



Space Debris: Challenges and Legislation for Sustainable Space Exploration

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Abstract. The space exploration has seen a rapid boost in the past years because of the swift advancement of technology. This has resulted in the congestion of the most used orbits i.e. “Low Earth Orbit and Geostationary Orbit” with satellites. The paper relies upon secondary data and has analyzed space debris statistics and space treaties to study the threat that hinders future space exploration posing a risk of cascading effect known as Kessler Syndrome. Though they are international space treaties regulating space missions, they are not compatible for the present needs due to their non-binding feature. The paper explores mitigation strategies including collision avoidance and satellite reentry techniques, use of graveyard orbit to reduce space junks. Also, the paper recommends establishing a space tribunal, scrapping outdated laws and opting for multi-mission satellites to ensure sustainability of space exploration.

Keywords: Space Debris, Low Earth Orbit, Geostationary Orbit, Operating Satellite, Orbiter Velocity

1. Introduction

Space debris or more informally called “space junk” is any piece of machinery or debris left by humans in space during space missions. With the launch of space missions in 1957 by the “Soviet Union”, space orbital debris came into existence [1]. In the initial years of the space missions the objects launched were relatively very less but 2020 saw a rapid boost of nearly 50% in launch activity compared to previous years. As of 2023 almost 2890 objects were launched in outer space and 2024 is yet to witness even more exponential growth. With space exploration comes the threat of space junk or space debris which is growing rapidly. It is posing a bigger challenge to sustainable space travel and exploration. Breakups account for the largest contributor to the space debris population. Till 2024 more than 650 number of collisions, explosions, break-ups have resulted in fragmentation [2]. These fragmentations have generated almost 40500 objects greater than 10cm, 1100000 objects between 10 cm to 1 cm and 130 million objects smaller than 1cm. The first satellite collision occurred between Iridium 33, a communication satellite with Kosmos 2251 a Russian satellite which alone generated around 2200 objects. Besides such collisions and breakup events, the Anti-Satellite Test has alone increased traceable objects by 25%. One such worst event is the Chinese Fengyun -1C Anti-Satellite test in 2007 which added around 3500 traceable objects. In 2021 Russia conducted an “Anti-Satellite test” to destroy its defunct satellite which generated near about 1500 pieces of space debris [3]. Following the footsteps of USA, China and Russia, India too joined in the ASAT test in 2019 drawing a lot of criticism [4]. Apart from this there are other

multiple reasons for causing congestion in earth orbit such as the space agency paying least attention to decommissioned satellites or defunct satellites.

2. Outer Space Environment

Satellites are put up in space with the help of rockets and gravity keeps these satellites in their required orbit. Based on different goals and purposes for which a satellite is designed, the satellite tends to use that particular orbit (Fig. 1). And continuous use of a particular orbit leads to congestion and pollution. Most of the human activities take place in “Low Earth Orbit” which ranges between 160 km above the earth to 2000 km and is used for the “International Space Station” and capturing high resolution images followed by Geostationary Orbit at an altitude of 35,786 km in which satellites tend to move from west to east taking “23 hours 56 minutes and 04 seconds” to complete one circle thus making this particular orbit more useful for telecommunication and weather forecasting satellites [5].

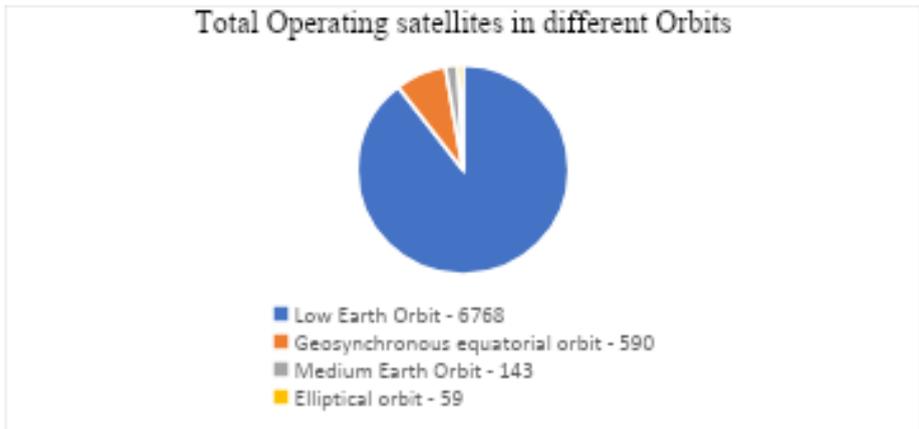


Fig. 1. Total number of operating satellites till 2023 in orbits [6].

