/education-center/treaties-and-regimes/proposed-prevention-arms-race-space-paros-treaty/

[74] ITU.INT: https://www.itu.int/en/un/Pages/un-agency.aspx

- ISS shielding penetration requirement of less than 24% over 10 years. This equates to a probability of no penetration of 0.76.
- The development of designs to reduce hardware failure rates.

Furthermore the ISS has implemented operational procedures to avoid and recover from the micrometeoroids and orbital debris damage including the following:

- Flying spacecraft altitudes in order to protect the most vulnerable portion of the spacecraft. Worth noting that this function is limited due to mandatory and thermal constraints.
- Providing range of leak and repair capabilities which are continually improving.
- Procedures for maneuvers to avoid collisions with space debris that can be tracked with ground radars (pieces greater than 10 centimeter). Space debris with a small size still can be a threat for catastrophic damages.

ISS is the most complicated structure that in Space by the mankind. Space debris has led NASA and other organizations who participate in the ISS design to make preventive measures for keeping it safe from space debris. Although ISS uses maneuvers for avoiding purposes small space debris can be a threat. The next figure presents the ISS.

Figure 25: ISS structure.[75]

[75]NASA, 'Final Report of the International Space Station Independent Safety Task Force', February 2007, https://www.nasa.gov/pdf/170368main_IIST_%20Final%20Report.pdf

5.8 Europe's active role and policy in space activities 2008

The European Parliament with its Resolution of 10 July on space and security (2008/2030(INI)) 2009/ C. 294 E /16 requests [37]:

- To strengthen the international legal regime for the regulation and protection of non-aggressive uses of outer space and the strengthening of TCBMs , in the context of drawing up guidelines for the mitigation of space debris by the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) which must be consistent with the activities of the Interagency Coordinating Committee on Waste, as well as with the preparation by the United Nations Conference on Disarmament of a multilateral agreement to prevent a space arms race. It also requests the presidency of the European Union to proactively represent the European Union in COPUOS. It therefore calls on the institutions of the European Union to promote a conference on the revision of the Outer Space Treaty, with the aim of strengthening and extending its scope to the prohibition of all weapons in the space domain.
- It applauds the efforts of the International Academy and Astronautics and the International Union for the Promotion and Safety of Space, to promote the remediation, understanding and measures in relation to space debris.
- It supports the creation of a European space surveillance system that will lead to the surveillance of the situation in space in order to control space infrastructure, space debris and other threats from space.

On December 17, 2008, the role of the European Union becomes more active in space activities, as concern begins about possible effects on its programs. The increasing risk of collisions with other satellites and with space debris is typically considered to be the most serious threat to the space arm of the Copernicus programme [76]. In particular, there is an awareness of space debris and regulations are being issued to limit it. According to the European Union meeting entitled "Council Conclusions and Draft Code of Conduct for Outer Space Activities", they are [38]:

- Member States must have national policies to prevent accidents and collisions. Space is a space with advantages as long as there is teamwork.
- Each member state to refrain from activities that bring about disastrous results. Should such an action occur, measures must be in place to mitigate the residuals.
- Rules and procedures aimed at reducing space technologies.
- Maneuvers should be accompanied by protective measures to mitigate debris.
- The standards of space activities emanating from each state must be long-standing.
- Avoidance of activities that produce space debris with a long stay in outer space.
- Adoption of the rules and procedures derived from the United Nations Organization aimed at the peaceful use of space.
- Update after a maneuver, satellite orbit change, re-entry of a satellite and malfunctions that may occur.

[76] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing the Copernicus program and repealing Regulation (EU) No 911/2010 /* COM /2013/0312 final - 2013/0164 (COD) */ 52013 PC 0312.

The study by Marta Lucia was related to finding a common space policy in Europe [39]. In Europe, the institutions dealing with space activities are the European Union and the European Space Agency [77]. These are 2 different organizations with different goals and policies. The purpose of this study was to find a balance line between these 2 organizations and make them sail in a common line. The reason this happens is that because of the differences the 2 organizations have, they lead Europe to cumbersome decision-making processes. The European Space Agency has technical as well as political skills enabling it to manage complex space programs that benefit the European Union. It also targets research and development programs that are clearly research and not defense military in nature. Due to its government procurement, it becomes a magnet for many major space agencies and is primarily an intergovernmental organization. The European Union on the other hand manages complex systems such as GMES [78], Galileo [79]. Although following an upward trend in space technologies the European Space Agency is not ready to incorporate its principles [39]. The European Space Agency shows difficulties in a common policy while, on the contrary, the European Union has the right status to represent space interests on the international stage.

5.9 Active role of United Nations and policy in space activities 2008-2009

As early as 2007 in its resolution 62/217 of December 22, the UN General Assembly endorsed the Committee on the Peaceful Uses of Outer Space [80]guidelines for debris mitigation and agreed that the voluntary space debris mitigation guidelines reflect the existing practices as developed by various national and international organizations and invited Member States to implement the said guidelines through the relevant national mechanisms.

In 2008, specifically on February 29, the role of the United Nations began to become more active. Specifically, a session was held with subject "Treaty on Prevention of the placement of weapons in outer space and of the threat or use of force against outer space objects" where the Russia and China, they presented them their suggestions [40]. These are the following:

- The term weapon means any device placed in space that can cause destruction or disrupt the functioning of objects and wipe out the population of Earth. It is considered to have been placed in space if it is in orbit around the Earth, in a part of the orbit or generally exists in space. Finally, the use of force means disrupting the operation of space systems or, more generally, some destruction in space.

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[77]ESA & European Union: https://www.esa.int/About_Us/Corporate_news/ESA_and_the_EU

[78]GMES: https://www.esa.int/About_Us/Ministerial_Council_2012/Global_Monitoring_for_Environment_and_Security_GMES

[79]Galileo: https://www.esa.int/Applications/Navigation/Galileo

[80]COPUOS, Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space: https://www.unoosa.org/pdf/publications/st_space_49E.pdf

- Member States commit not to bring into outer space - celestial bodies weapons that can disturb the balance or not to participate in such actions.
- Each state undertakes the responsibility to prevent such actions on its territory or from some of its jurisdiction.
- With the aim of promoting global peace and trust, Member States implement agreed building measures on a voluntary basis.
- In case of disagreement between the states, they consult with the aim of resolving the disputes through negotiations and cooperation. If there is no agreement, a member state refers the situation to the relevant competent body. Also, each member state must cooperate.
- International governmental organizations may participate in the treaty.
- Any state can propose amendments and, with the help of the responsible body, be distributed to the other member states. If there is agreement, then the amendment applies .

And in this session, there was no unanimous agreement between the member states. Therefore, the UN did not proceed with any of them. Overall, the principles adopted by the UN general assembly based on the model entitled "United Nations and principles in outer space" have to do with [41]: 1) With the declaration of the legal principles governing the activity of countries for the peaceful use of outer space, 2) Principles related to remote sensing of the Earth, 3) Principles related to the use of nuclear energy in space, 4) The international cooperation of countries for the use of outer space for the benefit of states, taking into account developing countries. But based on all these resolutions adopted by COPUOS are: 1) Resolutions 1721 A and B (XVI) of December 20 , [1961] – International cooperation for the peaceful uses of outer space, 2) Paragraph 4 of resolution 551122 of 8 [1] December 2000 – International Cooperation in the Peaceful Uses of Outer Space, 3) Resolution 591115 of 10 December 2004 – Application of the concept of “launching state”, 4) Resolution 621101 of 17 December 2007 – Recommendations to strengthen the practice of States and international governmental organizations for the registration of space objects.

Since the topic "National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris” [42] has entered the agenda and is discussed annually by the countries within the framework of the COPUOS committee in 2009 national positions were presented by the countries Germany, Italy, Japan. From Germany were presented results from experiments related to collisions of micro particles with speeds reaching 10 kilometers per second. Italy demonstrated maneuvers it carried out to avoid collisions with its space systems. Of particular interest is the country of Japan, which decided to deal with the protection of space missions from space debris as well as the protection of the environment. The development of new sensors will help track debris especially those in geostationary orbits. Finally, the JAXA space station monitors the space debris every day, while at the same time he emphasized that importance should also be given to their removal.

In January 2009 in Budapest, a conference was held on how best to structure European space governance. A total of 4 sessions addressed the topic. The following emerged from the sessions [44]:

- Upgrade of the European programs Galileo [81], GMES[82]

The study carried out by Sebastian Rieder, Jean Bruston, Charlotte Mathieu, Kai - Uwe Schrogl entitled "Governance of national space activities" reported that through a speech made by Mr. Dordain emphasized the governance of the space programs Galileo, GMES. Political and regulatory measures had to be set up for the Galileo program in order for the agency to have access to satellite handling services. For the GMES program it was necessary to define a legal framework as well as an action plan identifying the relevant bodies with all their responsibilities.

- Awareness of space exploration and status.

In the sessions that followed, the European Space Agency's need for a Space Situational Awareness Tracking System [83]was highlighted. Europe's space agencies must have such a system in place in order to control problems caused by space debris and solar flares but also with the security of the organization in general. ESA once a month maneuvers satellites and this happens over the United States. Priority must therefore be given to defining a governance model.

Another conference came to improve the situation, on June 5, 2009, where Canada's laws-regulations followed in the UN regarding issues of proposals for trust and space security. The measures and proposals presented are [45]:

- Ban on the use of anti-satellite weapons. The amount of space debris increases from such activities. Even the abandonment of debris in space signals the detonation of space debris because collisions of satellites with them are increasing.
- The continuous increase in technology has led states to be equipped with defensive missile mechanisms. Therefore, the need to prevent weapons of mass destruction has been transferred to the issue of space security.
- Since there are regulations regarding the re-entry of satellites into the Earth's atmosphere, an agreement involving all states would be preferable for better security.
- No state will attempt to use anti-satellite weapons on a satellite.
- In the future, new rules and behaviors will have to be created in order for space activities to continue safely and peacefully taking into account the advances made in weapons. Therefore, there must be security guarantees from the United Nations Organization dealing with space activities.
- Support from the new US government to take on leadership issues related to banning weapons that interfere with the military and advertising satellites.

[81]Galileo: https://www.esa.int/Applications/Navigation/Galileo/What_is_Galileo

[82]GMES:

https://www.esa.int/About_Us/Ministerial_Council_2012/Global_Monitoring_for_Environment_and_Security_GMES

[83]SSA program overview: https://www.esa.int/Safety_Security/SSA_Programme_overview

5.10 Active Europe /America role and policy in space activities 2009

In the same year, awareness on the issue of space debris also emerged from the European Union. This also results from the fact of the reformormation of European governance, as Alain Gaubert, Andre Lebeau's study entitled "Reforming European Space Governance" [43]. Europe wants to know the big players, its strengths, as well as its weaknesses. Her growing interest in space activities led her to study global government spending on civilian space programs as well as global government spending on defense space programs. The amounts of money for each country that invests in space activities can be seen in the following images. Figure 23 shows the amounts of money invested for civil space programs, while figure 24 shows the amounts of money invested for defense space programs.

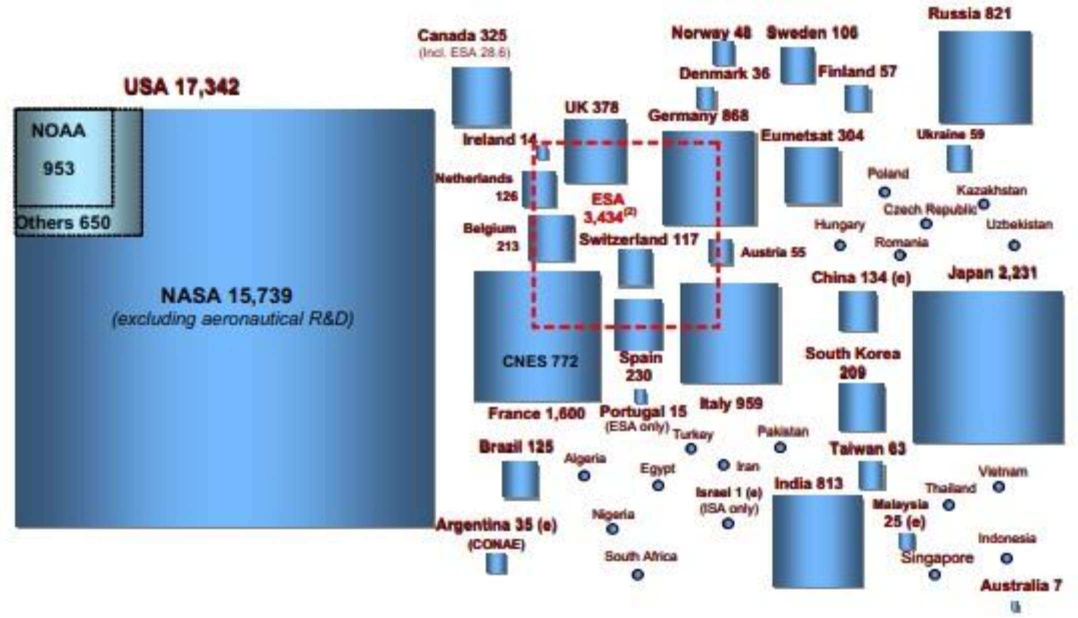

Figure 26: World Government Expenditures for Civil Space Programs 2006.[84]

[84] Alain Gaubert, Andre Lebeau, Reforming European space governance, Space Policy, Vol 25, Issue 2, pp 67-68, May 2009. https://www.sciencedirect.com/science/article/abs/pii/S0265964608001057

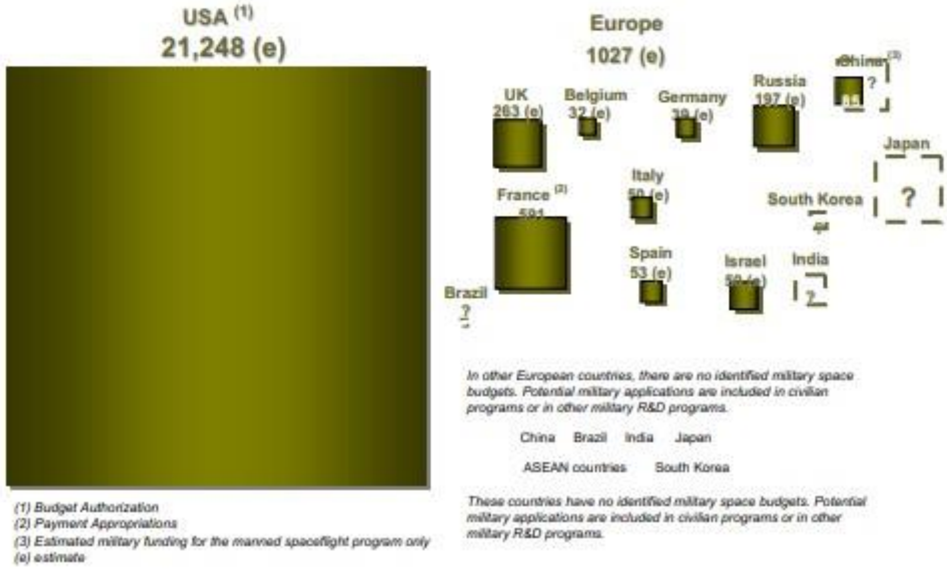

Figure 27: World Government Expenditures for Defense Space Programs 2006.[85]

Similar interest was shown by the USA. In 2010 the Obama Administration wanted to give more emphasis on space activities than the previous administration. Specifically, he dealt with 1) securing the space sector for space peace, 2) protecting space assets, 3) extracting resources from space safely [46]. These are included in the new space policy from the United States. The guiding principles for space according to the United States' 2010 National Space Policy of the United States of America are [47]:

- Development and operation of space systems and networks to ensure national security.
- Development of advanced technologies that respond to changes in the threat environment.
- Cooperation with competent departments and agencies and even foreign entities for rapid detection and warning of disturbances.
- Improving the collection of information as well as its analysis.
- Coordination for any radio frequency surveys.

Therefore, in the period between 2000-2010, several standards - regulations and government decisions were posted in order to mitigate the problem of space debris. These measures were related to the design part as well as to governmental agreements. What is certain is that a global awareness was registered to deal with the phenomenon. During period 2000-2010 IADC with standards and the European Union made a difference with their efforts to mitigate the problem. From the other hand when the problem space debris must be dealt with from all nations it is difficult, because there is not an agreement between them. For this reason all the standards and regulations it is difficult to be followed when the great nations do not agree with them.

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[85] Alain Gaubert, Andre Lebeau, Reforming European space governance, Space Policy, Vol 25, Issue 2, pp 67-68, May 2009. https://www.sciencedirect.com/science/article/abs/pii/S0265964608001057

6. MODERN MEASURES - SPACE DEBRIS MITIGATION STANDARDS 2011 - 2020.

6.1 Introduction

In this chapter, the actions and standards concerning space debris are introduced. But apart from these, great weight has been given to the decisions that prohibit the use of weapons in space since they create space debris. Decisions of the UN, studies of the European Space Agency, and decisions of the European Union play a decisive role in mitigation. The development of technology is a great asset in the limitation of space debris, but the greater burden belongs to the global awareness and cooperation of all states in order to face the problem so that space activities can continue safely.

6.2 UN Conference and the New Approach to Space Debris Mitigation 2011

On December 9, 2011, [48] the discussion on the topic of "National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris" continued in COPUOS of the UN. Japan showed some interesting studies there. These are:

- Limiting the energy produced by combustion devices. The production products should not exceed 1 mm.
- For the satellites that are in geosynchronous orbit after their re-entry, their eccentricity must be less than 0.003.
- During the operation of a vessel, the probability of breaking up has a value of less than 0.001.
- Maneuvers to be carried out with a probability of success greater than 0.9.
- Satellites intended primarily for low-grade orbits have a lifetime limit of less than 25 years.

At the same time, Japan presented technical changes concerning the re-entry of spacecrafts. These changes are related to [48]:

- Use of new fuel cylinders to repressurize fuel in rocket systems.

- Changes to the walls of the spacecraft to make them more resistant to high temperatures.
- New changes to electronic systems to minimize the possibility of downtime.
- Introduction of special algorithms to better control combustion.

Switzerland focused mainly on space debris removal methods but also on the design of special small satellites. The United Kingdom along with Ireland focused on space debris monitoring as well as various modeling programs. Finally, studies from international organizations such as Asia Cooperation Organization [86] and Secure World Foundation [87] were presented. Particularly, their own efforts were focused on monitoring but also on quick and valid warning.

