# An Overview of Space Debris and Its Related Aspects

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**ABSTRACT-** This paper aims to delve into the present situation regarding the various aspects of space debris. It considers the current statistics concerning space junk concentration and the diverse sources of space junk. The sources considered in the paper include anti satellites weapons, derelict crafts and spent rocket stages etc. The paper further discusses the threats posed by space junk on future and current space missions along with the threats posed to humans on Earth (including explosions and radiation exposure). Also discussed are the various methodologies employed to track space junk for reasons such as maintaining updated information to be used while charting safe paths for ISS etc. Finally, an account of the current measures adopted to grapple with space junk are mentioned along with an account of projects under development, their status and the future of spacefare with respect to space debris.

**IMPORTANT ABBREVIATIONS-**

1. ISS- International Space Station
2. LEO- Low Earth Orbit
3. GEO- Geostationary Orbits
4. NORAD- North American Aerospace Defence Command
5. UNCOPUS- United Nations Committee on Peaceful Uses of Outer Space
6. ASAT- Anti Satellite Weapons
7. ESA- European Space Agency
8. ITU- International Telecommunications Union

**Important Terms -**

1. Kessler's Syndrome - The Kessler syndrome (also called the Kessler effect, collisional cascading or ablation cascade), proposed by the NASA scientist Donald J Kessler in 1978, is a scenario in which the density of objects in Low Earth Orbit (LEO) is high enough for collisions between objects to cause a cascade—each collision generating space debris that increases the likelihood of further collisions. One implication is that the distribution of debris in orbit could render space activities and the use of satellites in specific orbital ranges unfeasible for many generations.

2. Apogee – The point in the orbit of the moon or a satellite at which it is furthest from the Earth.

3. Perigee – The point in the orbit of the moon or a satellite at which it is closest to the Earth.

4. Orbital Period- The period of revolution of one body about another with respect to the distant stars.

5. Low Earth Orbit- The region of space around the Earth below an altitude of 2,000 kilometres.[1] This is where the ISS conducts operations. One complete orbit in LEO takes about 90 minutes [2].

6. Geosynchronous Orbit- A geosynchronous orbit (sometimes abbreviated GSO) is an orbit around the Earth with an orbital period of one sidereal day, intentionally matching the Earth's sidereal rotation period (approximately 23 hours 56 minutes and 4 seconds). It is also referred to as Geostationary Orbit. A satellite in such an orbit is at an altitude of approximately 35,786 kilometres above mean sea level.
7. Graveyard Orbits- Orbits into which communications satellites may be moved at the end of their operational lives, where there is no risk of interference or collisions with live satellites in normal orbits.
8. Geostationary/Geosynchronous Transfer Orbit- An elliptical orbit, with an apogee of 35,784 km, a perigee of a few hundred km, and an inclination roughly equal to the latitude of the launch site, into which a spacecraft is initially placed before being transferred to a geosynchronous or geostationary orbit [3].

## SOURCES OF SPACE DEBRIS-

### A. DEAD SPACECRAFT-

As a rule, spacecraft contain extra propellant that is used to move them to graveyard orbits at the end of their lifetimes. However, many organisations do not make use of the option of moving derelict spacecraft to graveyard orbits. Thus, after the work of the spacecraft is fulfilled, the organisation, more often than not, stops bothering about it entirely and does not take the pain of proper disposal. The fact that not many corrective measures exist to keep defaulters in check furthers this prevalent practice of the organisations. In this manner, improper disposal of decommissioned spacecraft adds to space debris[4]. It should be noted that this state of events is particularly disheartening as the debris that could easily have been safely disposed of is actually contributing to the overall critical mass of junk in space. Moreover, satellites which have been disposed of have an estimated eight-percent probability of puncture and coolant release over a 50-year period. The coolant freezes into droplets of solid sodium-potassium alloy, forming dangerous debris[5]. The amount of debris from dead spacecraft is also increasing due to the annual addition to the existing quantity in the form of decommissioned spacecraft and the addition as a result of collisions between 2 derelict spacecraft or collisions between a derelict spacecraft and a live satellite etc. The most famous incident involving such a collision involved a derelict Kosmos 2251 and the active Iridium-33 satellite. Both satellites were destroyed and released about 1880 pieces of debris into orbit. This remains as one of the most severe of space debris causing collisions ever[6].

