Space Debris: Types, Impacts and Mitigation

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Abstract— In the past Sixty-Three years, Space around and orbits of our Earth themselves had gone from a virtually debris-free environment, now to a space cluttered and shattered with artificial (Man-Made) objects that threaten all the accesses and assets for future space explorations, launches, active satellites, operational satellites, and even the ISS. The Space Debris is more than 128.934 million shreds, drifting in insanely fast orbital speeds, reaching sizes from a Computer Monitor to a tiny piece of paint fleck. These huge amounts of fragments are mainly from the space activities of three main countries China, Russia, and the United States of America. Now there are more than 100 million objects that are larger than 1 mm orbiting around Earth and impossible to monitor and also hard to get shielded, causing huge damage and economical loss. We integrate and propose new systems. The efforts of our study are made to know all possible ways to solve and overcome this problem. Ensuring a safe future for Space Exploration. By the end of this context, one can illustrate the Reasons, Types, Impacts or Effects, and Management Strategies of the Space Debris and peaceful uses of the universe.

Keywords: Space Debris, Debris Management, Debris Mitigation, Time to act, Space Hazards, Future space exploration, Orbital space debris

I. Introduction

Space debris encompassing both artificial and Celestial Waste, orbiting around the planet Earth with speeds of up to 4 to 5 miles/second (8-7 kph), which are a threat to all the assets of the Earth's orbits making the Space deployments impossible to guide, get shielded and immune to space debris. NASA reported that as of 2019, a total of 28.934 million pieces were being tracked, and an estimated 34,000 pieces at the size of more than 10 centimeters are thought to exist. And nearly 100,000 debris that is ranging down to the size of a tiny fleck of paint, that is too small to detect or track. Active satellites, numbering about 2,787 comprise about 63% of are in LEO, 6% are in MEO, 29% are in GEO and the remaining 2% are in Elliptic Orbit of the Earth's-orbiting objects the rest is junk. Also including the mitigation and propulsion of Near-Earth-Asteroids will be diffused further in this paper. The availability of implementing space missions like Operational launches, missions are vigorously decreasing every year. And there are also chances of preventing space exploration in the future. Further, in the topics of the paper, we are going to explain in detail various mitigation operations. However, many space debris communities including NASA, UNOOSA (United Nations Office for Outer Space Affairs) had already proposed various types of mitigation procedures and guidelines, we propose integrated, improved, and practical methods, guidelines of Debris Mitigation. As space debris is an issue to all leading and fairing nations, this context provides the basic ideas and guidelines of Active-Debris mitigation or removal.

II. Space Debris

A. *Reason:*

After the first launch on October 3, 1957, of an artificial satellite in earth orbit space debris began to accrue in the Earth's track. The space scrap and trash of dead satellites revolving in the Earth Orbit is nothing but space debris. There have been many launches till now and many more launches will happen in the future. The fragments of the spaceships or the departed satellite remain in the Earth's Orbit which frontrunners to increase in the sum of space debris. There are more than ten million bits and pieces revolving around the Earth orbit. Vast Detonation can be instigated by a minor element. Through 1991-2001 several lessons accompanied and believed that conferring to future launch rates the probable in the Earth satellite inhabitants can be the foundation for several grim unintentional accidents among the resident universe. This context explains that the Space Debris Mitigation process should be implemented with no delay because the more we launch the more we face problems in the future of space exploration followed by the Kessler's Effect. [4]

B. *Space Debris and their Taxonomic characteristics:*

In common, significant categorization of any kind encompasses the subsequent steps :(a) Gathering of data, (b) documentation of groups, and (c) cataloging of groups. This means that at first all the pertinent data about the object that we would resemble to categorize should be collected. Then, objects should be organized in groups, grounded on their most pertinent and differentiating topographies. Finally, taxonomic should be hierarchical and methodical to make a taxonomic tree that demarcates it is inherited attired and slightest expanse of evidence required to confidently categorize an object. The source of taxonomic discrepancy prescriptions that fastening an object into taxa must be those physiognomies can be seen in table 1. [1], [3]

Characteristics	Definitions
Objective type	Artificial: a man-made object Natural: Celestial (Natural) object
Orbit type	LEO: 80-2000 km MEO: 2000-35,786 km GEO: At 35,786 km HEO: > 35,786 km
Orbital state	Controlled (C): Actively Controlled Uncontrolled (U): Self-Explanatory
Altitude state	Actively Stabilized (S): 3 axes stabilized Regularly rotating (R): passively controlled/uncontrolled sable (no Precession) Tumbling (T): Irregular altitude motion
External shape	Regular convex (without appendages) (X): cylindrical or spherical

	Shapes Regular polyhedral (with appendages) (P): regular cubic shapes of Spacecraft Irregular (I): self-explanatory
Size	Small (S): < 10cm (up to 5 cm) Medium (M): 10cm-1m Large (L): > 1m
Area to Mass Ratio (ASMR)	Low (lo): <0.8m^ Medium (me): 0.8m^2/kg High (hi): >2m^2/kg

Table 1: Main characteristics of the first layer of taxonomy:

C. Classifications and Composition of Space Debris:

Natural Debris: Natural Space Debris are some celestial rocks orbiting Earth's essential orbits with speeds up to 4 to 5 miles per second. There are many types of natural space debris such as meteoroids, asteroids, and comets. Meteoroids: They are commonly made of silicon and oxygen, together commonly called silicates and heavier metals like nickel and iron. Iron and nickel meteoroids are very dense and massive, whereas stony meteoroids are super fragile and very light.