A study carried out by Singer, Michael & Musacchio entitled "An International Environmental Agreement for Mitigation of Space Debris Among Asymmetric Nations" that same year [49] is of particular interest, since it argues that game theory[88] could contribute to mitigating space debris. Game theory is already used in greenhouse gases and ozone depletion to make important decisions. The model is called International Environmental Agreement (IEA) [89]and is a mathematical model. The function is: $\pi = \sum \pi_i$ where

$$\pi_i = B_i(Q) - C_i(q_i) \quad (2)$$

Each nation bears the costs $C_i$of its own abatement q_i while all nations share the harm reduction benefits of B_i global abatement Q. This model needs the following items:

- Environmental resources and pollutants.

The altitude of 900-1000 kilometers is considered an environmental resource since that is where the large load of satellites is found. In addition to that, space objects that have the potential for some collision with space objects are considered pollution. The situation will become increasingly dangerous as loads increase without some sort of removal occurring.

- Agencies and actions that affect the environment.

For a set of institutions, ownership data by nation for low-orbit spacecraft is examined, as it is actually stated in the study of A M Bradley, L M Wein titled "Space Debris: Assessing risk and responsibility, Advances in Space Research" [50].

- Assessment of the damage to the environment from space pollutants and the benefits for operators from this reduction.

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[86]Asia Cooperation Organization: https://www3.nd.edu/~ggoertz/rei/reidevon.dtBase2/Files.noindex/pdf/3/caco-info.pdf

[87]Secure World Foundation: https://swfound.org/

[88]Game Theoretic Analysis of the Space Debris Dilemma: https :// www . esa . int / gsp / ACT / doc / ARI / ARI %20 Study %20 Report / ACT - RPT - AI - ARI -15-8401- ActiveDebrisRemoval . pdf

[89] IEA: https://iea.uoregon.edu/

The model has the ability through differential equations to calculate the rates of change of spacecraft, rocket bodies as well as fragments and in this way, characterizes spacecraftσ as functional or non-functional. It also categorizes fragments as hazardous or non-hazardous. It should be noted that the damage results in the benefit function as follows:

$$\mathrm{NVP}_{\mathrm{Benefit}=\frac{1}{2}\,\text{cost of harm per spacecraft destroyed}}\ \mathrm{x}\int_0^{\infty} e^{-rt}\left[\frac{d(\text{spacecraft destroyed})}{dt}\right]dt \qquad (3)$$

The present net value of NVP is a function of avoiding the spacecraft as well as the segment destroyed.

- Estimate the cost for each factor of mitigating each damage.

Actual de-orbit costs vary especially if evasive maneuvers are included [51]. Such starships will have lower cost add-ons. But given the lack of data on shipments, it is assumed that the marginal costs are evenly distributed among them. For each nation that removes the satellite from orbit the Cost function is:

$$C_i(q_i) = \frac{C_i {q_i}^2}{2} \qquad (4)$$

Therefore, based on the study mentioned above, it appears that in the mitigation of space debris, beyond meetings of international organizations, mathematical models have also been introduced. Their calculations through differential equations are the ones that provide the solution to space systems in order to avoid collisions between satellite systems and space debris.

6.3 UN Conference and Europe's New Approach to a Common Space Policy 2012-2013

In 2012, the discussion on the topic "Nuclear space debris, safety of space objects with nuclear power source on board and problems relating to their collision with space debris" [52], continued in COPUOS of the UN. Specifically, on February 2, Japan presented a new technology which was developed for monitoring space debris. This technology would provide the ability to control space debris that would be in low and high-altitude orbits. The development of FPGA [90]electronic circuits in combination with CCD (Charge Couple Device) [91] cameras will make the detection of objects, especially those of low orbits, quicker. This system is shown in figure 28.

[90]FPGA: https://www.xilinx.com/products/silicon-devices/fpga/what-is-an-fpga.html

[91]CCD: https://www.techtarget.com/searchstorage/definition/charge-coupled-device

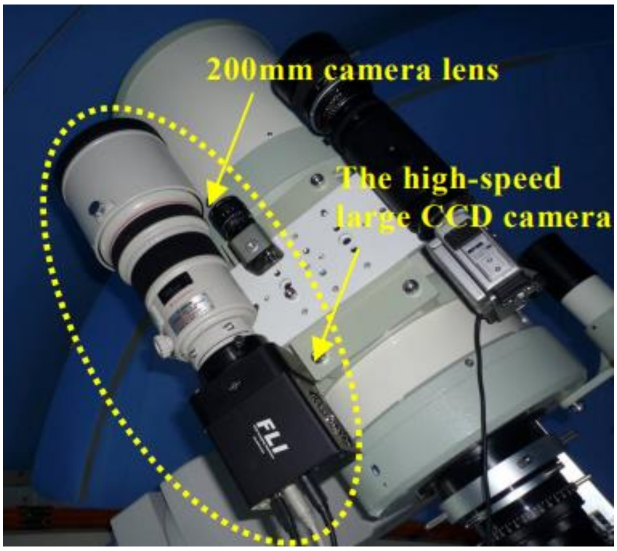

Figure 28: Surveillance system by Japan.[92]

Emphasis was also placed on the modeling between satellite systems and space debris. The software developed is called Turandot [93]and it is used for conflict modeling. The software is shown in the next image where a satellite is distinguished. A color bar is also visible to the right of the image. As they move towards the red, the material fails to collide.

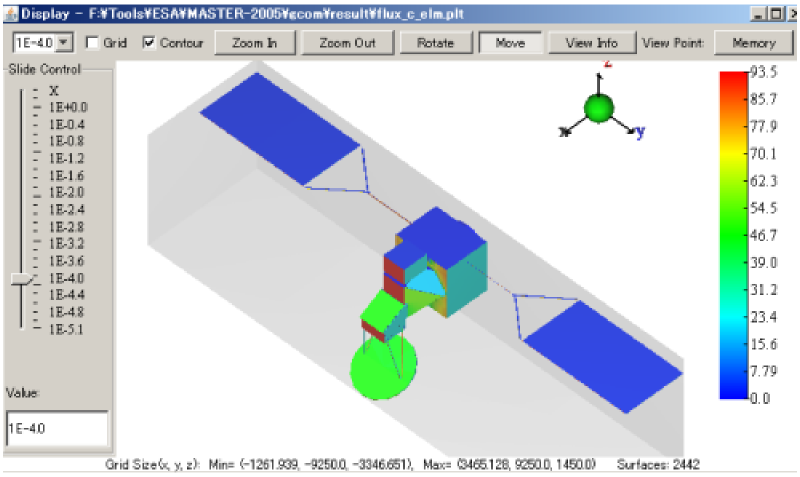

Figure 29: Debris collision tools .[94]

On November 13, 2013, other countries such as Switzerland participated in the discussion held by the UN on limiting space debris. The use of a special telescope called

[92] Committee On the Peaceful Uses of Outer Space, National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris, General Assembly A/AC.105/C.1/2012/CRP .11, Vienna , vol V.12-50417 (E), February 2012. https://www.unoosa.org/pdf/limited/c1/ AC105_C1_2012_CRP11E.pdf

[93]Turandot: https://www.kenkai.jaxa.jp/eng/research/debris/deb-model.html

[94] Committee On the Peaceful Uses of Outer Space, National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris, General Assembly A/AC.105/C.1/2012/CRP .11, Vienna , vol V.12-50417 (E), February 2012. https://www.unoosa.org/pdf/limited/c1/ AC105_C1_2012_CRP11E.pdf

ZIMAT in conjunction with a robotic mechanism can display many of the space debris found in space. Thailand also moved in the same direction; through observations, it was found that a system must meet certain criteria to switch to maneuvers [53]:

- Miss distance < object error + 3 1st body radius + 2nd body radius.
- Failure distance < 100 meters.
- Distance within orbit < 300 meters.
- Intersection distance < 100 meters.

The United Kingdom, along with Ireland, also contributed to the debate on limiting space debris. The regulations they established aim at tracking space debris, maneuvering systems and derailing space systems. These regulations are [53]:

- Control systems. Before using any system, a study must be carried out to ensure its suitability. After the end of the missions, a check should be made to ensure that there is no stored energy in instruments (feedback wheels).
- Study before each mission. Lifetime of each orbit, stability, possible perturbations that may arise from space weather, and crowding from other objects are factors that need careful attention.
- Beware of storage mechanisms. Before starting the space mission, it is necessary to check the storage elements in order to cope. The problems that exist because of them during the missions are an important part.
- Clarification of the concepts of separation and conjugation. The importance of this measure results from the fact that space debris is created during the separation phase.
- Taking measures regarding payloads as there is a risk of multiple payloads being released.
- Study of the space environment (space weather, debris, radiation, contamination of the space environment).
- Study of the space mission itself. The space environment should be affected as little as possible.
- Satellite reset plan. Operators need to know orbits that host inactive satellites in the event of an irreversible accident.

In 2011, United Nations Secretary-General Ban Ki-moon convened a group of government experts on transparency and confidence-building measures in space activities. This small group of experts reported on methods to improve cooperation in space and to reduce risks, misunderstandings, mistrust, and miscalculations. These were [13]:

- Exchange of information on space policies, objectives, and military spending.
- Information about space activities including orbital parameters, potential launches, potential mission risks.
- Information on how to avoid risks such as planned maneuvers, deliberate break-ups, uncontrolled re-entries, and other risk situations in general.
- Voluntary presentations and visits to launch sites as well as command and control centers to demonstrate the emerging new technologies.

Therefore, the measures - regulations aim at the unification of the peoples, the avoidance of misunderstandings, the mitigation of space debris and the peaceful use of space.

6.4 Europe, the UN meetings and the 2014 space code of conduct

2014 was a year of new efforts to limit space debris. On the part of the United Nations Organization, meetings were held on the limitation of weapons in space, the European Union decided to dedicate itself to security, while at the same time the code of ethics for space activities was presented by the European Union.

On February 3, the Japanese space station presented solutions at the conference "National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris" of the UN for protection against space debris smaller than 1 cm [54]. The solutions emerged from experiments with particle impacts [95]at speeds of up to 10 kilometers per second. The proposed material is called Alamido [55]. Alamido is a type of material that contains glass fibers while being light (it weighs 30% of an aluminum shield).

In the same year, Russia and China demonstrated an integrated model with regulations that prohibited the use of weapons in space. Specifically [56]:

- Do not place weapons in the space environment.
- Each State shall not resort to the use of force against objects or other States through space.
- Each state should not participate in actions aimed at the weaponization of space.
- Each state to non takes part in actions where is opposites with the treaty entitled "Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects" [96].

The European Union, on the other hand, in order for there to be continuity of space activities and unity of nations, aims at a common policy of the states so that there is cooperation, security and unity between its members. Specifically, it focused on the following [57]:

- Security.

Each state before joining an organization is important to have studied what this organization stands for. States have advanced a code of conduct which bans the use of weapons in space in order to mitigate space debris. In other words, the above regulation prohibits a state from shooting down its own satellite at will. Exceptions are made only for space debris mitigation.

- In the safety of space activities.

Safety and continued space activities require no increase in long-lived space debris. The growing amount of debris has led the Code of Ethics to be based initially on protection and less on Security. For the mitigation, the rules should be adopted by the United Nations Organization and the IADC organization.

- In trust measures.

[95]Alamido experiments: https://conference.sdo.esoc.esa.int/proceedings/sdc6/paper/1/SDC6-paper1.pdf

[96]Russia-China: https://reachingcriticalwill.org/images/documents/Disarmament-fora/cd/2014/documents/PPWT2014.pdf

Member States decide to provide each other with timely and valid information on space activities. On an annual basis, they need to provide political and strategic information including those related to security. The exchange of this information will strengthen the relations between them because it will help to limit doubts.

- In the legality of regulations.

The European Union should note that it is not an organization authorized by another body for space activities, so it cannot establish a code of conduct. Therefore, for space needs it is necessary that all organizations can contribute and follow some common rules.

The draft code of conduct presented in 2014 contained rules on cooperation between countries, security, defense, and sustainability of space activities. About the sustainability of the activities, mitigation standards – rules for the mitigation of space debris are contained. These are [58]:

- Implementation of common policies and procedures to minimize risk, accidents and collisions or any form of harm in outer space.
- States to refrain from any action that causes the destruction of space objects unless such action is justified (justified in case of danger to human life, reduction of space debris, collective self-defense).
- Conflict mitigation measures.
- Improving communications to deal with radio frequency interference.
- Adoption of appropriate policies and procedures by the UN Organization for the peaceful uses of space.
- Valid and timely communication between states in order to anticipate incidents such as: maneuvers that threaten the safety of flights, risk of collisions between space systems either with each other or with debris, warning of launches of space objects, break-ups in orbits, possible re-entry events in space or in planet that could potentially cause significant damage or contamination, malfunction of space electronic systems.
- States to provide information to each other about: their space activities, space research and programs, policies used to avoid conflicts that create space debris, efforts being made to comply with space policy instruments.
- Member States receive timely information on space conditions from early response awareness centers.
- Each state that possesses space capabilities should contribute to the promotion and encouragement of other states emphasizing international cooperation and solidarity.
- Member States to be organized on a voluntary basis to improve policies on space missions, observe object launches, mitigate space debris, and hold conferences on space activities.

Despite the effort of the European Union to present interesting proposals, no agreement was reached between the member states.

6.5 The European STEP program and EU decisions 2015

The economic, social, and strategic services offered by space to the European Union are unique. These are the reasons why the European Union is investing in space. In order to provide protection to its services it decided to invest in the SSA space status update program (Space Situational Awareness) [97]with the name STEP as stated in the study of Valero , J L Alves , J Gallardo , B Matute , J ODwyer , A Paradiso entitled “Contributions of the EU Satcen to a European SST Capability: Technical Elements on Governance and Data Policy” [59]. It is the third program prioritized by the European Union after Galileo and Copernicus. That SSA is divided into 3 sections and provides:

- Space Surveillance and Tracking (SST).
- Space Weather Environment (SWE).
- Tracking of Near-Earth Objects (NEO).

The policy of this program is based on 3 elements:

- In detection through sensors.
- In data processing.
- Provision of services.

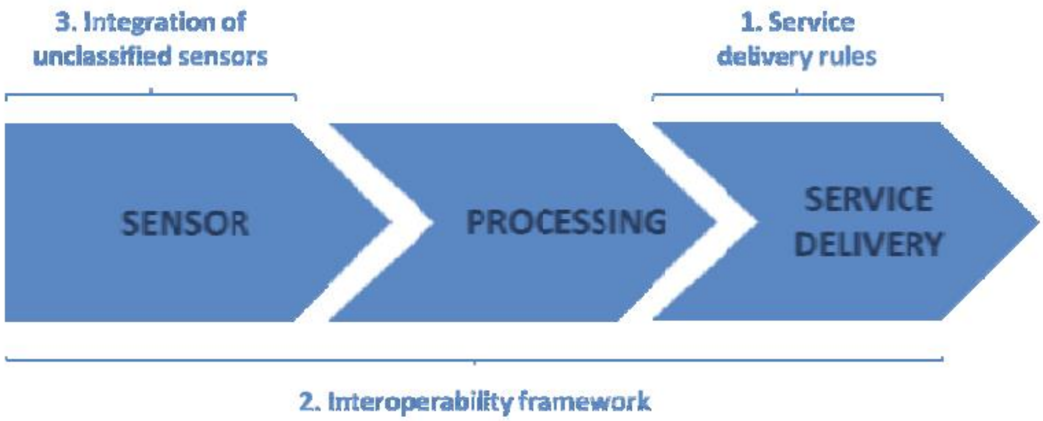

Figure 30: STEP Data Politics.[98]

The functions provided by this program are listed below:

- Monitoring of satellite systems.

Tracking satellites is a declarative action to limit space debris because it reduces the likelihood of collisions. The probability of the merger is calculated considering other parameters. Also, communication is an important part because the data should be sent in time to the system operator in order to implement some kind of maneuver to avoid any possible conflict. The next image shows the simulation between the International Space Station and a piece of space debris.

[97]Space Situational Awareness: https://www.satcen.europa.eu/page/ssa

[98] Valero, JL, Alves, J., Gallardo, B., Matute, J., O'Dwyer, A., Paradiso, N. (2015). Contributions of the EU Satcen to a European SST Capability: Technical Elements on Governance and Data Policy. In: Sgobba, T. Rongier, I. (eds) Space Safety is No Accident. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-15982-9_44

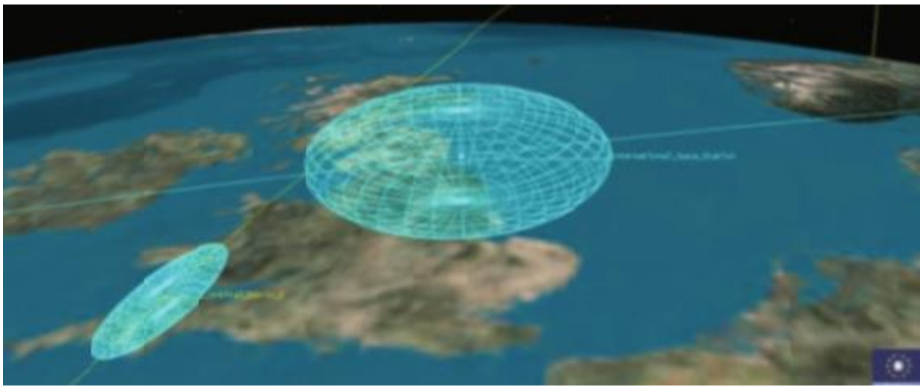

Figure 31: ISS Simulation with an object.[99]

- Forecasting services for reimported items.

This service specializes in objects that can fall into the Earth's atmosphere and reach the surface. The tracking service has a list of such objects and for this reason they also use probabilistic trajectory calculation software to predict their location. The next figure demonstrates the software.