Another method through which dead spacecraft contribute to the amount of space junk is explosion. Though explosions are not prevalent yet, a recent explosion took place in February, 2015 and certain other satellites have been identified to be at risk as well. The most prominent explosions yet that have added to the amount of space debris are-

1. In February 2015, the USAF Defence Metrological Satellite Program Flight 13 (DMSP-F13), a semi-retired satellite, exploded in orbit, creating at least 149 debris objects, which are expected to remain in orbit for decades.[7] this explosion was caused due to battery engine failure, experts have concluded.
2. Dmsp-F11 observatory exploded in orbit in April 2004, producing 56 known pieces of debris.[8]

### B. SPENT ROCKET/SATELLITE STAGES (ESPECIALLY BOOSTERS)

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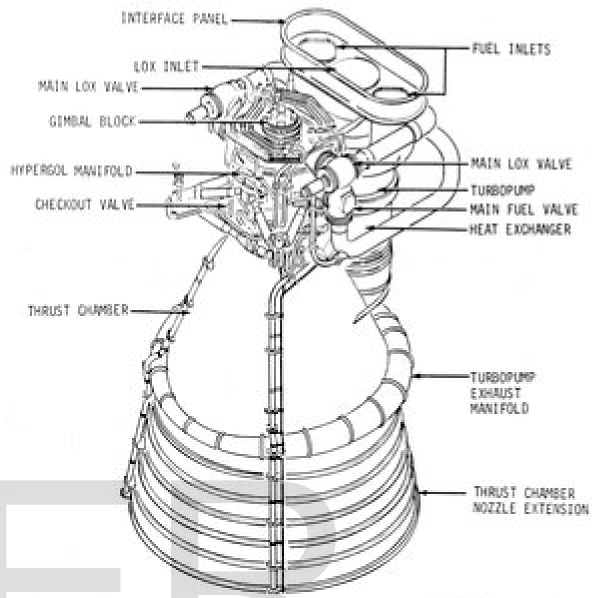
Spent rocket stages that are no longer in active use are a significant source of space junk. Usually, the bulk contribution is from the defunct upper rocket stages. These upper stages are designed to operate at high altitude, with little or no atmospheric pressure and are usually tasked with completing orbital injection and accelerating payloads into higher energy orbits such as GTO. Upper stages are used primarily to transfer payloads from low Earth orbit to GTO or beyond and are sometimes referred to as space tugs. Now, these stages contribute to the space debris by:

Remaining in orbit after their task is accomplished due to unavailability of feasible removal mechanism. They then proceed to collide with other pieces of debris or with active satellites etc.

They also add to the existing quantity of space junk through fragmentation brought about due to explosions. The explosions are triggered primarily due to decomposition of unvented and unburned fuel/propellant. There are two primary families of propellant for these stages, Liquid and Solid. The liquid propellant family contains Cryogenic propellants and Hypergolic propellants. Let's take a look at each independently:

- **Cryogenic[9 'a'][10 'a']-**

Nowadays, along with Liquid Oxygen (LOX), the most commonly used cryogenic fuel is Hydrogen (H2). It has a boiling point at a temperature of 20.37 K and a freezing point of ≈≈ 13 k so one must be very careful in storing Hydrogen. The appropriate temperature is achieved using installed temperature control mechanisms. However, when the function of the upper stage is fulfilled it becomes defunct and temperature control mechanisms cease to act on the unvented and unburned fuel. Eventually, the fuel will heat up due to the high temperatures of near Earth space. The temperature approaches room temperature. Room temperature on Earth results because the amount of light hitting the Earth and the thermal energy/light leaving the Earth sit in a balance. In the absence of functional temperature control mechanism, a similar balance will exist in the upper stages that orbit in the space near Earth. When the temperature rises, the propellant will vaporize and exert pressure on the walls of the container. Another thing is that all metals (including most alloys) have an increased performance (such as yield strength, ultimate strength) in the event of temperature rise, but still the fatigue strength decreases as temperature reaches cryogenic temperature, which means that if the metals at the cryogenic temperatures are exposed to harmonic {cyclic} stress (that is exerted by the hydrogen fuel vapours), they will break. As a result, the propellant container compartments, and consequently, the upper stages explode.