3. Risks connected with Space Debris

Tracking debris is one the most crucial tasks associated with remediation techniques. As estimated, there are currently 34,310 objects traced in orbit out of which only 25% are working satellites and the rest being discarded satellites and their fragments. At present Space Surveillance Network is able to track only 10cm objects or larger that is very minuscule as it accounts for only 0.02% of total debris population. And above all around 130 million debris are too small to be traced measuring between 1mm to 1 cm [7]. The

orbital velocity of LEO is (28,800 km/h or 8 km/s) which means that even minute particles can bring significant damage. For example, during the 1983 “Space Shuttle Flight 7 mission”, a 0.2 mm paint chip hit a window of the space shuttle Challenger and created a 0.4 mm diameter pit. Even though shields have been developed to protect the functional spacecraft from damage, they are effective only for fragments not larger than 1cm. In the coming future space debris population will be highly influenced by mega constellation projects by companies such as One Web, Starlink and Shanghai Spacecom Satellite Technology of China which is planning to launch a mega constellation of around 15000 satellites [8]. In 1978 a NASA scientist Donald J Kessler penned down a theory in his study known as the ‘Kessler theory’ which states that the high density of objects in space can have cascading effects thus further creating more debris and making the earth orbit unsustainable for space exploration.

4. Current Legal framework and its Deficiencies

4.1. Outer Space Treaty 1967

The Outer Space Treaty contains fundamental principles dealing with exploration and use of outer space. Article IX of the treaty contains provision to be relied on in regard to space debris [9]. According to this article, state parties to the treaty shall conduct activities in outer space with due regards to the interest of other parties to the treaty. The term due regards shall also include creating space debris by the state party to the treaty resulting in detrimental interference with peaceful exploration of outer space by the states. The article creates an obligation on the state to ensure compliance with due regards and interest clause but absence of any specific guidelines for proving the guilt of the state party results in the drawback for the article. Article VI, VII and VIII further creates a state responsible for outer space activities.

4.2. Liability Convention 1972

“The liability Convention” further strengthens the liability provision i.e. “Article VII” set out in the Outer Space Treaty 1967. The convention clearly distinguishes between the place of damage i.e. on the surface of the earth and outer space. “Article II” of the liability convention creates an complete liability on the launching state for damage caused by its space object on the surface of the earth whereas “Article III” creates “fault-based liability” for damage caused elsewhere than on the surface of the earth. The treaty requires the faults to be proven but it has neither defined ‘fault’ nor set out any specific guidelines or standard of care for determining fault [10]. Another problem which arises is how to impose liability for the damages caused by debris which cannot be retracted to the launching vehicle or satellite or to the launching state.

4.3. Registration Convention 1972

The liability convention can only become effective after a piece of debris is identified. The establishment of the Registration Convention to a greater extent solves the problem of identifying the launching state or the state holding sovereignty over space objects. “Article IV” of the convention provides for giving basic information relating to the space object in the registry to the United Nations.

4.4. The Space Activities Bill 2017 - India

The Government of India instituted the Space Commission and established the Department of Space in June 1972 which is a nodal agency responsible for all the space activities in India. The department drafted a bill in 2017 on National space activities to regulate and promote space activities in India and also encourage private entities to participate as there has always been a dearth of private participation because of the absence of a regulatory framework. Under chapter II the Central government shall ensure conformity of space activity with international agreements, under chapter III licensee shall be required to conduct activities in such a mode so as to avoid pollution of the outer space and to avoid interference with the activities of other states in peaceful exploration and use of outer space and finally under chapter V penalties shall be imposed for damaging air space or outer space by any space activity [11]. But these provisions are ambiguous as they remain silent on specifically addressing the issue of space debris and also the bill further needs to explore the idea of defunct satellite end of life disposal.

4.5. Indian Space Policy 2023

“The Indian Space Policy 2023” envisions to enlarge space capabilities, enable, boost and develop a prosperous commercial presence in space, use space as a driver of technology and create an ecosystem for effective execution of space application. Though the policy entrusts the Department of Space to establish a framework for harmless and sustainable space operations in compliance with international space debris mitigation guidelines. But absence of any specific parameters and time frame within which the assigned task needs to be completed raises concerns for future space missions [12].