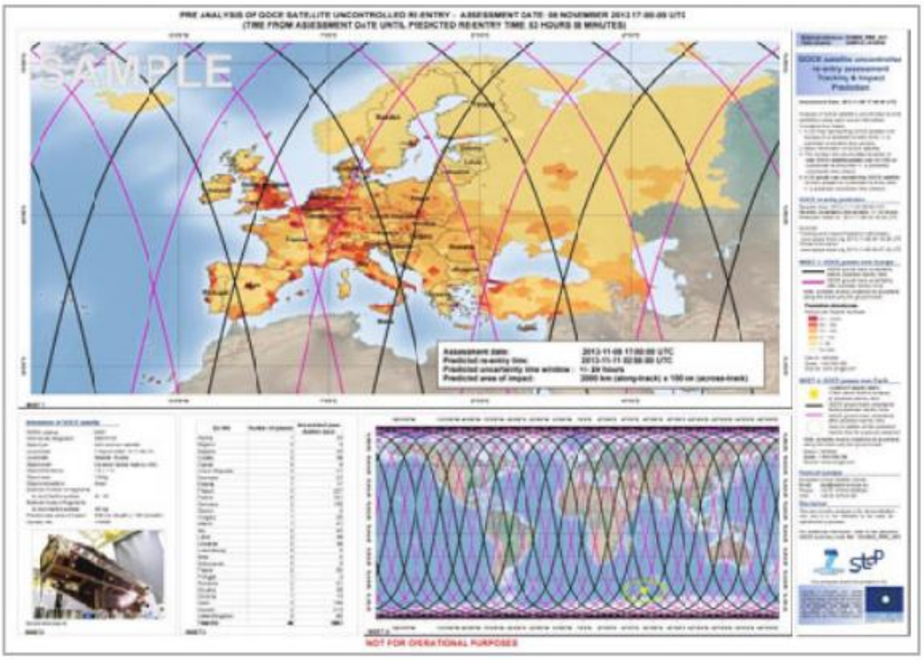

Figure 32: Space object re-entry sample interface.[100]

[99] Valero, JL, Alves, J., Gallardo, B., Matute, J., O'Dwyer, A., Paradiso, N. (2015). Contributions of the EU Satcen to a European SST Capability: Technical Elements on Governance and Data Policy. In: Sgobba, T. Rongier, I. (eds) Space Safety is No Accident. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-15982-9_44

[100] Valero, JL, Alves, J., Gallardo, B., Matute, J., O'Dwyer, A., Paradiso, N. (2015). Contributions of the EU Satcen to a European SST Capability: Technical Elements on Governance and Data Policy. In: Sgobba, T. Rongier, I. (eds) Space Safety is No Accident. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-15982-9_44

- Object hashing services.

The object tracking service tracks space debris resulting from collisions of satellite systems, rocket launches, and explosions of infrastructure used in space. A case in point is the next image which provides the debris from Iridium -33 [101](383 fragments) and Cosmos -2251 [102](924 fragments) after their collision. In the figure, the perigee and apogee resulting from the fragments are shown with red and blue dots. The y -axis is in kilometers while the x -axis is in minutes.

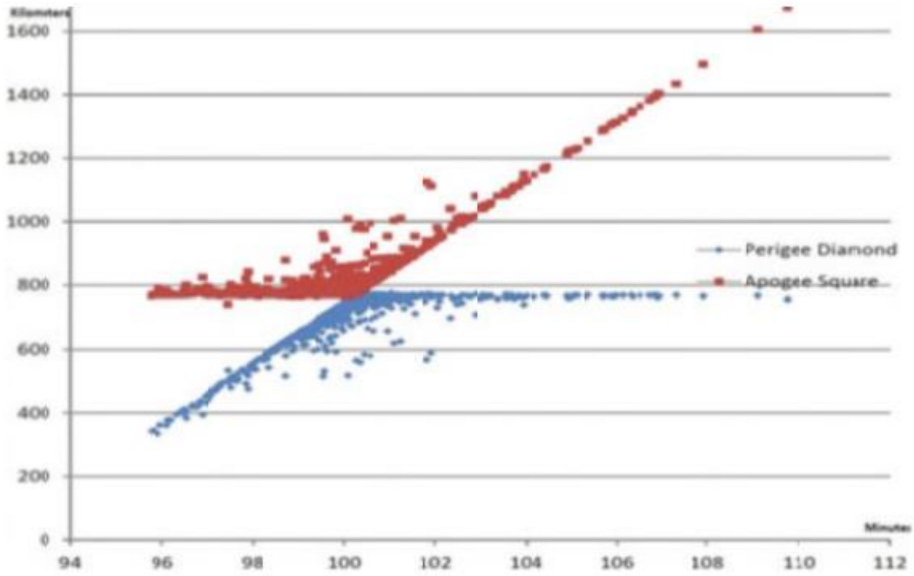

Figure 33: Gabbard diagram for Iridium-33 and Cosmos-2251.[103]

- Satellite overflight service.

This service provides real-time data. With this data the user can see when a satellite passes over them. Satellite overflights through the calculations needed to predict the location as well as the time a satellite will be over a location. Here it should be noted that this service is useful for communications. The next figure shows flybys of satellites in low orbits.

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[101]Iridium-33: https://ntrs.nasa.gov/citations/20100002023

[102]Cosmos-2251: https://ntrs.nasa.gov/citations/20100002023

[103] Valero, JL, Alves, J., Gallardo, B., Matute, J., O'Dwyer, A., Paradiso, N. (2015). Contributions of the EU Satcen to a European SST Capability: Technical Elements on Governance and Data Policy. In: Sgobba, T. Rongier, I. (eds) Space Safety is No Accident. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-15982-9_44

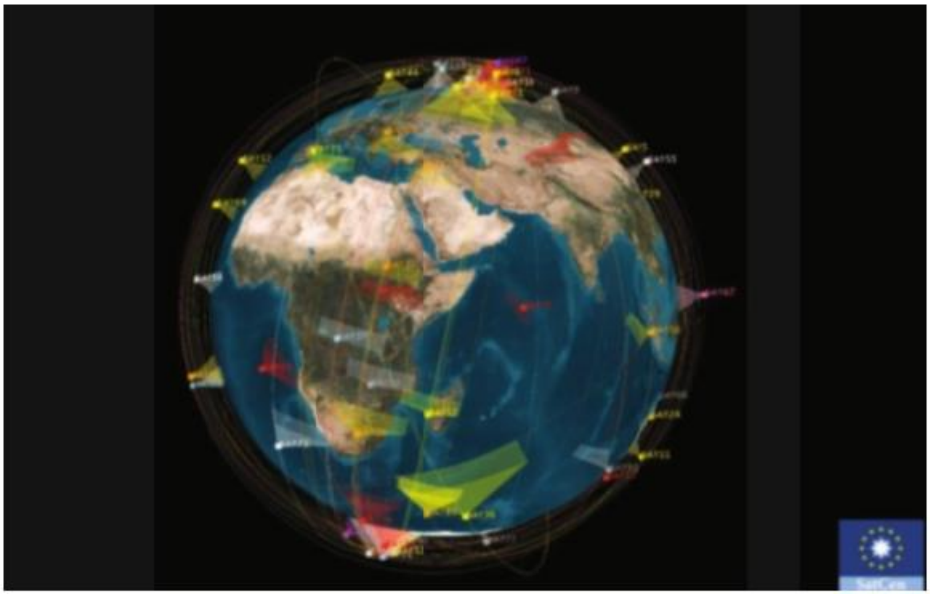

Figure 34: Multiple LEO Satellites.[104]

- List of space objects.

The catalog service of space objects provides information (parameters, characteristics) of various space objects. A more sophisticated service of this kind can offer tracking of such objects and in combination with the information offer access to data from their past.

On 9 February 2015, the Official Journal of the European Union published Council Decision (CFSP) 2015/203 in support of the European Union for an international code of conduct for space activities as a contribution to transparency and confidence-building measures in space activities [60]. These are:

Article 1: In order for the European Union to support its proposal for an international code of conduct for space activities in compliance with the resolution A / RES /68/50 of the United Nations General Assembly the European Union has the following objective: Through the decision 2012/281/CFSP [105]to lead the processes concerning the proposal for an international code of conduct and the participation of all Member States in order to allow the draft to be agreed and later approved by the whole community.

Article 2: The projects that will be covered by the European Union will cover the following fields. 1) Continue the fight to raise awareness for a code of conduct in space activities led by the European Union. 2) The continuation of a framework to conduct a multilateral process on an international code of ethics for space activities, in order to ensure the continued participation of the international community as well as the approval of the code itself.

[104] Valero, JL, Alves, J., Gallardo, B., Matute, J., O'Dwyer, A., Paradiso, N. (2015). Contributions of the EU Satcen to a European SST Capability: Technical Elements on Governance and Data Policy. In: Sgobba, T. Rongier, I. (eds) Space Safety is No Accident. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-15982-9_44

[105]Council Decision 2012/281/CFSP of 29 May 2012 in the framework of the European Security Strategy in support of the Union's proposal for an international code of conduct for outer space activities (OJ L 140 of 30.5.2012, p. 68).

6.6 Space Debris Mitigation Studies and the EU Space Security Position 2017

In 2017, a study was carried out by Habimana Sylvestre, V R Ramakrishna Parama on space debris mitigation titled “Space Debris: Causes, Types, Effects and Management” [2]. As mentioned above, space debris mitigation strategies are divided into prevention strategies and removal strategies. Since removal strategies are more difficult to implement, much of the weight falls on preventive efforts. Therefore, the space debris management methods are divided into [2]:

- In Key Aspects of Space Debris Mitigation Guidelines.

The main aspects include the following actions: 1) Redesigning the spacecraft so that no space debris is released, 2) Checking for possible explosions, 3) Short lifetime of satellites in low orbits (25 years), 4) In case space debris entering the Earth, they should not pose a threat, 5) Use of maneuvers [61], 6) Removal of satellites in distant orbits [62].

- To avoid conflicts.

Tracking information usually helps to detect the space systems and maneuvers can be used if there is a risk of collision. A typical example is the international space station, which performs one maneuver per year. Increasing debris in space can also lead to more evasive maneuvers. In each maneuver, more fuel is used, which shortens the life of the satellites [63].

- In removal methods.

Removal methods include space robots, vehicles, laser structures that can remove space debris from orbit.

In the same year, an assembly was held in the European Union on the theme "Conference on Disarmament - Working Group on the Way Forward - EU Declaration on the Prevention of an Arms Race in Space" where it clearly shows its opinion on weapons in space [64]. In particular, the European Union promotes the maintenance of a safe space. Space is a global commodity and should be used for the benefit of humanity. Space programs such as Galileo or Copernicus have been developed to provide space services and applications to its members. Therefore, in order to ensure the long-term uses of space, it is necessary to prevent weapons in it. A 2008 Code of Ethics helped prevent this[106], but efforts should continue. The global principles of responsible behavior should include the following:

- Promoting the safety and sustainability of the space field.
- The pursuit of strategic stability.
- Minimizing the risk of accidents, collisions, and other harmful actions for space.
- Refrain from intentionally damaging or destroying spacecraft except in self-defense or space debris mitigation.
- Taking appropriate measures and consultations to minimize risks.
- Minimizing the generation of long-lived space debris and implementing the COPUOS Committee on Space Debris Mitigation.

[106] Draft International Code of Conduct for Outer Space Activities: https://swfound.org/media/166384/swf_draft_international_code_of_conduct_for_outer_space_activities_fact_sheet_february_2014.pdf

Therefore, based on what was said by the EU, it is clear that it aims at the mitigation of space debris and the international cooperation of states for the continuation of space activities.

6.7 ESA's SSA Program 2017

As mentioned before for understanding space it is necessary the understanding of space weather. The space environment poses a great risk for space – based systems, to the population and infrastructure to the ground, because of space weather, near Earth objects and space debris. Since 2009 ESA recognized that need has been undertaking a program with conclude 3 segments. These segments are: 1) Space Weather, 2) Near Earth Objects, 3) Space Surveillance and Tracking according to the study by Tim Flohrer, Holger Krag with title "Space Surveillance and tracking in ESA'S SSA programme" [65].

- Space Weather Environment: Space weather addresses all aspects on monitoring conditions at the Sun and solar wind, and Earth's magnetosphere, ionosphere that can affect spaceborne, ground – space stations and human life on Earth. Measurements from space environment must be fed into advanced computational models and tools in order to have real time information on space weather conditions that may affect a diverse range of systems and activities that can cause space debris.
- Near Earth Objects: Near Earth Objects are asteroids, comets with sizes from meters to kilometers that orbit around the Sun. Sometimes their orbits come close with Earth's and that makes them dangerous. In the Solar System there are 700,000 known asteroids and 16.000 are characterized as Near Earth Objects. More than 90% of them have been discovered with diameter larger than 1km. The goal of Near Earth Object Center is to expand the knowledge for these objects and to develop deflection methods. Furthermore predicts their orbits and produces impact warnings when is necessary and it is involved in developing preventive measures.
- Space Surveillance and Tracking: Space debris are becoming a threat. It is estimated by ESA's model [66] that more than 750.000 objects are larger than 1 centimeter with the potential risk of damaging the satellites in orbit. This segment has the technologies that can detect, catalogue and predict the objects that orbit the Earth. Nowadays it is needed real time data in order to have avoidance collisions and re- entry events. Despite of progress with space debris mitigation standards [67] the in orbit fragmentation events is still a significant issue. Today ESA and other European national space agencies depend on the surveillance data.

ESA'S developments in the SST program are also in mind. These developments conclude 1) Sensors, 2) Data Processing technologies, 3) Applications as the next figure present.

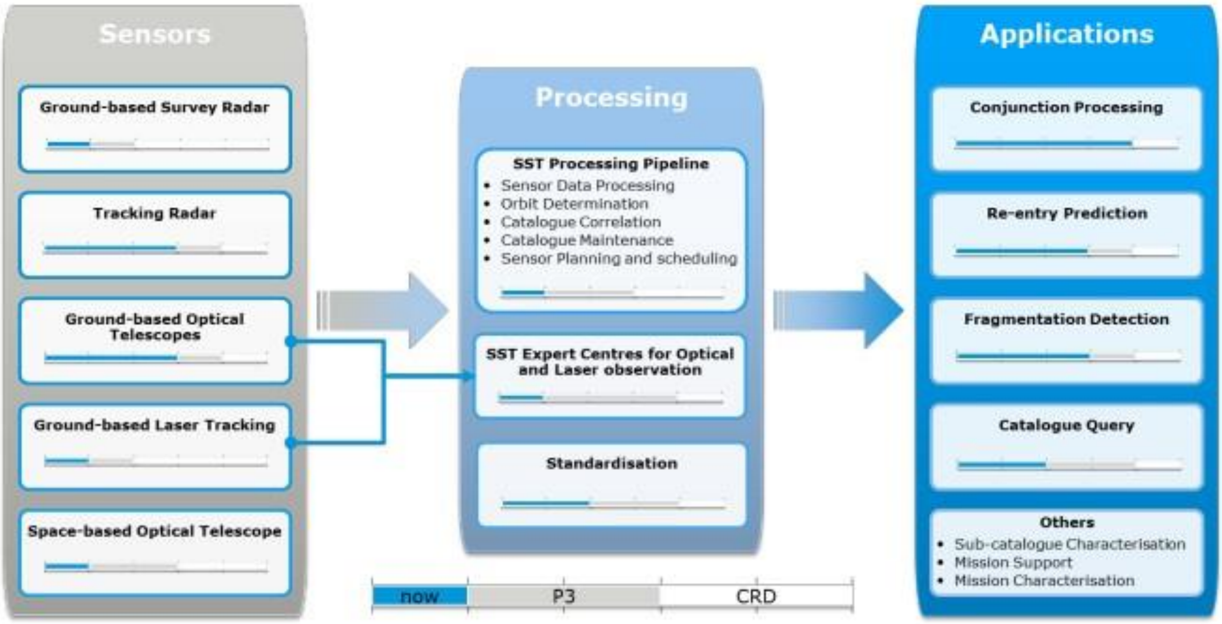

Figure 35: Status of the SST activities.[107]

Sensors: Development of Sensors focuses on studying and specifying cross national component at all technology and to the support to qualifying national sensors. First for SST tasks it used a passive fix-mounted telescope with an aperture of 20cm [65]. The same sensor can contribute to improving the statistical knowledge on the catalogue with small size space debris population in Low Earth Orbits. Laser ranging systems and radar sensors are further objectives.

Data Processing Technologies: It is SST core software for data generation kernels and formats [65]. Such a software approach will allow existing and developing national systems to deliver compatible results, efficient data, and establishing common data processing techniques and formats. Data processing activities will address advanced processing techniques and orbit determination of objects in space.

Applications: SST applications can predict avoidance collisions, re- entry events, fragmentation events, even detection and catalogue querying, as well as support tools for visualization, system architecture analysis and data conversion [65].

According ESA document with title “Space Situational Awareness – Space Weather Systems Requirements Document” published in 2013, the high level requirements for SSA program focuses on [68]:

- Provision of comprehensive knowledge, understanding and maintained awareness of the space environment and space weather.
- Detection of Space weather and its effects.
- Prediction of natural meteoroids and space debris that are not covered from SST segment and their effects.

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[107] T. Flohrer, H. Krag, “SPACE SURVEILLANCE AND TRACKING IN ESA'S SSA PROGRAMME”, April 2017, https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/242/SDC7-paper242.pdf

- The monitoring of the Sun, solar wind.

6.8 Qubesats preventive measures

Space Debris can be a serious problem due to launches in Space. The New Space contains launches of microsatellites. Although microsatellites offer benefits such as high speed communications and characterization of an Earth observation imager can release space debris as well. For this reason, nowadays Qubesats are used for space debris removal – project FREEDOM [69] and constructed with simple and strength materials which can be a preventive measure. As the study also states with the title “Orbit Verification Result of the De-Orbit Mechanism Demonstration Qubesat FREEDOM” by Hiroki Uto, Toshinori Kuwahara and Tomoyuki Honda a Qubesat with 1U size was equipped with the newest model De Orbit Mechanism and its mission was a demonstration of the deployment of the device in space and the tracking of the resulting orbit transition. This removal demonstration can work as a preventive measure for future accidental collisions.

NASA in the report 2017 with the title “Qubesat 101 Basic Concepts and Processes First – Time Qubesat Developers” constructs Qubesats satellites with the materials below: for the Qubesat structure use Aluminium 6061, for antennae Steel 410, and for the solar panels fiberglass [70]. These materials allow Qubesats to have better strength in Space. In next figure we present a Qubesat structure.