A basic cryogenic engine used in the Saturn spacecraft[32]



- **Hypergolic[9 'b'][10 'b']-**

A hypergolic propellant combination used in a rocket engine is one whose components spontaneously ignite when they come into contact with each other. The two propellant components usually consist of a fuel and an oxidizer. In contemporary usage, the terms "hypergol" or "hypergolic propellant" usually mean the most common such propellant combination: dinitrogen tetroxide plus hydrazine and/or its relatives monomethylhydrazine and unsymmetrical dimethylhydrazine. When the unvented derelict upper stage undergoes depressurisation (several possible scenarios exist for depressurisation) while the satellite is away from the sun and pressurisation when the satellite is facing the sun (pressurisation due to vaporisation of

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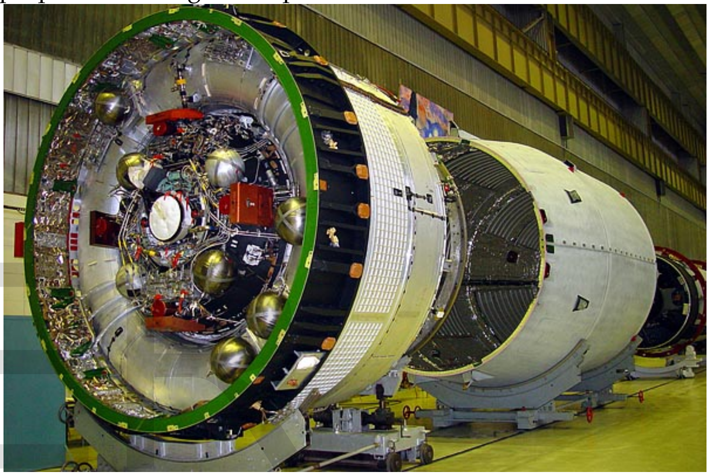
propellant), the consequent cyclic contraction and expansion can cause rupture of the bulkhead that separates the hypergols. The resultant mixing of the propellant can cause explosive combustion.

Noteworthy examples debris created due to upper stages (through collisions, due to explosions of propellants etc.) are-

1. One of the most recent hypergolic propellant explosions took place on the 16th of October, 2010, when a derelict Russian Breeze M rocket stage exploded in orbit due to mixing of leftover hypergolic propellants. The upper stage was launched on August 6 on a Proton rocket, and its job was to place Indonesia's Telkom 3 and Russia's Express MD2 communications satellites into geostationary orbit. But the Breeze M failed at the start of the third of four planned engine burns, leaving the vehicle and its payloads well short of their targeted altitude. At the time of the mishap, the Breeze M still had more than half of its hydrazine and nitrogen tetroxide propellants in its primary and auxiliary fuel tanks which were identified as the main causes of the explosion. Pentagon issued a statement declaring that about 500 pieces of debris were being tracked by the authorities. Experts, however, estimate the amount of debris created to be significantly larger than the amount being currently tracked.[11]
2. A Russian Briz-M rocket stage broke apart in orbit in January, 2016 and created a cloud of debris in GEO. The Joint Space Operations Centre identified the possible break up of the rocket stage when at least 10 pieces of debris were identified in close orbital proximity to the spent rocket body. In upper stage in question was involved in the launch of the Garpun- 12L military communications satellite on December 13 2015. It lifted off from the Baikonur Cosmodrome on a Proton-M rocket. After separation from the rocket body, it underwent manoeuvres for passivation and entry into graveyard orbit. The cause of the explosion is yet to be identified. Briz-M upper stages are known suspects when it comes to in-orbit upper stage debris formation, with 3 incidents in the last decade alone[12].
3. France's Cereise satellite struck a discarded Ariane upper stage in 1996. The incident marked the first verified case of a collision with space debris. It was a relatively minor collision.
4. A Chinese Long March 4 upper stage exploded in orbit on 11 March 2000. According to Nicholas Johnson (Chief Scientist for space debris at NASA's Johnson Space Centre in Houston), most of the particles in the cloud cannot be seen by the naked eye and their main threat comes in the form of continual collisions with spacecraft which causes damage over a period of time. However, about 300 detectable pieces have also been identified and it is believed that the explosion was caused by residual propellant left on board.[13]
5. A Russian Briz-M booster stage exploded in orbit over South Australia on 19 February 2007. Launched on 28 February 2006 carrying an Arabsat-4Acommunications satellite, it malfunctioned before it could use up its propellant. By 21 February 2007, over 1,000 fragments were identified. [14]
6. 2 failures of the second stages of the Russian SL-8 (Intermediate Cosmos Launch Vehicle) are attributed to propellant mixing and explosion.