5. Mitigation Techniques

Some suggested mitigation strategies include collision avoidance measures, reentry into earth's atmosphere for post mission disposal of LEO satellites and moving GEO satellites into graveyard orbit. Collision avoidance measures require tracking every bit of debris present in LEO. The US Space Surveillance Network can track only large objects between 1cm to 10cm. Satellites in LEO use reentry as a disposal method to avoid becoming debris due to presence of some gravitational pull in the orbit. Through the gravitational pull satellites are brought back into earth's atmosphere where few satellites are destroyed

upon reentry and in some cases reserve fuel is used for controlled reentry and where satellites are not destroyed upon reentry are directed towards landing in uninhabited areas. This is not possible in GEO due to lack of no or very little gravitational pull and also for requirement of excessive fuel. Satellites in this orbit are directed towards graveyard orbit. Apart from above mentioned techniques “The Inter-Agency Space Debris Coordination Committee” (IADC) and “United Nation Committee on the Peaceful Uses of Outer Space” includes mitigation strategies to help avoid internal breakups, collisions, limiting the stay of satellites in orbit after the end of the mission. These mitigation strategies are voluntary and non-binding making it less effective [13].

5.1. Mitigation Strategies - India

Since 1996 India has been an active member of the IADC. Since then, India has implemented the guidelines in its space mission to curtail or limit space debris such as passivation of rocket stages, post mission disposal of satellites and execution of collision avoidance maneuvers. In 2023 India passivated 12 Geosynchronous satellites in compliance with the guidelines recommended by IADC. An Indo-French satellite mission Megha Tropiques-I was successfully de-orbited making its atmospheric reentry successful after which all rocket stages were passivated by India successfully. Even Polar Satellite Launch Vehicle C-56 the launch vehicle used for the mission was deorbited to 300 km to limit its post mission lifespan to less than a month. As per the report published in 2024 by “Committee on the Peaceful uses of Outer Space” on the basis of information provided by India, India is setting up objects tracking radar and telescopes to monitor “Low Earth Orbit” and “Geostationary Orbit” as part of their NETRA project i.e. Network for Space Object Tracking and Analysis [14].

6. Recommendations

a. Scrapping the Existing laws

The current space laws are not very beneficial in curtailing space debris despite states ratifying it have obligations to comply with it because it came into existence even before space debris as a problem was recognized. The Outer Space Treaty prohibits deploying nuclear weapons in space but does not provide any specific provision to control use of weapons from earth such as prohibiting Anti Satellite Test. Either the United Nations needs to scrap the existing laws or need to make necessary changes such as proving guidelines to comply with in case of conducting space activities so that in case any nations fail to comply with those guidelines their guilt can be easily proven through given parameters.

b. Market Share Liability

It can be the best alternative to fault-based liability mentioned in liability convention which can only be applicable in case of identified debris but will fall short to tackle the problem of unidentified space debris. Under this scheme for any collision due to debris the launching nation or private entity shall be liable according to their proportion of debris in space. It will thus help reimburse the nation that suffers loss due to collision with debris and also provide incentive for debris removal. It may be difficult initially in determining the contribution of each launching nation to space debris but based upon the identified debris belonging to different states a conclusion can be sought and evidentiary problems related to fault-based liability can be solved. Also, once this scheme comes into existence the nation will eventually try to curtail its identified debris contribution thus minimizing its share liability.

c. Need for Space Law Tribunals

To deal with issues which arise due to collision and further leads to determining liability shall be dealt specifically by such tribunals having expertise in space laws and its technicalities similar to company, tax, environment tribunals. This will further help in ensuring stringent laws to ensure sustainable space exploration.

d. Multi-mission satellites

Instead of relying upon single task-oriented satellites, different entities should rather aim for bringing in satellites designed to fulfill multi tasks such as capturing images, forecasting weather conditions, earth observations and other similar tasks. Multi mission satellite projects may incur heavy cost but future space exploration can be safer and pocket friendly because different launching states will not have to spend much on collision avoidance techniques such as maneuvers which require extra fuel.

e. Remediation Measures

Remediation is a reactive strategy which aims to remove debris from outer space. Need of the hour demands involvement of remediation techniques to halt Kessler syndrome from happening in the near future. Using highly advanced lasers to move defunct satellites out of their orbit to make them reenter the earth's atmosphere where they are destroyed post mission.

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