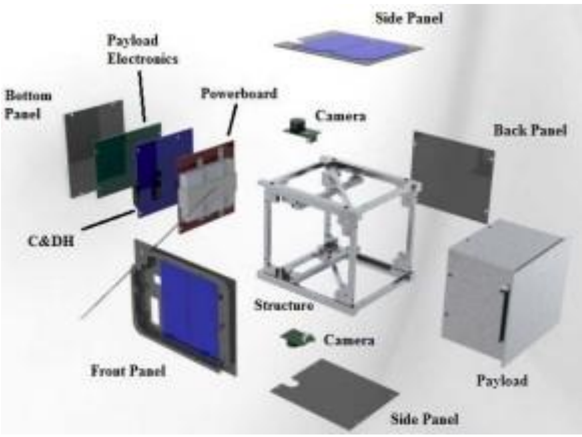

Figure 36: Qubesat structure.[108]

6.9 Space Debris Mitigation Measures 2019-2020

In 2019, the United States Government published an action plan to protect satellite systems from space weather. Studies focus on violent eruptions from the Sun (Solar mass ejections, Solar flares) [109]as they affect satellite systems. Typical examples are the blackout in Canada and the grid down in the United States in 1989. Consequently, the

[108] NASA, "Qubesat 101 Basic Consepts and Processes for First-Time Qubesat Developers", October 2017, https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf

[109]Space Junk and Space Weather: https://www.space.com/space-junk-asteroid-hazard-detection

United States proceeded with measures entitled "National Space Weather Strategy and Action Plan" which aim [9]:

- The protection of their national security and their network.

To protect national security and its network, the United States focused on the following measures: 1) Space weather benchmarks (ionizing radiation, radio bursts, ionospheric disturbances that can disrupt systems), 2) Vulnerability assessment of satellite systems, 3) In modeling the effects of space weather (forecast models that contribute to the protection of satellites), 4) Study and cost estimation of the most frequent weather phenomena that occur in space. Protection is also ensured by the existence of appropriate technologies and rules that minimize the effects of space weather. Therefore: 5) Heavy emphasis on the safety of critical operations from space weather, 6) Testing and reliability of new technologies released into space.

- The rapid propagation and forecasting of space weather.

The rapid dissemination and forecasting of space weather can be done with the following actions: 1) Utilization of all sea-air observation possibilities, 2) Ensuring basic space weather observation functions, 3) Research in the field of Heliophysics, 4) Improvement of existing space weather forecasting models, 5) Improving extreme weather alerts.

- Establishing plans for rapid recovery of systems from space weather.

The rapid recovery of systems from space weather relies on the cooperation of all Nations as well as rapid information. The measures are: 1) Updating programs and procedures to deal with space weather, 2) Valid and timely dissemination of information for the recovery of any critical failures, 3) Control of critical functions of satellite systems, 4) Development of appropriate methods and procedures to recover operations from the weather. The measures concerning the protection of satellite systems clearly aim to protect them from extreme weather phenomena, but they can also reduce the amount of debris in space. For the armoring of space technologies, mathematical studies have also been done in order to increase the strength of the materials in the event of a collision with space debris. The experiments carried out involved collisions of materials with high-velocity particles (12 kilometers per second) and were aimed according to the study of N. N. Smirnov, A. B. Kiselev, M. N. Smirnova, V. F. Nikitin titled "Space Traffic Hazards from Orbital Debris Mitigation Strategies" [71]:

- The approximation of a statistics of the space environment with space debris.
- Collisions with particles of various sizes in order to study the damage they cause.
- The development of numerical methods.

Mathematical formulas that emerged are shown below,

$$\mathrm{Av(p)} = \mathrm{p} - \mathrm{p_0} + \sum_{i=1}^{N(r_e)} m_i \vec{v_i}\vec{n}/\tau_* \qquad (5)$$

$$\tau_* = \frac{2h}{c_s}$$

$$c_s = \sqrt{\frac{E}{(1-v^2)p_{s0}}}$$

where E, v refers to the Young sizes Modulus [110](fundamental material property) and in Poisson 's ratio [111], ps0 is the density of the material, τ* is the shell force, m is the mass of the particle and v is the velocity.

In the same year, the European Space Agency published the report on space debris with measurements made to date. The following images provide insight into the space debris present in the space field, the amount of space debris, collision avoidance and finally the ability to identify objects as defined in the 2019 ESA report entitled " ESA Environmental Report on space debris mitigation" [72].

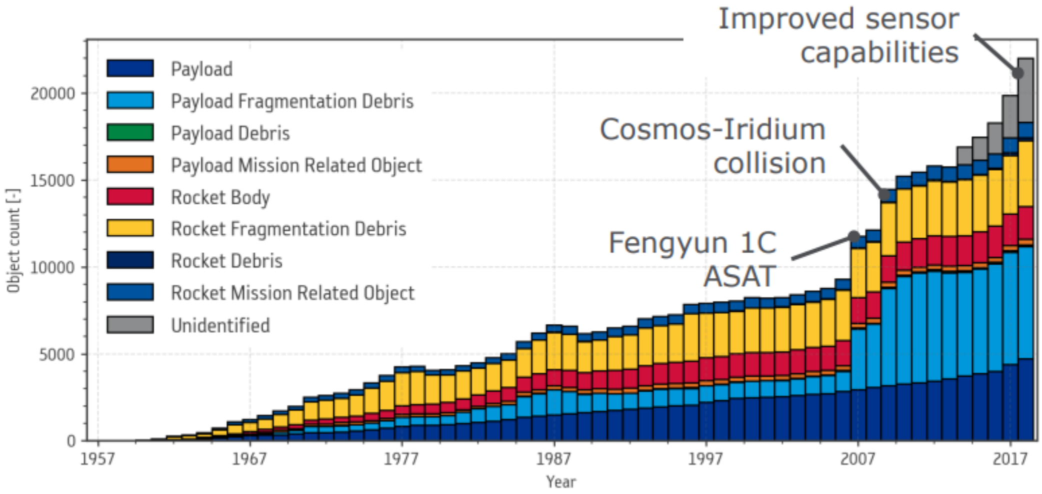

Figure 37: State of the environment per year.[112]

[110]Young's Modulus: https://ntrs.nasa.gov/citations/20100002023

[111]Poisson ratio: https://el.lambdayeks.com/poissons-ratio/

[112] Francesca Letizia, ESA Environmental Report on Space Debris Mitigation, European Space Agency, September 2019. https://www.sdo.esoc.esa.int/publications/ESA%20Environmental%20Report%20on%20Space%20Debris%20Mitigation_slides.pdf

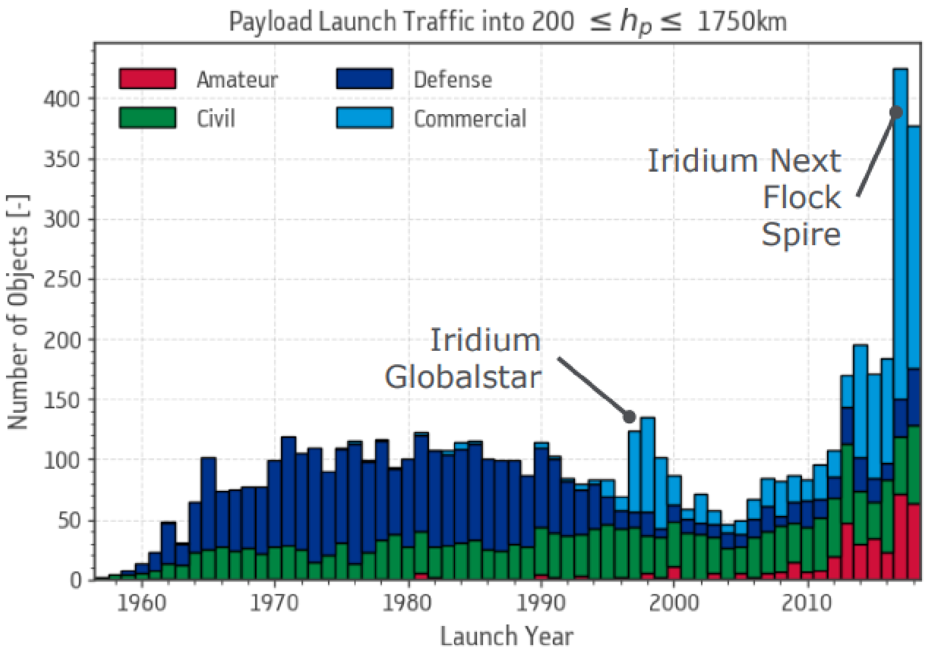

Figure 38: Number of objects per year.[113]

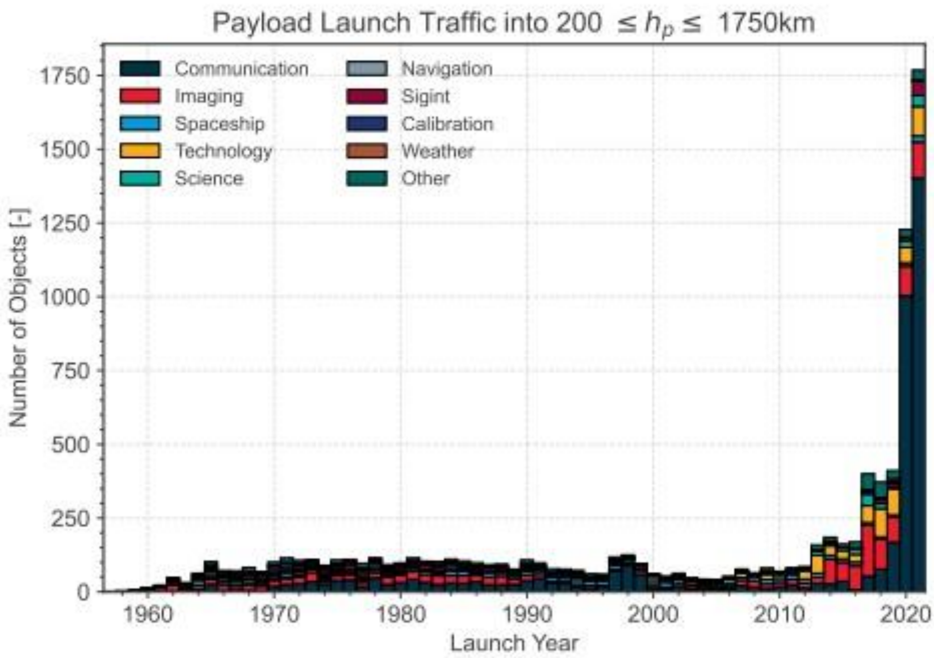

Figure 39: Traffic near Earth Orbits by ESA.[114]

113 Francesca Letizia, ESA Environmental Report on Space Debris Mitigation, European Space Agency, September 2019. https://www.sdo.esoc.esa.int/publications/ESA%20Environmental%20Report%20on%20Space%20Debris%20Mitigation_slides.pdf

114 ESA Space Debris Office, "ESA'S annual Space environmental report", Issue 6.0, GEN-DB-LOG-00288-OPS-SD, April 2022. https :// www . sdo . esoc . esa . int / environment _ report / Space _ Environment _ Report _ latest . pdf

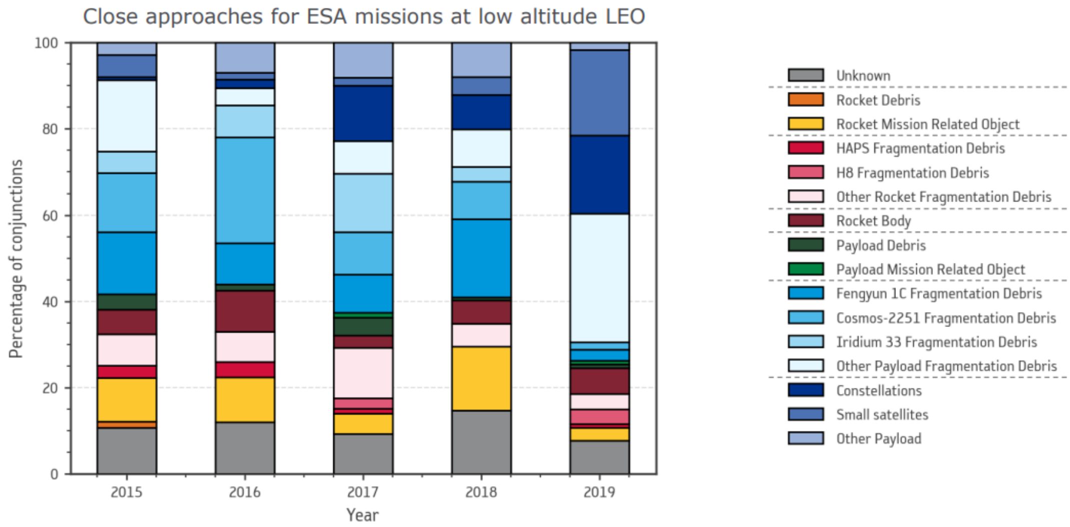

Figure 40: Collision avoidance.[115]

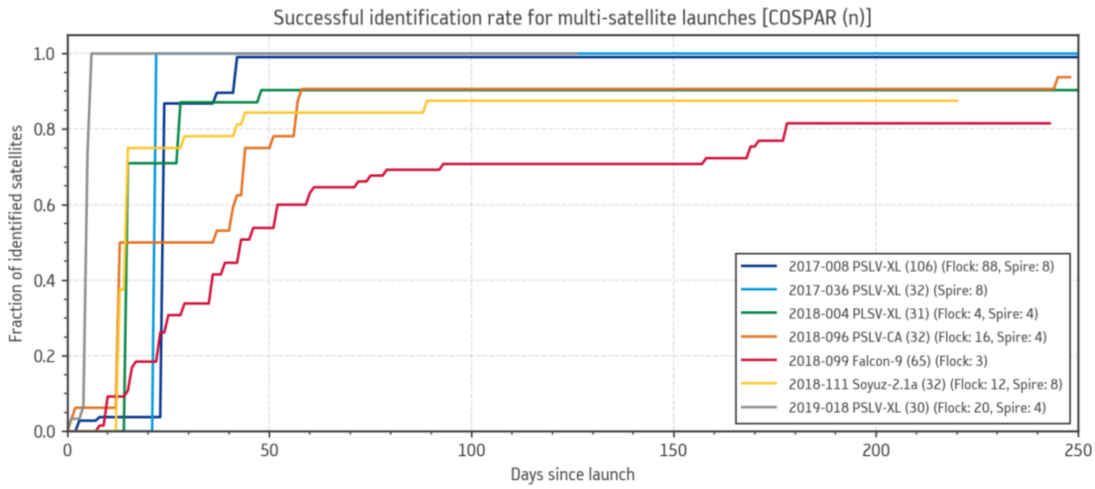

Figure 41: Identification tractability.[116]

In the figures above, measurements are seen regarding the path of space debris since the phenomenon began until today, the identification of space debris, the avoidance of collisions per year and the number of objects per year. Finally, in order to include security, defense and stability in space activities, the European Union is coordinating a council (3 SOS) [117]for the collective response to the phenomenon called space debris. Specifically, the head of the Carine program Claeys quoted the following phrase "Is this all sustainable

[115] Francesca Letizia, ESA Environmental Report on Space Debris Mitigation, European Space Agency, September 2019. https://www.sdo.esoc.esa.int/publications/ESA%20Environmental%20Report%20on%20Space%20Debris%20Mitigation_slides.pdf

[116] Francesca Letizia, ESA Environmental Report on Space Debris Mitigation, European Space Agency, September 2019. https://www.sdo.esoc.esa.int/publications/ESA%20Environmental%20Report%20on%20Space%20Debris%20Mitigation_slides.pdf

[117]3SOS: https://spacenews.com/eu-agency-starts-space-sustainability-initiative/

and responsible? No." [118]. Space debris is therefore still a threat, especially for low-spec orbits.

In 2020, the 58th congress from the Organization of United Nations took place with title "Research on Space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris". A comprehensive effort by the International Organization for Standardization (ISO) to mitigate space debris was presented at the conference. The proposals are [73]:

- ISO 11227: This standard refers to the testing and durability of materials impacted by high-velocity particles in order to test their durability. The resulting data contributes to the final decisions on whether they can be used for outer surfaces on spacecraft.
- ISO 14200: Selecting an appropriate model for simulations. A correct and accurate simulation provides safety for spacecraft.
- ISO 16126: This standard addresses the safety of spacecraft when encountering space debris to ensure its survival.
- ISO 27852: This standard describes a procedure for estimating the lifetime of orbiters, launch vehicles, satellites, upper stages and modeling methods.
- ISO 27875: This standard provides a protective framework to reduce the risk caused when space debris enters the Earth's surface.
- ISO / TR 16158: This standard describes approaches for calculating cumulative probability, for collision avoidance, for spacecraft survivability.
- ISO / TR 18146: This standard provides a guide for engineers to apply debris mitigation standards throughout spacecraft construction.

In the same year there was also the 75th session[119] of the UN. At the summit, Canada once again promoted the sustainable use of space for all nations. The use of anti-satellite weapons in space creates long-lasting space debris that poses a risk to all space users. This reason alone is enough for them to proceed with rules of their annihilation. He also argued that states that have nuclear weapons should proceed with special disarmament protocols. Finally, the cooperation of all member states is the key to the safety and sustainability of space activities and that the fight for a regime for the peace of space should not stop.

2020 was a defining year for space because there was great awareness not only of space debris but also of a regime for the peaceful use of space. The following propositions presented according to the study of Ram S. Jakhu, Kuan - Wei Chen & Bayar Goswami entitled "Threats to the Peaceful Purposes of Outer Space: Policy and Law" are [74]:

- The adoption of an international agreement prohibiting the placement and use of weapons in space. All anti-satellite weapons should also be banned.
- The creation and strengthening of a governance system that is based on space rules.

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[118]3SOS: https://spacenews.com/eu-agency-starts-space-sustainability-initiative/

[119]Canada's Recommendations: https://www.international.gc.ca/world-monde/international_relations-relations_internationales/un-onu/statements-declarations/2020-10-14-debate-debat.aspx?lang=eng

- The efforts of the UN are vital to the peace of space. Many states have become aware of the situation and as long as the action continues the UN will become a magnet for other states as well.
- The UN should consider potential risks that may threaten security, peace, and space activities.
- The term peaceful purposes does not include aggressive and military purposes. Nevertheless, for the precise concept it is necessary for the UN to define precise conditions.
- The UN General Assembly (General Assembly) should declare that intentional harmful damage in space constitutes a crime against humanity.