- Asteroids: They are often called "minor planets" but they are very small than planets or moons. They are hard rocky, metallic bodies that orbit the sun. They are made up of different kinds of rock and metals, out of which the majority of metals being nickel and iron and are of many kinds: I). C-type (chondrite), II). S-type (Stony), III). M-types (Metallic):
  - The C-Type (Chondrite): The C-Type asteroids are the most known variety comprising about 75% of discovered asteroids. As their composition is mostly of carbon, as the Type-C is carbonaceous they are not lustrous and are very dark (Less-albedo) and hence are hard to detect. The C-type asteroids most commonly contain silicate rocks and clay.
  - The S-Type (Stony): S-type asteroids are spectral types that are made of a siliceous (stony) and mineralogical composition including metals like nickel and iron. They
  - Constitute about 17% of the discovered asteroids and hence making them the second abundant after the C-type asteroids.
  - The M-Type [Metallic]: Some of them are made of nickel-iron, which may either be pure or mixed with small amounts of stone. These are thought to be fragments of the metallic core of differentiated asteroids that were collided by impacts and are also thought to be the source of iron meteorites. These are the third most abundant asteroid type.

Near-Earth Objects (NEO): The asteroids which are close to the planet Earth and which would be the biggest threat. And also, would be one of the Mass Extinction of life on Earth. There are many types of NEA Asteroids I.e., Aten Asteroids, Apollo Asteroids, and Amor Asteroids:

- Aten Asteroids: Aten asteroids are a dynamic group whose orbits and axis bring them into proximity to Earth. Most of them are classified into potentially hazardous asteroids (PHO).
- Apollo Asteroids: The Apollo asteroids are the group of Near-Earth-Asteroids. They are Earth-crossing asteroids that have an orbital semi-major axis greater than that of Earth.
- Amor Asteroids: The Amor asteroids are grouped as of the Near-Earth-Asteroids, usually most of them orbit Mars. The 433 Eros was the first armor asteroid to be orbited and landed by a robotic space-probe The NEAR Shoemaker. The Amor asteroids are also considered potentially hazardous asteroids (PHO). [2], [3]

Space Debris (Man-made): The artificial or man-made space debris is any man deployed space probe or an artificial-satellite which no longer serves any use or no longer be operational supposedly in Earth's essential orbits. The man-made space debris mostly includes derelicts of spacecraft:

- Non-Operational Satellite Debris: Non-operational satellites are satellites that no longer will be capable of performing tasks either due to re-entry of the satellites to Earth's atmosphere or due to termination of downlinks.
- Rocket stages Debris: Most of the space debris consists of the upper stages of multistage rockets. These are some of the main reasons to perform Kessler syndrome.
- Fragments from Hypervelocity collisions: Collision impact debris that occurs when debris or micrometeorite fragments collide with each other or with operational satellites with huge orbital speeds.
- Debris from failed missions: Deployments, missions, and anti-satellite missions that have failed due to hypervelocity collisions, chemical explosions, leakage of solid rocket fuel, etc.
- Deterioration fragments: Deterioration debris are peel-offing's and particles form exposed parts or matter of the spacecraft like peeling paint, solid-paint flecks, glass shards, etc.
- Fragments from Thermal explosions and rocket-exhaust
- Solid propellant slag
- Payloads and Launch Hardware debris: bolts, nuts, nose cones, derelicts from rocket engines, etc.
- Space activity derelicts: Human derelicts and fluids, etc.

III. IMPACTS

A. Kessler Syndrome:

The Kessler Syndrome (collisional or ablation cascading) is a theoretical scenario wherein the density of objects in Low Earth Orbit (LEO) due to space debris pollution is high enough that collisions between objects could cause a cascade in which each collision generates space debris that increases the likelihood of further collisions than cause severe damage and could even end the horizons of future Space Debris.

The Kessler syndrome is similar to the Domino effect or a chain reaction where a cumulative effect is produced when one event sets off a chain of another similar event.

B. Resource Extrication:

Every year, 61.1 Billion tons of resources like metal ores, minerals are being extracted from the earth's crust. And, in less than 20 years, the percentage of extraction can easily grow up to 60%, which not only affects earth but also affects the needs of mankind. And the most preferable solution to save our mother earth is to recycle every possible thing including space debris, Near-Earth asteroids, and reusing them in various ways. This process will extricate nature and fulfill our needs with minimal-effect on some minor things such as pollution, economical expenses, etc.