A Briz-M upper stage[33]

## C. WEAPONS-

In the 1960's and 1970's, extensive testing of Anti-Satellite Weapons (ASAT's) by USA and the Soviet Union resulted in creation of a large amount of debris. USA only had files on debris produced by the Soviet Union and the debris it itself produced was only identified later. Despite being closed in1975, the USA restarted its ASAT program in 1980 and destroyed a satellite in1985 creating thousands of debris larger than 1cm.

China's government was condemned for the military implications and the amount of debris from the 2007 anti-satellite missile test, the largest single space debris incident in history (creating over 2,300 pieces of golf-ball or larger

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sized debris, over 35,000 1 cm or larger, and one million pieces 1 mm or larger). The target satellite orbited between 850 km and 882 km, the portion of near-Earth space most densely populated with satellites. Since atmospheric drag is low at that altitude the debris is slow to return to Earth.[15]

On 20 February 2008, the U.S. launched an SM-3 Missile from the USS Lake Erie to destroy a defective U.S. spy satellite thought to be carrying 450 kg of toxic hydrazine propellant. The event occurred at about 250 km above sea level and the resulting debris had a perigee nearly 250 km. The missile was aimed to minimize the amount of debris, which (according to Pentagon Strategic Command chief Kevin Chilton) had decayed by early 2009.[16]

A U.S ASM-135 ASAT weapon[34]



**THREATS POSED BY SPACE DEBRIS-**

Spacecraft are continuously exposed to impact by miniscule debris particles. A standalone impact of this kind is not serious. However, prolonged and numerous impacts result in accumulated damage to the spacecraft. The solar panels particularly, despite being protected by Whipple Shields, are subject to wear by continuous low-mass impacts. Moreover, these create a plasma cloud which is an electrical risk to the panels. Window chipping due to impact with smaller sized debris and minor damage to the Thermal Protection System Tiles (TPS). The most obvious threat to spacecraft due to orbital debris is through collisions. These collisions can occur with derelict satellites, spent upper stages and fragments from other collisions or explosions. This results in loss of spacecraft as they are rendered defunct and are no longer able to fulfil their intended purpose apart from increasing the risk of further damage to other spacecraft due to addition of increased quantity of debris to the orbit. Numerous accounts of damage due to space junk have been recorded over the years.

These include-

1. The destruction of the Iridium-33 satellite mentioned before.
2. The collision of the Russian Ekspress AM11 communications satellite on 29th March, 2006 with an unidentified object which rendered it inoperable.
3. Collision of the Russian BLITS satellite with debris from the above mentioned Chinese Anti-Satellite Missile Test.
4. During an August 2007 STS-118 mission to the International Space Station, a micrometeroid/ orbital debris penetrated Endeavour's radiator panels and TPS blanket. This damaged the payload bay door and was the most severe impact of its kind.[17]
5. The ISS has to regularly perform manoeuvres to alter its course slightly to avoid collisions with space junk.
6. Kosmos 1275 broke up after a month in launch in 1981 and along with battery explosion, collision with space junk remains a prime theory to explain the explosion. This resulted in creation of about 300 pieces of space debris. Kosmos 1484 broke in similar manner in 1993.