Finally, smaller states also contribute to the mitigation of space debris. In particular, Indonesia has been involved and has been active since 1960 according to the study by J M Hutagalung C. I Tobing, J. Debastri , R T Amanda entitled “Space Debris as an Environmental Threat and the Requirement of Indonesia's Prevention Regulation” [7]. Having an active role in the UN, it has been dealing with space debris since 1976 when it put its satellite into orbit. The laws - regulations it put in place are as follows:

- Appropriate legal-political framework for the use of alternative techniques for space activities.
- Accurate tracking of space debris and willing organizations to mitigate it.
- Funding new missions using new technologies aimed at preventing space debris. If it is possible to apply technologies to remove them or to restore them.
- Development of new technologies that offer accurate localizations.
- Measures for the safety of humanity in space.

As an active state Indonesia has established rules. However, they do not offer 100% protection. For this reason, it will continue to prioritize the protection of the space environment.

As the technology evolves in the period between 2011- 2020 a new preventive measures come to mitigate the problem. Mathematical models and the SSA program by the European Space Agency are some of the most important actions. Mathematical models can predict the orbits of the objects while the SSA program can detect the object in space. One important preventive measure is the SSA program because the space debris can detected on time.

7. MODERN MEASURES - SPACE DEBRIS MITIGATION STANDARDS 2021 - 2022.

7.1 Introduction

This chapter focuses specifically on space debris mitigation efforts over the past 2 years. The current situation that prevails NASA and the European Space Agency are trying to reduce it with standards and rules that have been recognized by the UN. On the contrary, the United Nations Organization, in addition to the rules, aims at global cooperation and peace between member states. Since history, humanity has coped with many difficulties in the face of many dangers through cooperation. Therefore, the future goal is world peace and a regime that will make states use space for peaceful purposes.

7.2 US Space Debris Mitigation Efforts, ESA Observations and UN Sessions – 2021

On January 27, 2021, NASA presented a standard on space debris mitigation. According to studies, the space debris has taken on enormous dimensions. For this reason, their mitigation is a sovereign goal for the United States. NASA 's efforts so far have focused on the prevention of space debris rather than methods of disposal. An image that shows the space debris problem is the one below, where the y -axis refers to the number of debris and the x -axis to each year.

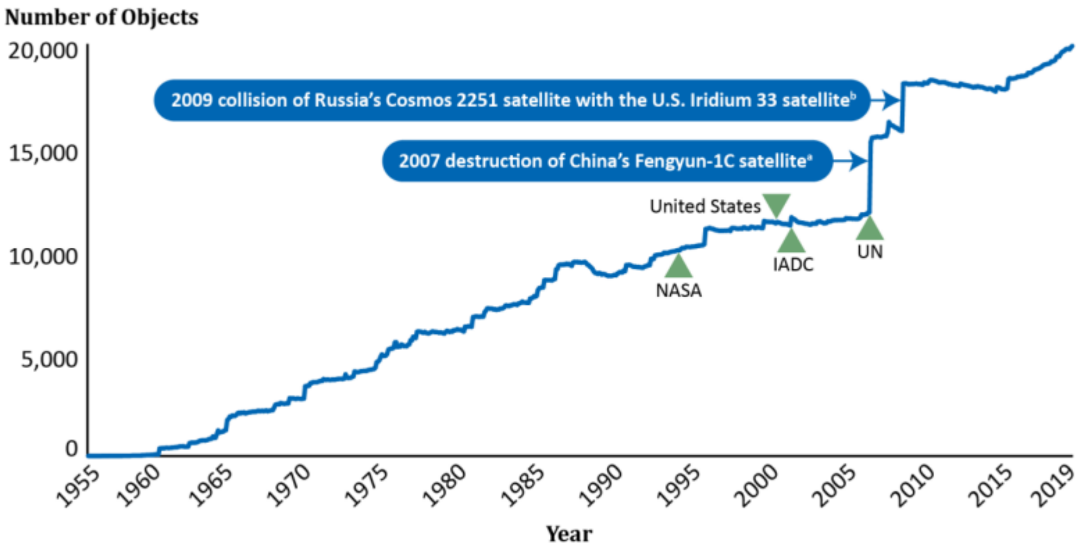

Figure 42: Number of Objects per year by NASA.[120]

As other countries entered space, the need to mitigate debris became necessary. The next figure features countries as well as the number of satellites they have sent into space. Clearly today these numbers have changed.

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[120] NASA Office of Inspector General Office of Audits, NASA'S Efforts to Mitigate the Risks posed by Orbital Debris, IG-21-011(A-20-002-00), January 2021. https://oig.nasa.gov/docs/ IG-21-011.pdf

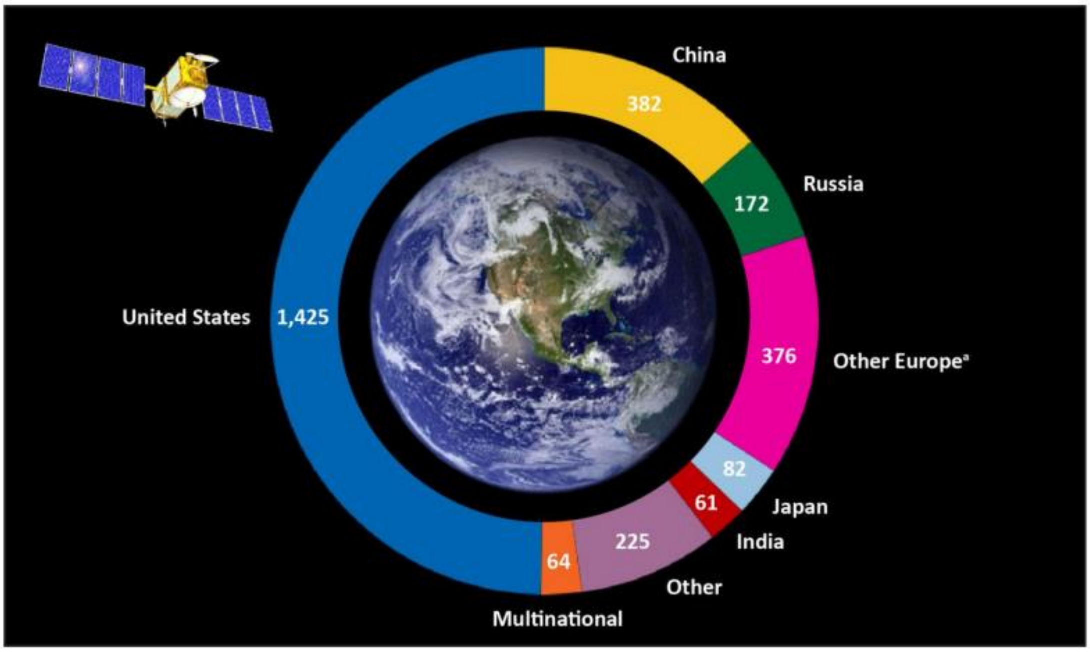

Figure 43: Number of Satellites.[121]

According to figures released in January 2019 by the European Space Agency Space Debris Office the numbers of satellites are:

Table 5: Numbers of satellites.[122]

Number of satellites launched into space	8.950
Number of satellites still orbiting the Earth	5000
Number of operational satellites	1950
Number of collisions break-ups and explosions	500

Mitigation measures and regulations are according to the report titled "NASA 's Efforts to Mitigate Hazards from Orbital Debris" [75]:

- Limit debris during missions.

This regulation aims to redesign spacecraft that will minimize the release of space debris during space missions.

- Limiting explosions that occur during spacecraft operation.

[121] NASA Office of Inspector General Office of Audits, NASA'S Efforts to Mitigate the Risks posed by Orbital Debris, IG-21-011(A-20-002-00), January 2021. https://oig.nasa.gov/docs/ IG-21-011.pdf

[122] Astroscale: https://astroscale.com/space-debris_/

Containment of explosions can be prevented in 2 ways. 1) Design of new subsystems with reduced probability of breakdown. 2) Removal of all energy sources (batteries, propellants) at the end of the mission.

- Avoid collisions in orbits.

Avoiding collisions in trajectories can be achieved: 1) By creating maneuvers. This process requires more fuel. 2) The protection of spacecraft from small debris that causes damage to the walls.

- Procedures after missions end.

At the end of the missions you should: 1) Transfer the satellite to remote orbits away from Earth (orbits - graveyards) to free up space. 2) Adoption of the 25-year rule. The altitude of the satellite system is gradually lowered in order to be pulled by the Earth's gravity. 3) Removal of the satellites within 5 years after the end of their mission.

- General mitigation measures.

The general mitigation measures relate to the following form: 1) The creation of microsatellites should follow the regulations mentioned above. 2) Servicing missions, rendezvous satellites should not create space debris. 3) The rejection success rate after the end of the missions should reach at least 90%. The above regulations are summarized in figure 42.

Objective	Implementation
Limit the amount of debris released during normal operations	Design spacecraft to eliminate or minimize debris released during normal operations
Limit the risk to other spacecraft by minimizing accidental explosions while the spacecraft is in operation and after the end of its mission	• Design spacecraft subsystems to limit the probability of accidental explosions • Deplete all on-board sources of stored energy (e.g., batteries, propellant) at the end of mission
Prevent on-orbit collisions	• Shield against small debris to ensure successful post-mission disposal • Make spacecraft maneuverable by loading it with extra propellant to allow for the avoidance of large debris and other spacecraft
Post-mission disposal	At end of mission: • Follow the "25-year rule" to lower the altitude of the spacecraft at the end of mission so that atmospheric drag pulls it into Earth's atmosphere to burn up or reenter within 25 years • Move the spacecraft into Earth's atmosphere or further away from Earth (into a storage orbit around Earth or out of Earth's orbit altogether) • Actively remove spacecraft from orbit within 5 years of the end of mission
"Other" objective category, including guidance for constellations, CubeSats, and satellite servicing missions	• Constellations with more than 100 spacecraft have a post-mission disposal success rate of at least 90 percent • CubeSats should comply with the first four objectives listed above • Satellite servicing, rendezvous, and proximity operations missions should not generate debris

Figure 44: Summary of Space Debris measurements.[123]

[123] NASA Office of Inspector General Office of Audits, NASA'S Efforts to Mitigate the Risks posed by Orbital Debris, IG-21-011(A-20-002-00), January 2021. https://oig.nasa.gov/docs/ IG-21-011.pdf

In addition to NASA, the United States Department of Defense has an active role in space. Through a report that was published in 2021, it was argued that the increase of active states in space activities generates more attention for possible conflicts. The growing attention led the Ministry of National Defense to adopt some regulations. According to the report entitled "Principles of Responsible Behavior in Space" [76]:

- Operation in space should be based on respect between all countries as well as professionalism.
- In every space mission, there should be a limitation of space debris, especially those that have a long life.
- Avoiding all actions that are harmful to outer space.
- Adoption of regular communications in order to provide valid information on the conditions in space as well as stability in the space sector.

The European Space Agency in 2021 published a report on space debris entitled " ESA 's Space Report 2021". Studying the phenomenon, the observations he gathered are not encouraging. The ever-increasing amount of space debris and the low clearance of orbits has led missions to a critical point. The concluded observations are [77]:

- Current behavior is unsustainable. The ever-increasing amount of space debris will make it difficult to continue space activities.
- The amount of debris including its mass is steadily increasing.
- New technologies help track space objects.
- The vast majority of rocket bodies in geostationary orbits are sustainably disposed of.
- Operators of low orbit bodies make no effort to sustain missions.
- In order to mitigate space debris, a necessary condition is the adoption of the rules of the Interagency Debris Coordination (IADC) and the UN.

The United Nations Organization on December 30, 2021, held th3 76th session on " Reducing space threats through norms, rules and principles of responsible behaviors ', so that member states can operate under a common set of regulations. Specifically, [78]:

- All Member States must conduct their space activities based on international space law including the UN Charter.
- It urges the encouragement of non-UN member states to also adopt laws and procedures for the use and exploration of outer space.
- All Member States can agree and have a common line of action on the best course of action, reducing threats to space systems in order for space to function as a space of stability and peace.
- The creation of a special group where they must: 1) Take stock of the legal framework concerning space threats, 2) Examine future threats, 3) Make recommendations for possible rules and legislation.
- Continue to ban weapons in space.

Therefore, mitigation efforts are still being made in the last 2 years. Despite this, space debris exists and as it can be seen based on the above, only the existence of common guidelines and international cooperation can act as a brake on the increase of debris.

7.3 Current mitigation studies - 2022

On April 22, 2022, the European Space Agency published its annual space debris report. The first goal of this report was to describe the space environment through observable space debris. The second objective was to focus on the guidelines set for space debris as well as to present measurements of the current situation. Space debris mitigation measures that are internationally accepted are the following [79]:

- Limiting space debris.

As it has been described in previous chapters, the limitation of space debris concerns the residues released during missions. Of course, such a scenario is not realistic, so the debris released during the missions should have a short life and their number should be small.

- Minimizing possible splits in trajectories.

Splits that occur in orbits to be avoided. One reason why splits occur is due to stored energies (batteries, flywheels). If it cannot be avoided, then fissions occur at low altitudes in order for the resulting debris to be lost to the Earth's atmosphere.

- Adoption of break-up procedures.

The 2 orbits that deserve attention are low-spec orbits and geostationary orbits. Trajectories of these classes are vital and must not contain non-functional objects (payloads, rocket bodies). Such objects should be maneuvered to reduce their lifetime (depending on the type of orbit they are on) or moved to other locations if they cause interference.

- Avoid collisions in orbits.

During missions, the systems should be designed to be able to maneuver. Also, the assessment of the probability of accidental collision with a space object should be as small as possible.

Finally, in order to continue efforts for the peaceful use of space, the United Nations has set a series of measures - regulations that it wants to be implemented by 2023. Specifically [80]:

- To provide a task force on the long-term sustainability of space activities with the main role of 1) Identifying the challenges and potential risks arising from space, 2) considering new guidelines for the sustainability of space activities, 3) raising awareness and capacity building between developed and developing countries.
- Promoting cooperation between Member States and non-governmental actors in the peaceful use of space through 1) Registration of all objects launched into space, 2) Mitigation of space debris found in space, 3) Building trust, 4) Contribution of all of Member States for an international regime, 5) Satellite positioning.
- Provision of educational events and technical advisory support for the development of the new member states: 1) In space activities, 2) In satellite communications, 3) In space weather monitoring, 4) In the reduction of risks from space and the response to emergencies , 4) in the development of platforms for solving space-related issues.
- Promote cooperation with space technology and science centers to develop satellite communications, space debris tracking and navigation systems.

7.4 Preventive measures by Space X - 2022

Preventive measures can also be achieved by constructing new generation of satellites. Starlinks is a new generation of satellites and can play a huge role in telecommunications, Internet especially in remote regions, in weather stations, in government, in arctic transport, in disaster risk alert, in trains and trams, containers tracking [81] because they create mega constellations around Earth. Examples of mega constellations are OneWeb constellation and Starlink constellation [82]. In Figures below we see the OneWeb constellation and Starlink constellation.

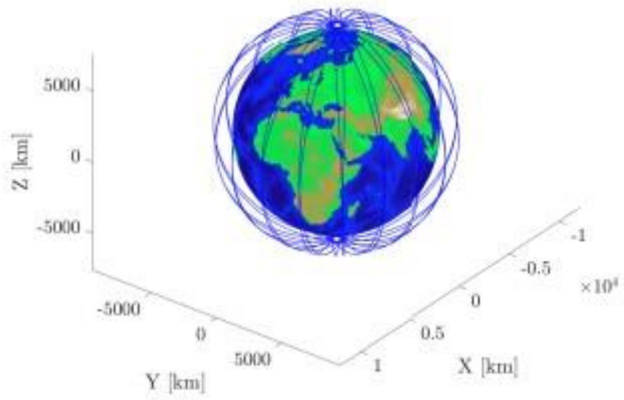

Figure 45: Schematic of the OneWeb constellation.[124]

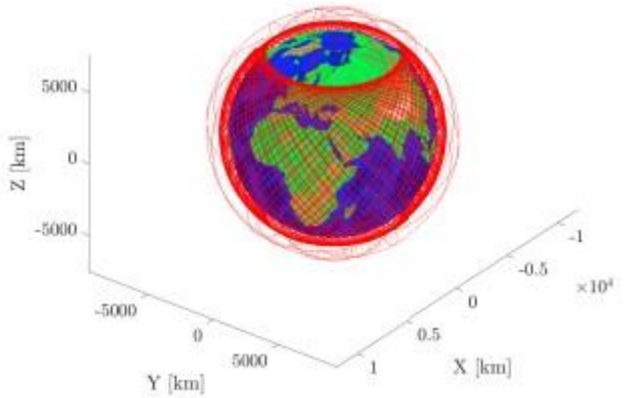

Figure 46: Schematic of the Starlink constellation.[125]

[124]C. Alvaro Arroyo-Parejo, N. Sanchez-Ortiz, and R. Domınguez-Gonzalez, "EFFECT OF MEGA-CONSTELLATIONS ON COLLISION RISK IN SPACE", May 2021, https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/246/SDC8-paper246.pdf

[125] C. Alvaro Arroyo-Parejo, N. Sanchez-Ortiz, and R. Domınguez-Gonzalez, "EFFECT OF MEGA-CONSTELLATIONS ON COLLISION RISK IN SPACE", May 2021, https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/246/SDC8-paper246.pdf

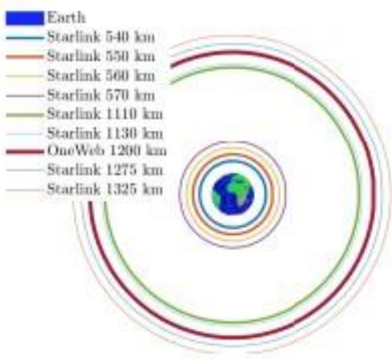

Figure 47: Schematic of mega constellations.[126]

NASA concerns about the proposed Starlink network, but Elon Musk with Space X gave reasons not to. These are mentioned above[127]:

- Each Starlink satellite is built with a collision avoidance system capable of producing maneuvers when it is necessary. If there is a probability greater than 1/100000 for collision satellites will operate avoidance maneuvers.
- Space X operators are on call 24 hours a day in order to update their coordination and respond to new data from other companies.
- Each satellite is been tested and their failure ratio is at 1%.
- If it necessary all Starlink satellites operate a self cleaning process at low Earth orbit at 600 kilometers. It means that satellites can naturally de orbit and burnt up in Earth's atmosphere causing no debris at all.