C. Abolishes accidents and Hypervelocity Collisions:

Some space debris can be so tiny as 3.2cm which is hard to detect because the SSN cannot detect objects which are smaller than 10cm. nearly, 128 million pieces smaller than 10cm, 900,000 pieces around 1-10 cm, and 38,000 pieces larger than 10cm are appraised to be surrounding earth in 2019. Removing space junks not only cleans up space but will also prevent accidents and hypervelocity explosions in orbits, increasing the possibilities and horizons of future Space Exploration events. [1], [2], [4]

IV. ACTIVE-DEBRIS MITIGATION

Two main classifications can be divided to study further and can minimize and prevent the creation of new space debris: Preventative Measures to preclude the explosive failures of the space crafts, upper-stages, paint flecks and eliminate placement in space of space debris and Mitigation Guidelines, which by reducing the number of objects in orbits and reducing the probability and severity of Space Debris in orbits, therefore reducing hypervelocity collisions and explosions.

A. Preventative Measures:

Since 1981 NASA has been working on reusable rocket stages that reduce the likelihood to explode and reduce orbital debris and reduce solid propellant slag. From 1995, when NASA became the first space agency to propose a comprehensive set of Orbital Space-Debris Mitigation guidelines. The most effective and near-term measures are to develop and operate launch vehicles that have minimal chances of colliding and less probability of creating new debris and new threats in orbits of Earth. Most launch vehicles are now reusable.

B. Active-Debris Mitigation Procedures:

Nevertheless, since NASA became the first space agency to put forward the debris-mitigation guidelines, Japan and the European Space Agency (ESA) had been adapted to the similar ways of mitigation guidelines of NASA. Although agencies and observers had introduced many ways of Active-debris removal methods and guidelines, some of them are prohibitively, economically expensive, and conceivably be counterproductive to debris-population. According to NASA and other space agencies, the most practical techniques of debris-mitigation are:

1) Space Tethers:

Fig. 1: Space Tether

Space tether refers to a momentum exchange tether used to propel, accelerate or thrust, stabilize and control attitude and altitude of dispersed satellites and thrust spacecraft to hypervelocity speeds in Space, usage of this type of spacecraft propulsion system is significantly less expensive than using Staged-rocket engines and rocket fuel. Tethers use the orbital motion as the main principle to thrust the spacecraft from on an on-board source. The similar integrated system Tethers are Electrodynamic Tethers (EDT's) which operate on electromagnetic principles as generators, by converting the kinetic energy acting upon it due to their orbital motion to electrical energy. These systems could be used even to deorbit debris or propel them far into deep space. In this case, we could either catapult the targeted impact debris back to earth or propel them far into deep space.

2) Capture and Return Missions:

Fig. 2: Hosting and capturing debris through nets

The Capture and return missions include a small satellite attired with one of the intercourse debris mitigation procedures that host and deorbits the targeted impact debris, this type of mitigation procedure is seriously taken into consideration and widely being tested. Out of many possible methods, one of them involves a satellite hosting debris then loading it into a net and deorbiting leading it to burn them during the reentry into the earth's atmosphere. Targets too gigantic for the net might be instead apprehended with a harpoon, a robotic arm, or a tether. Instead of firing so many anti-satellite rockets, harpoons are more efficient. The harpoons work by deploying large sails that produce atmospheric drag, leading debris to orbital decay.

3) High- energy pulsed Laser radiations:

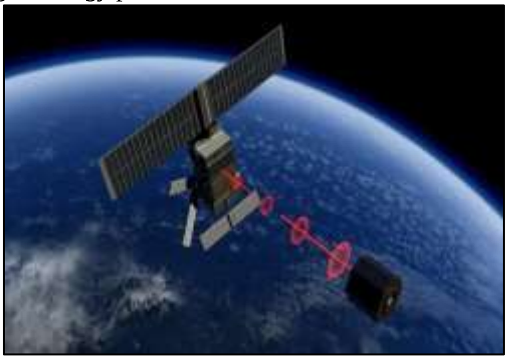

Fig. 3: Space-based laser mitigation

High-energy pulsed laser radiation is the most feasible means of debris mitigation. As the size of the debris may vary but not the threat they pose for the space stations, future space exploration, or the valuable space assets with orbital debris ranging sizes from 1-10 cm. Orbital debris under laser irradiation a part of debris material is ablated creating impulse, enough to deflect them from their orbital trajectory. Even smaller debris may be vaporized completely. The space-based laser mitigation wouldn't need to host any of their targeted impact debris, they can execute them from far and much safer distances.

4) Electromagnetic attraction:

Fig.4: Space-based Electromagnetic satellite

Utilizing and taking advantage of magnetic components inside satellites like magnetic torques or any other metallic components, the usage of space-based electromagnets are the most efficient and practical way to mitigate space debris. Using electromagnetism to control the altitude or ablate space debris to safer orbits are the safest because they can even protect themselves from debris by ablating them. [2], [3], [4]

V. CONCLUSIONS

However, the population of space debris is gradually increasing over years. If this growing population of space debris is not controlled there would be huge exploitation of the uses of space, leading to irreversible damage for the future of space exploration. Even so, there are many scientific proposals to mitigate space debris, not all the methods or processes can work practically, this context provides the classifications of Space Debris and their reasons, impacts they can cause, and types including various mitigation procedures. To prevent this kind of disaster the efforts were made in this context to prevent the worst possible cases and the peaceful uses of outer space.

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