Routinely space junk also enters the Earth's atmosphere. Usually it disintegrates as it re-enters the atmosphere but occasionally it is also responsible for isolated incidents of damage on the surface of the Earth as well. Some of the examples pertaining to this are-

1. A woman in Oklahoma was struck on the head by a falling fragment of a Delta-2 rocket stage in January 1997. Later, a steel propellant tank and titanium pressure spheres also entered the Earth's orbit.[18]
2. A titanium sphere, later identified as the tank use for drinking water in the Gemini-5 spacecraft was spotted in Merkanooka in Western Australia.[19]

3. On 18th September 1977, Cosmos-954, a Soviet satellite careened out of control and began to undergo an orbital decay. It contained 2 antennae which sported nuclear reactors and threatened to contaminate the Earth's surface with hazardous nuclear/ radioactive waste. On Jan. 24, 1978, it re-entered over Canada and shed debris across the frozen ground of the Canadian Arctic. Following the crash, the U.S. and Canada conducted overflights of the area and associated cleanup efforts.[20]

**TRACKING OF SPACE DEBRIS-**

Concerned authorities and officials maintain a catalogue of space junk which is continuously updated with addition of new specimens and filtering out of pieces that have undergone decay. Images of Earth orbiting objects are obtained and converted to plots and graphs which are used for estimating trajectory/path of that particular object. The obtained plot is the perused to determine whether the object under consideration is a newly discovered object or a known one. If the object under consideration is known, then the observations are used to update the catalogue for that particular object and bring it up to date. If the plot indicates a new object, then the surveillance system is employed to obtain more extensive data about the object. Once this is done, the object is entered into the catalogue along with the other known objects. The data in the catalogues is also used to detect when any particular registered object is undergoing re-entry into the Earth's atmosphere. If large enough, these objects can harm the environment through radioactive contamination or striking infrastructure etc. The data from the catalogue is utilised to issue prior warning to concerned authorities regarding the same. Once re-entry is complete, that particular object is removed from the catalogue.[21 'a'] The sensors employed to located the objects are of 2 kinds-

1. **SURVEILLANCE SENSORS-**

They provide data for the initial catalogue development as well as the day to day maintenance of the catalogue. They survey a large area of the sky at a time and instead of actively seeking out individual specimens of space junk, waits for the same to pass by its observation field. Once debris is detected, data regarding the same is passed on to the catalogue maintenance system.[21 'b']

2. **TRACKING SENSORS-**

Unlike surveillance sensors, tracking sensors have a small field of view and are used to locate debris particles within their field of view with high level of precision. When certain amount of information regarding an object already exists in the catalogue, tracking sensors are a great option to obtain more detailed data about the same. Since general location is known as the object passes by the field of view of a surveillance sensor, a tracking sensor can then be employed to obtain more detailed data. However, these sensors are inefficient as standalone sources of debris detection due to their limited viewing range.[21 'c']

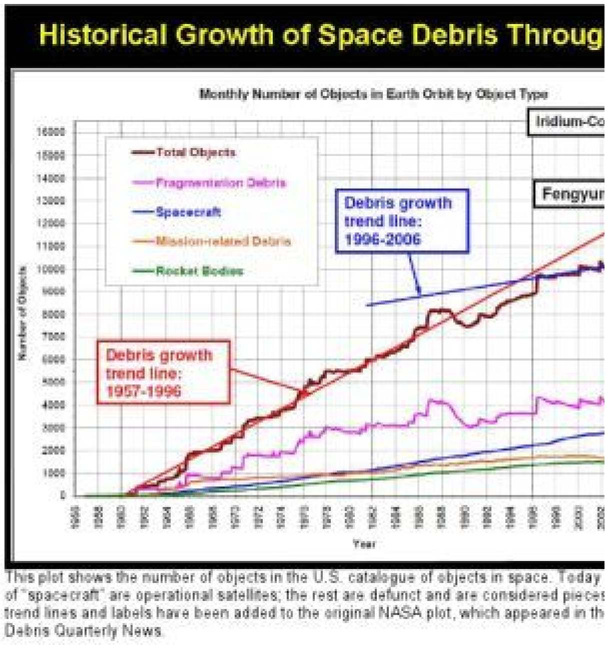


Illustration source- [35]

Examples of ground based radars and observatories that are employed in satellite tracking are-

1. ESA Space Debris Telescope
2. TIRA Radar
3. Goldstone Radar
4. Haystack Radar
5. EISCAT Radar
6. Cobra Dane Phase Array Radar
7. NASA Orbital Debris Observatory

Debris can also be tracked by projecting FM Radio Waves and reflecting them onto receivers.[22] To some extent, tracking and determining the outer space conditions with respect to space junk can also be determined by study of space debris which re-enter to the Earth's atmosphere and is retrieved for further study.