These satellites are constructed to perform a huge amount of maneuvers. In 2019 it is estimated that a Starlink satellite in order to avoid collision performed over 7000 maneuvers[128]. In the same page China wants to send over 10000 satellites on its own, making the collision probability and space conjunction grow. Because of space conjunctions ESA focus on mega constellations[129] as well.

7.5 Astroscale preventive measures

Preventive measures as mentioned above can help reduce the space debris. As the technology evolves another way to prevent the growth of space debris is the removal

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126 C. Alvaro Arroyo-Parejo, N. Sanchez-Ortiz, and R. Domınguez-Gonzalez, "EFFECT OF MEGA-CONSTELLATIONS ON COLLISION RISK IN SPACE", May 2021, https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/246/SDC8-paper246.pdf

127 Space X and Starlinks: https://www.pcmag.com/news/spacex-heres-why-starlink-poses-no-orbital-hazard

128 Satellite and space conjunction: https://www.npr.org/2022/04/06/1091308672/amazon-s-satellite-fleet-has-some-experts-even-more-worried-about-space-congesti

129 ESA mega constellations: ESA - Managing mega-constellations

strategies. Astroscale is the first private company with a vision for the safe and sustainable development of space for the benefit of future generations, and the only company dedicated to on – orbit servicing across all orbits. It founded in 2013. Astroscale[130] is developing innovative solutions for space situational awareness, active debris removal, and mitigate the growing and hazardous build up of space debris.

On 4th May 2022[131] Astroscale announced that successfully succeeded the complex rendezvous operation between satellites and uncontrolled object. Although the Rendezvous completed the capture still remains. Elsa-D mission was a mission in order to remove space debris from the field. Despite the capture Elsa-D mission in order to prevent the growth of space debris has brought to light key technologies as:

- Autonomous guidance navigation and control algorithms.
- Closed loop control with on board navigation techniques.
- Magnetic capture mechanisms.
- GPS and ground based observations.
- Autonomous thruster rendezvous maneuvering and attitude control.

On 27th May 2022[132] OneWeb, Astroscale United Kingdom, and European Space Agencies partner to launch space debris servicer Elsa-M with an investment 14.8 million Euros. The goal is to support the advancement of next generation technologies ranging from artificial intelligence to new payload and user terminal technology to support the space debris removal.

7.6 ClearSpace preventive measures

ClearSpace is a startup company in Swiss established by an experienced team of space debris researchers based at Ecole Polytechnic Federale de Lausanne research institute. Supported by ESA'S safety program the goal is to contribute in cleaning space while also demonstrating new technologies for space debris removal. The debris removal will also contribute as preventive measures. The mission ClearSpace-1 planned for launch in 2025[133].

At May 2022 ClearSpace is joining the Net Zero Space a French forum in order to avoid generating space debris and actively remove space debris from orbits. This platform brings together major industry players to collect the threat from space debris and ensure that space operations are safe and sustainable.

For ClearSpace the space debris problem exists because of space activities. Luc Piguet CEO and Co-founder says "By taking part in this initiative, we reiterate our commitment

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130 Astroscale: https://astroscale.com/about-astroscale/about/

131 Astroscale and ELSA-D: https://astroscale.com/astroscales-elsa-d-mission-successfully-completes-complex-rendezvous-operation/

132 Astroscale: https://astroscale.com/oneweb-astroscale-and-the-uk-and-european-space-agencies-partner-to-launch-space-junk-servicer-elsa-m-with-e14-8-million-investment/

133 ClearSpace: https://www.esa.int/Space_Safety/Clean_Space/ESA_commissions_world_s_first_space_debris_removal

to a safer and more sustainable space ecosystem. The cost-effective debris removal and spacecraft disposal solutions we develop are key building blocks of a thriving, resilient and sustainable space economy”[134].

As the years goes by space debris problem is treated by a huge amount of organizations. Space X for example has started to build the Starlinks with no probabilities of producing Space debris. Similar pattern follow and other companies such as Astroscale and CleanSpace. The politics of these organizations is to prevent the growth of space debris and furthermore to reduce them from the space field. Although debris removal is something new to the space community with the preventive measures can have a better result.

[134] ClearSpace today: https://clearspace.today/clearspace-joins-the-net-zero-space-initiative-to-reduce-orbital-junk/

8. TODAY'S DEBATE

8.1 Introduction

In this chapter there is a small introduction about what is really happening in the last 2 years. Despite the measures put in place to mitigate space debris, the behavior of the major powers is quite different. Due to the development of technology and the desire to increase superiority, anti-satellite weapons in space have increased. Therefore, the behavior of the major powers will be analyzed as well as what is really happening with the existence of anti-satellite weapons.

8.2 The behavior of the great powers and the return of anti-satellite weapons

Before the end of the cold war, the anti-satellite programs used in space by the USSR and the USA had ceased to be used. The appearance of new powers, such as China and India, and the competition between them brought the anti-satellite programs to the fore again, as stated by the study of Kolovos Alexandros entitled "Space as the central field of competition of the great powers" [83]. The importance that the United States shows in space is not unnoticed by countries like China, Russia. In recent wars, China has noticed that much weight is given to satellite systems. So, these are the initial target based on the Stares study P entitled "The Military Uses of Space: Does Britain Have a Choice?" [84].

For the security of the interests of the great powers, a great possibility is the technology that tends to destroy or disarm the enemy's satellite systems, even if this action results in space debris or permanent contamination of the space field. Such efforts have been made by Russia and China to disarm the United States. Also according to “Defense Intelligence Agency" Russia and China’s doctrines show that they consider Space important for modern warfare and that anti-satellite capabilities are a reduction in US military effectiveness based on the US Department of Defense study entitled "Challenges to Security in Space" [85].

A beginning of the use of anti-satellite technologies in the field of space was carried out by China in 2005-2006 which indicates the effort of UN as well as other organizations for space security. Specifically, in 2006, the director of the US National Reconnaissance Office (NRO) stated that China is using technology to blind US satellites [135]. In fact, in 2007, according to Jessica West and Lauren Vyse's study titled “Weapons Control in Space, Status, Timeline and Analysis” [13]China conducted the first test of an anti-satellite weapon. It destroyed a 900 km high satellite causing 1500 pieces of space debris. This act led to not to use anti-satellite weapons that cause space debris in the space field. In 2013 China again raised suspicions as the technology it released into space could destroy a geostationary satellite 36,000 kilometers high.

Russia believes that space dominance will be the determining factor in future conflicts according to Jackson, N J's study entitled "Space in Russia's Security Strategy" [87]. With the end of the Soviet war, Russia did not deal with anti-satellite weapons mainly for

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[135] Ferster, W., Colin, C. (October 2, 2006). “NRO Confirms Chinese Laser Test Illuminates US Spacecraft,” Defense News. https :// spacenews . com / nro - confirms - chinese - laser - test - illuminated - us - spacecraft /

economic reasons. In 2009, however, an event brought the revision when a Russian satellite collided with an American one, which resulted in 2,000 pieces of space debris. In fact, during the years 2015 [136]- 2020, Russia conducted 9 tests of anti-satellite weapons. According to the US space administration if these tests are tried on real satellites, they will cause a large amount of debris [88].

France is the third country to build and launch its own satellite [83]. Having the greatest power of the European countries in the space sector, it emphasized the protection of its military satellites. In 2019, the president E. Macron transferred space command to the air force to provide space surveillance. In addition, the defense minister brought to the fore a new program that would provide protection for its satellites [89]. This fact combined with the ground radars and telescopes it has given the ability to detect objects at a height of 1500 kilometers high [83].

On March 27, 2019 India had an anti-satellite test which created a cloud of high velocity space debris in Low Earth Orbit. Their target was Microsat-R with mass 740 kg, orbit 268km x 289km and inclination 96.60 degrees. NASA criticized this phenomenon as the test occurred space debris. From this collision the number of objects larger than 1cm is about 6587 and larger than 0.1cm is about 7.22 x 100000. The impact of other debris fragments with the fragments created by the India anti – satellite test leads to secondary space debris which can create more debris in space field [90].

On April 18, 2022, the US government announced a commitment not to conduct destructive tests of direct-ascent anti-satellite (ASAT) missiles. The declaration solidifies tacit US policy since 2008 and reinforces recent efforts to promote responsible behavior in space [137].

However, it is pointed out that the existence for world peace as well as the peaceful use of the space field is quite difficult with the development of technology and the great interests of the great powers. As long as there are weapons that can be used in space then the risk of contamination of the space field will increase. The above US initiative should be followed by other countries.

8.3 Categories of great powers

The use of anti-satellite weapons in space has led to an increase in space debris. Russia's ever-increasing testing led the United States of America and the United Kingdom to accuse it in 2020 as Jessica West and Lauren Vyse 's study titled “Weapons Control in Space, Status, Timeline and Analysis” [13] states how it degrades outer space [138]by using anti-satellite weapons. Specifically, the United States accused Russia of conducting tests and enhancing the development of weapons that threaten American satellites.

[136]Russia and anti-satellite tests: https://www.iiss.org/blogs/analysis/2021/11/russia-conducts-direct-ascent-anti-satellite-test

[137] https://swfound-preprod.azurewebsites.net/news/all-news/2022/04/swf-applauds-us-policy-to-commit-not-to-conduct-destructive-asat-tests-urges-other- states-to-join

[138]US and UK accuse Russia: https://www.cbc.ca/news/science/russia-anti-satellite-weapon-space-allegation-us-1.5661108

In 2021, [13] Russia using an anti-satellite weapon [139]on November 15, destroyed an inactive Soviet Union satellite. The collision created over 1500 pieces of space debris in the field. According to NASA 's bulletin, the International Space Station's flight control team disseminated the breakup to the space station crew and recommended that they take emergency procedures. Based on this incident, the United States of America, specifically Anthony Blinken, characterized Russia's test as irresponsible and reckless, threatening world peace and the field of outer space[140].

China is also moving at a similar page. In 2021, China launched a hypersonic weapon [141]over the South China Sea. This technology involved a technological advance with a speed 5 times the speed of sound. Of course, this discovery worried the United States and the Pentagon because of the many efforts China is making in the field of military weapons [91]. Again, in this case, the United States stated that "it will continue to maintain capabilities for defense and deterrence against a range of threats from China" [142].

Therefore, efforts to dominate space are something that will bring about the increase of anti-satellite weapons together with space debris. It degrades peace, threatens humanity and pushes space activities to an end.

8.4 NATO action

For the protection of space activities in 2019, [13] the regional military organization North Atlantic Treaty Organization (NATO)[143] established for the first time a Space Policy in order to have a common line between member states [144]. NATO, recognizing that space is the 5th operational area, defined the basic principles that should be followed by its countries, as stated by the organization's own report entitled " NATO 's general space policy " [92]:

- Key roles of NATO in space: 1) To integrate issues related to collective defense, crisis management, where necessary, into cooperative security. 2) To act as a forum for consultation and exchange of information on space developments. The consultations should mainly cover issues such as possible threats, challenges, weak points, the development of an appropriate legislative framework in space activities and rules of conduct. 3) To provide assurance of effectiveness in space

[139]Russia conducts a direct-ascent Kinetic ASAT-test: https://www.iiss.org/blogs/analysis/2021/11/russia-conducts-direct-ascent-anti-satellite-test

[140]Russia ASAT-test: https://abcnews.go.com/International/wireStory/russia-rejects-accusations-endangering-iss-astronauts-81199632

[141]China and ASAT: https://www.ft.com/content/a127f6de-f7b1-459e-b7ae-c14ed6a9198c

[142]China and ASAT: https://www.ft.com/content/a127f6de-f7b1-459e-b7ae-c14ed6a9198c

[143]NATO and Space Policy: https://www.airforcemag.com/nato-publishes-overarching-space-policy-outlines-4-roles-it-could-play/

[144]NATO and Space Policy: https://www.airforcemag.com/nato-publishes-overarching-space-policy-outlines-4-roles-it-could-play/

activities, missions and activities concerning the alliance itself. 4) To provide facilitation and interoperability between services.
- Providing support to space operations: 1) Awareness of the state of the space field in order to identify potential risks and threats from space as well as to make mitigation proposals. 2) To provide spatial capabilities for situational awareness and decision-making and planning. 3) The monitoring of the atmosphere, the sea and the space environment is necessary for the proper planning of space missions and operations. 4) In order to ensure control, securing telecommunications is a necessary condition. 5) In every mission there should be positioning and navigation. 6) Timely and valid warning that contributes to the defense.
- Deterrence, defense, and resilience: In order for the alliance to be able to cope with any possible danger, it should: 1) Each member state recognizes that outer space is suitable for conflict prevention. Also, the alliance should consider a series of possible threats and their prevention. 2) Developing a common understanding of concepts such as the role of space in crisis or conflict. 3) Development of guidelines on space-based products and services.
- Strengthening partnerships: The NATO alliance will work with international organizations such as the United Nations and the European Union on space-related issues.
- Attacks to, from, or within the space domain present a clear challenge to Alliance security. Such actions should be avoided in order to ensure safety and prosperity in outer space.
- The role of this Alliance will be in accordance with international space law.

However, the growth of anti-satellite systems has increased due to the concern of major powers. The United States of America is trying to maintain its dominant role in space, while other powers are trying to compete with it. Their existence may undermine world peace and create space debris, but there are still efforts to improve security. NATO and the UN are trying to bring order. Space is space as described above as the 5th operational domain that provides many advantages and it would be a mistake to use it as yet another space for conflict.

8.5 Preventive strategies or removal strategies

In this section we present which is the best strategy[145] for a clean space. As we mentioned before we have the prevention strategies and the removal strategies. Prevention strategies focus on how we can prevent space debris. Avoiding collisions, Batteries and accidental collisions are more of them in order to reduce them. An expanding sector in this section is about the space debris monitoring. Telescopes with large size and radars are always in action. While this is a good idea the collision avoidance, space debris tracking and other preventive measures are not going to solve the problem.

From the other hand we have the removal strategies. Removal strategies focus on how we can remove debris from the space field. Tethers, balloons solar nails and active decommissioning devices are all examples of being able to decompose satellites at the end of their live. There are several studies for removal techniques, but not all of them are

[145] Space Debris Prevention or Mitigation: https://spacenews.com/op-ed-space-debris-prevention-remediation-or-mitigation/

technologically mature due to technologically challenges. Although there are not various technologies for the space debris removal whatever is ready is better than doing nothing.

For a clean space field we need a combination between these strategies. First preventive measures are the first actions that need to take place and then the development of efficient and effective technologies for the removal strategies. Taking all these recommendations into consideration in order to have a better result, we need peace and cooperation between Nations.

Although there are preventive and removal procedures, the reality is different. As the technology evolves the great powers want domination over the space field. For this reason they develop and test anti satellite weapons which can produce a huge amount of space debris. Anti satellite weapons must be forbidden. Exception only for a threat that come from outer space. The only way to succeed a ban in anti satellite weapons is with a stricter legislation on space and its supervision by competetions.

9. CONCLUSIONS ON SPACE DEBRIS MITIGATION

In this section, the conclusions obtained from this thesis are recorded. Several efforts have already been made to mitigate space debris. Nevertheless, they are not enough, as the problem continues to threaten not only the space field but also life on Earth. Consequently, some conclusions that have been reached are as follows:

- In order not to produce space debris during collisions, more weight should be given to the materials used in spacecraft. Shielding against space debris is a priority to prevent damage and other debris in space.
- A great emphasis should also be given to the energy sources of the spaceships. Batteries, propellants, electrical circuits require special attention as they cause explosions in technologies.
- Emphasis on spacecraft tracking systems. The detail in monitoring is the key to valid and timely preparation to deal with any phenomenon.
- Adoption of technologies that benefit space debris removal procedures.
- Emphasis on international space law related to space debris. The international treaties related to space are: [93]1) The Outer Space Treaty. 2) The Rescue Agreement. 3) The Liability contract. 4) The registration contract. 5) The Moon Agreement. All of these are unrelated to space debris. So, one more treaty would limit things quite a bit when it comes to space debris.
- Since space missions continue without giving space debris a basis there should be a space regime that gives basis to [94]: 1) kinetic hazards from space debris, 2) nuclear hazards, 3) chemical hazards, 4) on space debris in orbit, 5) on ways to clean up the space field.
- United Nations must place great emphasis on the creation of an international regime so that all states follow a common line. The creation of a special body that will be responsible for the observance of space regulations in order to comply with the regulations. Space is a shared space and must be kept safe.
- UN effort to ban anti-satellite weapons in space. These weapons, in addition to the space debris they create, endanger global peace and public health. Moderation is therefore necessary for world peace and the well-being of mankind. Already the USA with a statement by Vice President Camalla Harris recused themselves from using destructive anti-satellite tests that produce debris.
- Adoption of correct norms and behaviors for the exploration and use of space for the benefit of all states taking into account developing countries. Common will for global cooperation and peace [95].
- Space debris tracking from the United States of America concludes that much of the debris comes primarily from spacecraft equipment (crumpled thin plates) [96]Therefore, studies could be done on the objects so that they completely disintegrate over time so as not to create space debris.

The above objects will be the subject of new future efforts to remove space debris and clean up the space field. These objects aim at preventive actions and not at removal strategies. The upgrading and interest of humans in space lay the foundation for the removal strategies for the space environment and also for the continuation of the missions.

From my personal view, in order to achieve a better result we must focus in preventive measures and after that in the removal strategies. Preventive measures are quite important but themselves withough the removal strategies cannot achieve the space debris problem. In order to achieve a clean space field each state must follow preventive measures, removal strategies from organizations such as IADC, COPUOS under a common space policy. Most important of all a commitment for all states is necessary to implement whatever decisions they make. Corporation and peacefully purposes for space can achieve a better result for the space debris problem.

10. EPILOGUE

Space debris exists and is now a fact. As a new object, it threatens the states and organizations involved in space activities. Although the studies started since 1981, an absolute solution has not been found in order to clean the space field from these debris. Prevention strategies tend to pay off when followed faithfully but, by themselves, are not enough to promise quick and satisfying results. Major organizations such as NASA and ESA are trying to mitigate the situation through space debris reduction standards, becoming a positive influence for new countries entering space.

But the problem of space debris continues to exist since there is no political will from all states. The evolution of technology and the recognition of space as the 5th operational domain have mainly led the major powers to a competition for who will dominate space leading to the development of anti-satellite technologies. Global organizations such as United Nations through a special committee responsible for the peaceful use of space COPUOS enables states to present their ideas, their findings on mitigation but no agreement is reached once there is no consensus among them. Also, the Inter- Agency Space Debris Committee IADC is trying to solve the problem of space debris from a technical point of view with regulations.

The urgent need for more programs should be realized in all states and organizations. In order to have the continuation of space activities, global cooperation and mutual understanding of those involved is needed and not global domination as a goal. History has shown that when there is no cooperation and peace, problems that threaten humanity are created. Space debris is here to stay unless there is a common will from all nations.

However, the problem is now perceived, and humanity has proven that it can cope. Prevention strategies combined with removals can give encouraging results as long as there is cooperation and political will from all involved. Thus, humanity will be freed from the problem of space debris and will continue space exploration without threats.

ABBREVIATIONS – ACRONYMS

Table 6: Abbreviations.

LEO	Low Earth Orbit
MEO	Medium Earth Orbit
GEO	Geostationary Earth Orbit
NASA	National Aeronautics and Space Administration
ESA	European Space Agency
EU	European Union
IADC	Inter-Agency Space Debris Coordination Committee
UNCOPUOS	United Nations of the Peaceful Uses of Outer Space
USA	United States of America
UN	United Nations
ISS	International Space Station
TCSS	Technical Committee on Space Systems
SIPA	Agency for the Processing of Satellite Image
GEODSS	Ground-Based Electro-Optical Deep Space Surveillance
ASI	Italian Space Agency
CNES	Center National D'Etudes Spatiales
CNSA	China National Space Administration
CSA	Canadian Space Agency
DRL	German Aerospace Center (German)
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
KARI	Korean Aerospace Research Institute
SSAU	State Space Agency of Ukraine
ROSCOSMOS	Russian Space Agency
IAEA	International Atomic Energy Agency
ITU	International Telecommunication Union
NORAD	North American Aerospace Defense Command
PAROS	Prevention of an arms in Outer Space
GMES	Global Monitoring for Environment and Security
SSA	Space Situational Awareness
FPGA	Field Programmable Gate Array

CGE	Group of Governmental Experts
SST	Space Surveillance Telescope
SWE	Space Weather Environment
NEO	Near Earth Objects
NATO	North Atlantic Treaty Organization
NVP	Net Present Value
RCS	Radar Cross Section
TCBM	Transparency and Confidence Building Measures

ANNEX I – VOTING OF UN MEMBER STATES

The annex will present images of the UN vote on the status of international agreements on activities from 1 January 2022.

A) Treaties of the United Nations: 1) Treaty on the Principles Governing the Activities of States in the Exploration and Use of Outer Space including the Moon and Other Celestial Bodies, 2) Agreement on the Rescue of Astronauts, 3) Convention on International Responsibility for damages caused by space objects, 4) Convention on the registration of objects, 5) Agreement on the moon and other celestial bodies.

B) Other agreements: 6)Treaty prohibiting weapons tests in the atmosphere in space and under water,7)Convention on the distribution of program signals transmitted by satellite, 8)Agreement on international communications, 9)Agreement on the establishment of Intersputnik , 10) Convention on the establishment of the European Space Agency, 11) Agreement of the Arab company for space communications, 12) Cooperation agreement on the use and exploration of space, 13) Convention on the international mobile satellite organization, 14) Convention for the establishment of European telecommunications, 15) Convention for the establishment of the European organization for the exploitation of meteorological satellites, 16) International constitution and convention of Telecommunications.

(R = ratification, acceptance, approval, accession or succession; S = signature only;
D = declaration of acceptance of rights and obligations)

State, area or organization	*United Nations treaties*					*Other agreements*										
	(1) 1967 OST	*(2) 1968 ARRA*	*(3) 1972 LIAB*	*(4) 1975 REG*	*(5) 1979 MOON*	*(6) 1963 NTB*	*(7) 1974 BRS*	*(8) 1971 ITSO*	*(9) 1971 INTR*	*(10) 1975 ESA*	*(11) 1976 ARB*	*(12) 1976 INTC*	*(13) 1976 IMSO*	*(14) 1982 EUTL*	*(15) 1983 EUM*	*(16) 1992 ITU*
Afghanistan	R					R		R	R							R
Albania														R		R
Algeria	R		R	R		S		R			R		R			R
Andorra														R		R
Angola								R								R
Antigua and Barbuda	R	R	R	R		R							R			R
Argentina	R	R	R	R		R	S	R					R			R
Armenia	R	R	R	R	R	R	R	R						R		R
Australia	R	R	R	R	R	R	R	R					R			R
Austria	R	R	R	R	R	R	R	R		R				R	R	R
Azerbaijan	R							R	R					R		R
Bahamas	R	R				R		R					R			R
Bahrain	R		R	R			R	R			R		R			R
Bangladesh	R					R		R					R			R
Barbados	R	R						R								R
Belarus	R	R	R	R		R			R				R	R		R
Belgium	R	R	R	R	R	R	S	R		R			R	R	R	R
Belize																R
Benin	R		R			R	R	R								R
Bhutan						R		R								R

Figure 48: Voting of states [146].

146 https://www.unoosa.org/res/oosadoc/data/documents/2022/aac_105c_22022crp/aac_105c_22022crp_10_0_html/AAC105_C2_2022_CRP10E.pdf

Bolivia (Plurinational State of)	S	S				R		R					R			R
Bosnia and Herzegovina	R	R	R			R	R	R					R	R		R
Botswana	S	R	R			R		R								R
Brazil	R	R	R	R		R	S	R					R			R
Brunei Darussalam								R					R			R
Bulgaria	R	R	R	R		R			R			R	R	R	R	R
Burkina Faso	R					S		R								R
Burundi	S		S	S		S		S[a]								R
Cambodia			S													R
Cameroon	S	R				S		R					R			R
Canada	R	R	R	R		R		R		[b]			R			R
Cape Verde						R		R								R
Central African Republic	S		S			R		R								R
Chad						R		R								R
Chile	R	R	R	R	R	R	R	R					R			R
China	R	R	R	R		R		R					R			R
Colombia	S	S	R	R		R	R	R					R			R

Figure 49: Voting of states [147].

State, area or organization	United Nations treaties					Other agreements										
	(1) 1967 OST	*(2) 1968 ARRA*	*(3) 1972 LIAB*	*(4) 1975 REG*	*(5) 1979 MOON*	*(6) 1963 NTB*	*(7) 1974 BRS*	*(8) 1971 ITSO*	*(9) 1971 INTR*	*(10) 1975 ESA*	*(11) 1976 ARB*	*(12) 1976 INTC*	*(13) 1976 IMSO*	*(14) 1982 EUTL*	*(15) 1983 EUM*	*(16) 1992 ITU*
Comoros								R					R			R
Congo								R								R
Cook Islands													R			
Costa Rica		S	S	R		R	R	R					R			R
Côte d'Ivoire						R	S	R								R
Croatia		R	R			R	R	R					R	R	R	R
Cuba	R	R	R	R				R	R			R	R			R
Cyprus	R	R	R	R		R	S	R					R	R		R
Czech Republic	R	R	R	R		R		R	R	R		R	R	R	R	R
Democratic People's Republic of Korea	R	R	R	R				R	R				R			R
Democratic Republic of the Congo	S	S	S			R		R								R
Denmark	R	R	R	R		R		R		R			R	R	R	R
Djibouti											R					R
Dominica																R
Dominican Republic	R	S	R			R		R								R
Ecuador	R	R	R			R		R					R			R
Egypt	R	R	S			R		R			R		R			R

Figure 50: Voting of states [148].

147 https://www.unoosa.org/res/oosadoc/data/documents/2022/aac_105c_22022crp/aac_105c_22022crp_10_0_html/AAC105_C2_2022_CRP10E.pdf

148 https://www.unoosa.org/res/oosadoc/data/documents/2022/aac_105c_22022crp/aac_105c_22022crp_10_0_html/AAC105_C2_2022_CRP10E.pdf

Georgia		R						R	R				R	R		R
Germany	R	R	R	R		R	R	R	R	R			R	R	R	R
Ghana	S	S	S			R		R					R			R
Greece	R	R	R	R		R	R	R		R			R	R	R	R
Grenada																R
Guatemala			S		S	R		R								R
Guinea								R								R
Guinea-Bissau	R	R				R		R								R
Guyana	S	R														R
Haiti	S	S	S			S		R								R
Holy See	S							R						R		R
Honduras	S		S			R	R	R								R
Hungary	R	R	R	R		R		R	R	R		R	R	R	R	R
Iceland	R	R	S			R		R					R	R	R	R

Figure 51: Voting of states [149].

European Organization for the Exploitation of Meteorological Satellites		D	D	D												
European Space Agency		D	D	D												
European Telecommunications Satellite Organization			D	D												
Intersputnik International Organization of Space Communications		D	D	D												
Total R (ratification, acceptance, approval accession or succession)	**112**	**99**	**98**	**72**	**18**	**126**	**38**	**149**	**26**	**22**	**21**	**10**	**103**	**49**	**30**	**193**
Total S (signature)	**23**	**23**	**19**	**3**	**4**	**11**	**10**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total D (declaration of acceptance of rights and obligations)	**0**	**3**	**4**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Figure 52: Voting results [150].

149 https://www.unoosa.org/res/oosadoc/data/documents/2022/aac_105c_22022crp/aac_105c_22022crp_10_0_html/AAC105_C2_2022_CRP10E.pdf

150 https://www.unoosa.org/res/oosadoc/data/documents/2022/aac_105c_22022crp/aac_105c_22022crp_10_0_html/AAC105_C2_2022_CRP10E.pdf

REFERENCES

[1] US Congress, "Office of Technology Assessment", *Orbiting Debris: A Space Environmental Problem-Background Paper*, OTA-BP-ISC-72 Washington, DC: US Government Printing Office, September 1990. http://ota.fas.org/reports/9033.pdf

[2] S. Habimana, "Space Debris: Reasons, types, impacts and Management", *VR Ramakrishna Parama*, Indian Journal of Radio and Space Physics, Vol 46, March 2017. (PDF) Space debris: Reasons, types, impacts and management | Sylvestre Habimana - Academia.edu

[3] Χ. Παναγιωτόπουλος, "Ευθύνη από τα διαστημικά συντρίμμια", Διπλωματική Εργασία, Αθήνα, Ελλάδα, 2014-2015. https://pergamos.lib.uoa.gr/uoa/dl/frontend/file/lib/default/data/2838965/theFile

[4] D.Rex, "Will Space Run out of Space? The orbital Debris Problem and its mitigation", *Space Policy* article 'Mitteilungender TU Braunschweig', Carolo-wilhelmina, vol 14, Page 95-105, May 1998. Will space run out of space? The orbital debris problem and its mitigation - ScienceDirect

[5] F.Alby, D.Alwes, L.Anselmo, H.Baccini, C.Bonnal, R.Crowther, W.Flury, R.Jehn, H.Klinkrad, C.Portelli, R.Tremayne Smith, "The European Space Debris Safety and Mitigation Standard", *Advances in Space Researcher*, Darmstadt Germany, vol 34, Page 1260 - 1263, 10.106/j.asr.2003.08.043 , August 2001. Microsoft Word - 3sdc_paper_cro (esa.int)

[6] L. Hall, The history of Space Debris, Space Traffic Management Conference, Jim Henderson Welcome Center, Embry-Riddle Aeronautical University - Daytona Beach, September 2014. https://commons.erau.edu/cgi/viewcontent.cgi?article=1000&context =stm

[7] JM Hutagalung C. I Tobing,J. Debastri, RT Amanda , "Space debris as environmental threat and the requirement of Indonesia's prevention regulation", *Earth and Environmental Science Conference*, Indonesia , 10.1088/1755-1315/456/1/012081 , 2020. Space debris as environmental threat and the requirement of Indonesia's prevention regulation - IOPscience

[8] Alec J. Cavaciuti, Joseph H. Heying, and Joshua Davis, “IN-SPACE SERVICING, ASSEMBLY, AND MANUFACTURING FOR THE NEW SPACE ECONOMY ”, CENTER FOR SPACE POLICY AND STRATEGY, July 2022, https://csps.aerospace.org/sites/default/files/2022-07/Cavaciuti-Davis-Heying_ISAM_20220715.pdf

[9] "Space Weather Operations, Research and Mitigation Working Group, Space Weather, Security and Hazards Subcommittee Committee on Homeland and National Security of the National Science & Technological Council", *National Space Weather Strategy and Action Plan*, Washington DC, March 2019. https :// trumpwhitehouse . archives . gov / wp - content / uploads /2019/03/ National - Space - Weather - Strategy - and - Action - Plan -2019. pdf

[10] Laurence Nardon, Christophe Venet, Space Weather and NEOS in the European Space Policy, ISBN 978-2-86592-901-6, August 2011. https://www.ifri.org/sites/default/files /atoms/files/europespaceseries6neoandswe.pdf

[11] P. Lubos, "Space Debris Mitigation and Prevention: How to build a Stronger International Regime", *Astropolitics* 2:2 215-226, 10.1080/14777620490489471, August 2004. https://www.tandfonline.com/doi/abs/10.1080/14777620490489471

[12] D. SFPortree, J. P. Loftus, Jr L. B. Johnson, *Orbital Debris: A chronology*, National Aeronautics and Space Administration, NASA/TP-1999-208856, January 2009. https://ntrs.nasa.gov/api/citations/19990041784/downloads/19990041784.pdf

[13] J. West, L. Vyse, Arms Control in Outer Space Status, timeline and analysis, Plowshares report, March 2022. https://ploughshares.ca/wp-content/uploads/2022/03 /ArmsControlOuterSpace_Report.pdf

[14] USSR, "Transmitting draft treaty", CD/274, Letter 6 April 1982, 3p, Geneva https://digitallibrary.un.org/record/33285?ln=en

[15] General Assembly, "Conclusion of a treaty on the prohibition of the stationing of weapons of any kind in outer space", *United Nations* https://digitallibrary.un.org/record/27062?ln=en

[16] L. Stojak, The Non-Weaponization of Outer Space, International Security Research and Outreach Program International Security Bureau, May 2002. https :// www . international . g.c. _ ca / arms - armes / assets / pdfs / stojak 2002. pdf

[17] P. Gasparini Alves, "Prevention of an Arms Race in Outer Space: A Guide to the Discussions in the Conference on Disarmament", ISBN 92-9045-056-8, Sales No. GV.E.91.0.17, NewYork1991. https ://

unidir . org / sites / default / files / publication / pdfs / prevention - of - an - arms - race - in - outer - space - a - guide - to - the - discussions - in - the - cd - en -451. pdf

[18] J. P. Loftus, A. E. Potter, *US Studies in Orbital Debris*, Acta Astronautica, vol 24, Page 333-341, DOI 10.1026/0094-5765(91)90183-6, Great Britain, 1991. https://ui.adsabs.harvard.edu/abs/1991AcAau..24..333L/abstract

[19] P. Lubos, *Management of outer space, Space Policy*, Issue 3, p.189-198, DOI: 10.1016/0265-9646(94)90070-1, 1994, https://ui.adsabs.harvard.edu/abs/ 1994SpPol..10..189P/abstract

[20] United Nations, *Technical Report on Space Debris*, A/AC.105/720, Sales No. E.99.I.17, ISBN:92-1-100813-1,NewYork1999, https://www.orbitaldebris.jsc.nasa.gov/library/un_report_on_space_debris99.pdf

[21] Dr. M. Benko, Dr. K.-U. Schrogl, THE 1999 UNCOPUOS TECHNICAL REPORT ON SPACE DEBRIS AND THE NEW WORK PLAN ON SPACE DEBRIS (2002-2005): PERSPECTIVES AND LEGAL CONSEQUENCES, Technical Subcommittee on the Peaceful Uses of Outer Space, SAO/NASA Astrophysics Data System (ADS)), February 1999. https://articles.adsabs.harvard.edu//full/2001ESASP.473..857B/0000862.000.html

[22] R. Walker, C.Martin, H.Stokes, J.Wilkinson, H.Sdunnus, S.Hauptmann, P.Beltrami, P.Klinkrad, *Update of the ESA Space Debris Mitigation Handbook*, Reference QINETIQ/KI/SPACE/CR021539, July 2002. https :// nebula . esa . int / sites / default / files / neb _ study /423/ C 14471 ExS . pdf

[23] N.N. Smirnov (Ed.). (2002). *Space Debris: Hazard Evaluation and Debris* (1st ed.). CRC Press. https://doi.org/10.1201/9781482288193

[24] Chobotov VA eta/. *Dynamics of Debris Motion and the Collision Hazard to Spacecraft Resulting from an Orbital Breakup.* The Aerospace Corp., El Segundo, CA. ADA203482.pdf (dtic.mil)

[25] NL Johnson, " Developments in Space Debris Mitigation Policy and Practices", Special Issue Paper 907, Johnson Space Center, USA, DOI 10.1243/09544100JAERO166, October 2006. https://journals.sagepub.com/doi/10.1243/09544100JAERO166

[26] Steering Group, Working Group 4, IADC Space Debris Mitigation Guidelines, Inter Agency Space Debris Coordination Committee, IADC-02-01 Rev. 3, June 2021. IADC (iadc-home.org)

[27] Working Group 4, "Support to the IADC Space Debris Mitigation Guidelines", *Inter Agency Space Debris Coordination Committee,* IADC-04-06 Rev. 5.8, June 2021. IADC-04-06_Support_to_IADC_Guidelines_Rev5_8.pdf

[28] International atomic energy, Applicability of the leak before break concept, ISSN 1011-4289, Austria, June, 1993 https://wwwpub.iaea.org/MTCD/Publications/PDF/te_710_web.pdf

[29] L. Perek. "Safety in the Geostationary Orbit After 1988", IAA-89-632, 40th Congress of IAF. Malaga, 1989. https://www.sciencedirect.com/science/article/abs/pii/009457659190064C