**MEASURES TO GRAPPLE WITH THE SITUATION CONCERNING SPACE JUNK AND MITIGATION AVENUES-**

Several approaches exist to deal with the menace of space junk. The most prevalent of these approaches include-

1. [23]Charting the course of active space endeavours such as ISS, active satellites etc. and periodically matching their courses with charted courses in updated log of space debris to obtain prior information about potential collisions so that evasive action can be undertaken if required. If evasive action is warranted, debris avoidance manoeuvres are carried out. An imaginary box of dimensions (1.5*50*50) Kilometres is considered. This box is also called as the Pizza Box. If the probability of a collision or the probability of debris entering this region is greater than 1 in 100,000, manoeuvres are executed unless mission objectives are compromised. If the probability is 1 in 10,000, a manoeuvre is executed unless it puts the crew at additional risk. Similar systems for risk mitigation were implemented by NASA for select other facilities such as Earth Observation System Satellites in LEO and Tracking and Data Relay Satellite System in GEO in 2005. In 2007, the facility was extended to all NASA manoeuvrable satellites in LEO and satellites present within 200 kilometres of GEO. The manoeuvre typically takes about 30 hours and if sufficient time is not available, the crew, if present, is transferred to the Soyuz spacecrafts which are isolated from the station and act as lifeboats for the astronauts in the event of a collision.

2. [24]Spacecraft such as the ISS and other satellites etc. have specialised shields (Whipple Shields) that protect the solar panels and other components from the action of minute un-trackable components of space junk. As mentioned before, these particles are not large enough to be efficiently tracked and individual impact severity is low. However, if persistent impact from many such pieces is experienced for a long duration of time, significant damage is undergone. Whipple shields are utilised to counter this problem.

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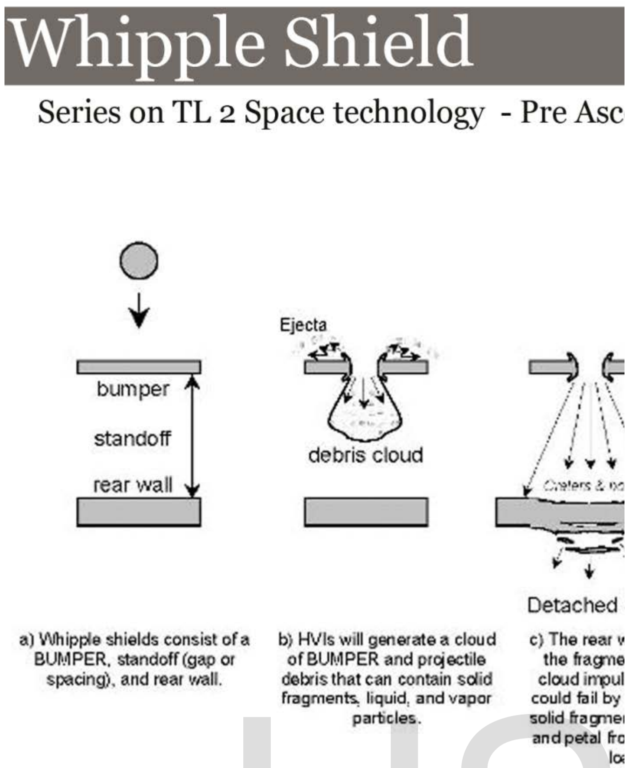



Basic working of Whipple Shields[36]