[30] NL Johnson, "Orbital Debris Research in the US, Proceedings of the 4 th European Conference on Space Debris(ESA SP-587)", BitCode 2005ESASP.587....5J, p.5, August 2005, https://articles. adsabs.harvard.edu//full/2005ESASP.587....5J/0000009.000.html

[31] United Nations, Transparency and confidence-building measures in outer space activities, General Assembly A/RES/60/66, December 2005. https :// documents - dds - ny . un . org / doc / UNDOC / GEN / N 05/491/56/ PDF / N 0549156. pdf ? OpenElement

[32] D. Danesy, *Position Paper on Space Debris Mitigation Implementing Zero Debris Creation Zones* (ESA SP-1301, 2004). https://www.esa.int/esapub/sp/sp1301/sp1301.pdf

[33] W. L. Huntley, "Smaller State Perspectives on the Future of Space Governance", *Astropolitics: The International Journal of Space Politics & Policy*, 5:3, 237-271, 2003 https://www.tandfonline.com/doi/abs/ 10.1080/14777620701615145?journalCode=fast20

[34] H. Gilbert, Implementation of the UN Space Debris Mitigation Guidelines in Canada, Canadian Space Agency. https://www.mcgill.ca/iasl/files/iasl /Session_3_Hugues_Gilbert.pdf

[35] United Nations, "Space Debris Mitigation Standards – Canada", *Space Debris Compendium*, September 2015. https://www.unoosa.org/documents/pdf/spacelaw/sd/Canada.pdf

[36] NASA, 'Final Report of the International Space Station Independent Safety Task Force', February 2007, https://www.nasa.gov/pdf/170368main_IIST_%20Final%20Report.pdf

[37] European Parliament Resolution of 10 July 2008 on space and security (2008/2030(INI)), Space and Security, July 2008. https://www.europarl.europa.eu/doceo/document/ TA-6-2008-0365_EN.pdf

[38] Council of the European Union, "Council Conclusions and draft Code of Conduct for Outer Space Activities", 17175/08, Brussels, December 2008. https :// data . consilium . Europe . eu / doc / document / ST -17175-2008- INIT / en / pdf

[39] Marta Lucia, National visions of European Space Governance: Elements for a new institutional architecture, Space Policy, Vol 29, Issue 1, Page 20-27, DOI 10.1016/j.spacepol.2012.12.004, February 2012. https://ui.adsabs.harvard.edu/abs /2013SpPol..29...20M/abstract

[40] United Nations, "Treaty on Prevention of the placement of weapons in outer space and of the threat or use of force against outer space objects", CD/1839, Conference on Disarmament, 2008. https://digitallibrary.un.org/record/633470 ?ln=en

[41] United Nations, *United Nations Treaties and Principles on Outer Space*, ISBN 978-92-1-101164-7, ST/SPACE/11/Rev.2, NewYork, 2008. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1009&context=spacelawdocs

[42] United Nations, "National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris", General Assembly A/AC.105/951, vol V.09-88571 (E) 301209 311209, December 2009. https://www.unoosa.org/pdf/reports/ac105/AC105_951E.pdf

[43] Alain Gaubert, Andre Lebeau, Reforming European space governance, Space Policy, Vol 25, Issue 2, pp 67-68, May 2009. https://www.sciencedirect.com/science/article/abs/pii/S0265964608001057

[44] R. Sebastian, Bruston, Jean & Mathieu, Charlotte & Schrogl, Kai-Uwe, (2009), "Governance of national space activities. Space Policy", vol 25, pages 133-135, DOI 10.1016/j.spacepol.2009.03.003. https://www.researchgate.net/publication/248494356_Governance_of_national_space_activities

[45] United Nations, "Canada on the Merits of Certain Draft Transparency and Confidence-Building Measures and Treaty Proposals for Space Security", 5p, CD/1865, Geneva June 2009. https://digitallibrary.un.org/record/662457?ln=fr

[46] N. Gallagher, "Space Governance and International Cooperation", *Astropolitics: The International Journal of Space Politics & Policy*, 8:2-3, 256-279. : http://dx.doi.org/10.1080/14777622.2010.524131

[47] United States of America, *National Space Policy of the United States of America*, June 2010. https :// obamawhitehouse . archives . gov / sites / default / files / national _ space _ policy _6-28-10. pdf

[48] United Nations, "National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris", General Assembly A/AC.105/C.1/101, Vienna, vol V.11- 87322 (E) 161211 191211, December 2011. https :// www . unoosa . org / pdf / reports / ac 105/ C 1/ AC 105 _ C 1_101 E . pdf

[49] Singer, Michael & Musacchio, John. (2011). An International Environmental Agreement for space debris mitigation among asymmetric nations. Acta Astronautica. 68. 326-337. 10.1016/j.actaastro.2010.08.019. https://escholarship.org/uc/item/7w5912qm

[50] AM Bradley, LM Wein, Space debris: assessing risk and responsibility, Advances in Space Research 43 (9) (2009) 1372–1390, doi: 10.1016/j.asr.2009.02.006. https://www.sciencedirect.com/science/article/abs/pii/S0273117709001240

[51] R. Janovsky, M. Kassebom, H. Lubberstedt, O. Romberg, H. Burkhardt, ¨ M. Sippel, G. Krulle, B. Fritsche, End-of-life de-orbiting strategies ¨ for satellites, in: 54th International Astronautical Congress of the International Astronautical Federation (IAF), 2003 [cited 7/30/2010], URL: /http://www.dlr.de/Portaldata/55/Resources/dokumente/sart/dglr-2002-028. pdfS

[52] Committee On the Peaceful Uses of Outer Space, National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris, General Assembly A/AC.105/C.1/2012/CRP .11, Vienna, vol V.12-50417 (E), February 2012. https://www.unoosa.org/pdf/limited/c1/ AC105_C1_2012_CRP11E.pdf

[53] Committee On the Peaceful Uses of Outer Space, National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris, General Assembly A/AC.105/C.1/2012/CRP .11, Vienna, vol V.12-50417 (E), February 2013. https://www.unoosa.org/pdf/reports /ac105/C1/AC105_C1_108E.pdf

[54] United Nations, "National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris", General Assembly A/AC.105/C.1/2014/CRP.8, Vienna, vol V.14-00640 (E), February 2014. https :// www . unoosa . org / pdf / limited / c 1/ AC 105 _ C 1_2014 _ CRP 08 E . pdf

[55] Masumi Higashide, Kumi Nitta, Sunao Hasegawa, Naomi Onose, Ryo Matsuzawa, Atsushi Takeba, Masahide Katayama, Ballistic Limit of Alamido fiber stacking for sub-millemeter debris impact, ESA 6 th European Conference on Space Debris, vol 6, 2013. https: //conference.sdo.esoc.esa.int/proceedings/sdc6/paper/1

[56] Draft, "Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects", 2014. https :// reachingcriticalwill . org / images / documents / Disarmament - fora / cd /2014/ documents / PPWT 2014. pdf

[57] J. Su, "The European Union Draft Code of Conduct for Outer Space Activities: An Appraisal", *Space Policy*, Vol. 30, 2014, Page 34-39. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2635038

[58] European Union, "DRAFT: International Code of Conduct for Outer Space Activities", March 2014. https :// eeas . Europe . eu / archives / docs / non - proliferation - and - disarmament / pdf / space _ code _ conduct _ draft _ vers _31- march -2014 _ en . pdf

[59] Valero, JL, Alves, J., Gallardo, B., Matute, J., O'Dwyer, A., Paradiso, N. (2015). Contributions of the EU Satcen to a European SST Capability: Technical Elements on Governance and Data Policy. In: Sgobba, T. Rongier, I. (eds) Space Safety is No Accident. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-15982-9_44

[60] Council of the European Union, "Council Decision" (CFSP) 2015/203, February 2015. https :// eur - lex . Europe . eu / legal - content / EL / TXT / PDF /? uri = CELEX :32015 D 0203& from = ET

[61] "Inter-Agency Space Debris Coordination Committee (IADC), 53rd Session of the Scientific and Technical Subcommittee United Nations Committee on the Peaceful Uses of Outer Space", 2016. https :// www . unoosa . org / documents / pdf / copuos / stsc /2016/ tech -26 E . pdf

[62] M. Griffiths, "The Parliamentary Office of Science and Technology", *Post note* (Millbank, London), 355(2010)7. https://www.parliament.uk/globalassets/documents/documents/upload/postpn355.pdf

[63] M. Paul, "Space debris threat to future launches", *New Scientist*, Oct. 2009. https :// www . news scientist . com / article / dn 16584- satellite - collision - creates - copious - space - junk /

[64] EU, "Conference of Disarmament – Working Group on the “Way Ahead”-EU Statement on the Prevention of an Arms Race in Outer Space", Geneva, June 2017. https://www.eeas.europa.eu/node/28329_en

[65] T. Flohrer, H. Krag, “SPACE SURVEILLANCE AND TRACKING IN ESA'S SSA PROGRAMME”, April 2017, https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/242/SDC7-paper242.pdf

[66] Flegel, S., Gelhaus, J., Wiedemann, C., Vorsmann, P., Oswald, M., Stabroth, S., Krag, "The MASTER-2009 Space Debris Environment Model. In: Proceedings of the Fifth European Conference on Space Debris, Darmstadt", 2017, Germany.

[67] ESA Space Debris Office, "ESA’s Annual Space Environment Report", GEN-DB-LOG-00208- OPS-GR, available via, 2017. https://discosweb.esoc.esa.int/ web/guest/statistics

[68] ESA SSA team, "Space Situtional Awareness-Space Weather System Requirements Document", Issue 1, Ref SSA-SWE-RS-RD-0001, September 2013, https://swe.ssa.esa.int/DOCS/SSA-SWE/SSA-SWE-RS-RD-0001_i1r4.pdf

[69] H. Uto, T. Kuwahara, T. Honda, "Orbit Verification Results of the De-Orbit Mechanism Demonstration Qubesat FREEDOM", vol 17, No. 3, pp 295 – 300, DOI 10.2322/TASTJ.17.295, 2019, https://www.jstage.jst.go.jp/article/tastj/17/3/17_17.295/_pdf

[70] NASA, "Qubesat 101 Basic Consepts and Processes for First-Time Qubesat Developers", October 2017, https://www.nasa.gov/sites/default/files/atoms/files/nasa_csli_cubesat_101_508.pdf

[71] NN Smirnov, AB Kiselev, MN Smirnova, VF Nikitin, "Space traffic hazards from orbital debris mitigation strategies", *Acta Astronautica*, vol 109, Page 144-152, April-May 2015. Space traffic hazards from orbital debris mitigation strategies - ScienceDirect

[72] F. Letizia, "ESA Environmental Report on Space Debris Mitigation", *European Space Agency, September 2019*. https://www.sdo.esoc.esa.int/publications/ESA%20Environmental%20Report%20on%20Space%20Debris%20Mitigation_slides.pdf

[73] United Nations, "National research on space debris, safety of space objects with nuclear power sources on board and problems relating to their collision with space debris", General Assembly A/AC.105/C.1/118, Vienna , vol V.20- 06834 (E) 091220 101220, November 2020. https :// www . unoosa . org / oosa / en / ourwork / topics / space - debris / index . html

[74] R. S. Jakhu, K. C. & B. Goswami, "Threats to Peaceful Purposes of Outer Space: Politics and Law", *Astropolitics,* 2020 18:1, 22-50, DOI: 10.1080/14777622.2020.1729061. https://www.tandfonline.com/doi/abs/10.1080/14777622.2020.1729061?journalCode=fast20

[75] NASA Office of Inspector General Office of Audits, *NASA'S Efforts to Mitigate the Risks posed by Orbital Debris*, IG-21-011(A-20-002-00), January 2021. https://oig.nasa.gov/docs/IG-21-011.pdf

[76] "Secretary of Defense 1000 Defense Pentagon Washington", DC 20301 – 1000, Tenets of Responsible Behavior in Space, Washington DC, July 2021. https :// media . defense . gov /2021/ Jul /23/2002809598/-1/-1/0/ TENETS - OF - RESPONSIBLE - BEHAVIOR - IN - SPACE . PDF

[77] ESA, "ESA'S Space Environment Report 2021", May 2021. https :// www . esa . int / Safety _ Security / Space _ Debris / ESA _ s _ Space _ Environment _ Report _2021

[78] United Nations, "Reducing space threats through norms rules and principles of responsible behaviors, General Assembly" A/RES/76/231, 21-19662(E) 050122, Vienna 2021. https://documents-ddsny.un.org/doc/UNDOC/GEN/N21/417/21/PDF/N2141721.pdf?OpenElement

[79] ESA Space Debris Office, "ESA'S annual Space environmental report", Issue 6.0, GEN-DB-LOG-00288-OPS-SD, April 2022. https :// www . sdo . esoc . esa . int / environment _ report / Space _ Environment _ Report _ latest . pdf

[80] Committee on the Peaceful Uses of Outer Space, Proposed program budget for 2023, General Assembly A/77/6, Vienna, 22-04340(E) 060422, March 2022. https :// www . unoosa . org / res / oosadoc / data / documents /2022/ a 77/ a 776 _ sect _ 6 _0 _ html / A _ 77_06 _ SECT -06 E . pdf

[81] ESA, "ESA MEGA CONSTELLATIONS ENABLERS FOR NEW SERVICES AND APPLICATION OPPORTUNITIES", Issue 1, 4000118725/17/UK/AD, September 2018. https://artes.esa.int/system/files/AB5%20ESA%20MC8585%20Final%20Report%20FV.pdf

[82] C. Alvaro Arroyo-Parejo, N. Sanchez-Ortiz, and R. Dominguez-Gonzalez, "EFFECT OF MEGA-CONSTELLATIONS ON COLLISION RISK IN SPACE", May 2021, https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/246/SDC8-paper246.pdf

[83] Α. Κολοβός, Το Διάστημα ως Κεντρικό Πεδίο Ανταγωνισμού των Μεγάλων Δυνάμεων, Ινστιτούτο Διεθνών Ευρωπαϊκών και Αμυντικών Αναλύσεων, Πανεπιστήμιο Μακεδονίας, Κείμενο Εργασίας no 4, Απρίλιος 2021. http://idea.uom.gr/wp-content/uploads/2021/05/%CE%91%CE%BB%CE%AD%CE%BE%CE%B1%CE%BD%CE%B4%CF%81%CE%BF%CF%82-%CE%9A%CE%BF%CE%BB%CE%BF% CE%B2%CF%8C%CF%82-%CE%A4%CE%BF-%CE%94%CE%B9%CE%AC%CF%83%CF%84%CE%B7%CE%BC% CE%B1-%CF%89%CF%82-%CE%9A%CE%B5%CE%BD%CF%84%CF%81%CE%B9%CE%BA%CF%8C-%CE%A0%CE%B5%CE%B4%CE%AF%CE%BF-%CE%91%CE%BD%CF%84%CE%B1%CE%B3%CF%89%CE%BD%CE%B9%CF%83%CE%BC%CE%BF%CF%8D-%CF%84%CF%89%CE%BD-%CE%9C%CE%B5%CE%B3%CE%AC%CE%BB% CF%89%CE%BD-%CE%94%CF%85%CE%BD%CE%AC%CE%BC%CE%B5%CF%89%CE%BD-%CE%99%CE%94% CE%95%CE%91%CE%91-27-%CE%B1%CF%80%CF%81%CE%B9%CE%BB%CE%AF%CE%BF%CF%85-2021.docx .pdf

[84] P. Stares, "The military uses of outer space: Does Britain have any choice? " The RUSI , *Journal*, 1982, 127(4), 47–52. https://www.tandfonline.com/doi/abs/10.1080/03071848208523427

[85] United States, *Challenges to security in space. Defense Intelligence Agency*, 2019 https://aerospace.csis.org/wp-content/uploads/2019/03/20190101_ChallengestoSecurityinSpace_DIA.pdf

[86] W. Ferster, C. Colin, "NRO Confirms Chinese Laser Test Illuminates US Spacecraft," *Defense News*, October 2, 2006 https :// spacenews . com / nro - confirms - chinese - laser - test - illuminated - us - spacecraft /

[87] N. J. Jackson, *Outer space in Russia's security strategy*, January 15, 2019 227-237. https://www.taylorfrancis.com/chapters/edit/10.4324/9781351181242-22/outer-space-russia-security-strategy-nicole-jackson

[88] US Space Command Public Affairs Office, Russia tests direct-ascent anti-satellite missile, Dec. 16, 2020, https://www.spacecom.mil/News/Article-Display/Article/2448334/russia-tests-direct-ascent-an ti-satellite-missile/

[89] F.Parly, *Présentation de la stratégie spatiale de défense à Lyon,* July 25, 2019, https://www.defense.gouv.fr/english/content/download/563595/9727199/

[90] Y. Jiang, “Debris cloud of India anti-satellite test to Microsat-R satellite”, August 2020, https://reader.elsevier.com/reader/sd/pii/S2405844020315358?token=07FC2177AFCC4A060B41DA 037B7263911AFE4C76B95AFE84508CBDB92B439D6BD1D55B26D49354D6F8300F9C4064B0EE &originRegion=eu-west-1&originCreation=20220727135015

[91] Department of Defense Office, "Military and Security Developments Involving the Peoples republic of China", 2021. https://media.defense.gov/2021/Nov/03/2002885874/-1/-1/0/2021-CMPR-FINAL. PDF

[92] NATO, "NATO'S overarching Space Policy", January 2022. https://www.nato.int/cps/en/natohq/official_texts_190862.htm

[93] Office for outer space affairs, *International Space Law: United Nations Instruments*, New York, 2017. https :// www . unoosa . org / res / oosadoc / data / documents /2017/ stspace / stspace 61 rev _2_0_ html / V 1605998- ENGLISH . pdf

[94] M. Mejia – Kaiser, *Space Law and Hazardous Space Debris*, 30 January 2020. https://oxfordre.com/planetaryscience/view/10.1093/acrefore/9780190647926.001.0001/acrefore-9780190647926-e-70

[95] United Nations, *United Nations treaties and principles on outer space*, Sales.No: E.02.I.20, ISBN: 92-1-100900-6, New York, 2002. I515EN%20(1).pdf

[96] Anz-Meador PD, Potter AE Density and Mass Distribution of Orbital Debris. Acta Astronautica, 38(12), 927-936, 1996. https://www.sciencedirect.com/science/article/abs/pii/S0094576596001026?via%3Dihub