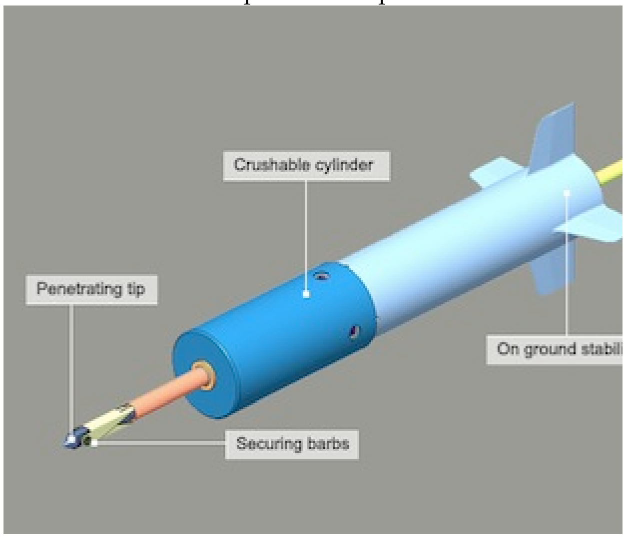


3. Growth mitigation measures are implemented to ensure that addition to the existing quantity of space junk does not occur. To this end, UNCOPUOS published a set of voluntary guidelines in 2007. Passivation (venting of unused fuel) of upper stages is being practiced by many (but not all) space organisations to ensure that explosion of derelict upper stages does not take place. By 2013, certain legal guidelines had been implemented which manufacturers had to abide by to be able to send their spacecraft into space. These guidelines generally pertain to mitigative action inducing systems which must be installed in the spacecraft for the manufacturer to obtain a licence. U.S.A [25] and the E.S.A [26] both have established sets of guidelines for space debris growth mitigation which all civilian and government space agencies have to abide by. Another proposed method of growth mitigation is to establish a 'One-Up, One-Down' launch licence policy according to which launchers would have to rendezvous with, capture and de-orbit a derelict satellite in approximately the same orbital plane as their satellite is being sent in before launch of their own satellite.

4. Self removal of space junk can be used to decrease the severity of the threats posed. If upper stages have enough left-over fuel, it may be used to propel the satellite into a graveyard orbit. If however, the satellites do not possess enough quantity of fuel, the available quantity may be used to send the satellite into an orbit in which it would experience atmospheric drag and eventually re-enter the atmosphere within acceptable time periods (this was done with the French Spot-1 satellite).

5. External Removal mechanisms have been devised and proposed with some scheduled to be implemented in the near future. This is another field with great scope for further research and practical uses. A major Russian space technology corporation, Energia plans to develop a nuclear powered pod shaped craft which will grab onto space junk and alter the trajectory of the said objects to send it to the atmosphere to burn up[27]. Energia has received and is currently utilising 2 billion dollars in funding to further develop the concept. A concept[28 'a'] similar to the Energia concept has been proposed by Dr. Jamie Reed, a UK scientist employed in the same firm which is also working on the aerodynamic sail concept (Astrium). A harpoon attached to a chaser craft is proposed which initially approaches a derelict satellite/ spent upper stage to within 100 metres. Then, on ground images are used to obtain more precise data about the location and course of the derelict satellite. The chaser craft then moves to within 20 metres of the concerned object and deploys the harpoon which then tugs the derelict

satellite into an orbit from which fast disintegration into the Earth's atmosphere takes place.




Harpoon proposed by Dr. Jamie Reed[37]

[29]Busek Inc., a Massachusetts based private firm has emerged with a similar concept but the general acceptance is that even though companies have come up with plans to deal with debris, they lack feasible business plans to carry out practical operations profitably. Busek Inc. Proposed the use of a large tug called the Orbital Debris Remover (ORDER) which will be harpooned to derelict materials comprising space junk and tug them into graveyard objects.

Also, the aerospace giant Boeing has applied for a patent for a concept that aims to release a gas cloud in a region through which a particular piece of space junk passes[28 'b']. When the junk enters the region in which the gas is released, the high density of the gas results in increased viscosity and the hindrance to the path of the satellite results in drag which causes the space junk to undergo faster de-orbit. The transient gas cloud comprises an expellant including at least one of the following-

- Burn metal of atomic weight higher than that of Aluminium.
- A cryogenic noble gas
- Heavy molecular fluid having low isentropic exponent
- Elements and halogens having a high atomic weight.

The apparatus further consists of a gas generator for generating gas for the cloud from the expellant and a nozzle for expanding the gas to form a gaseous cloud.

Another idea that is currently in development and has the potential to provide low cost and reliable method of removing junk from LEO is that of the Terminator Tether[30]. It is a tether 5 kilometres in length that is deployed to initiate de-orbit of the satellites when required. The cable interacts with ionospheric plasma and the Earth's magnetic field which causes a current to flow in it. This current gives rise to drag on the satellite which enables faster de-orbit. A comparative table depicting the tremendous gap between de-orbit times of real satellites with and without the Terminator Tether is given below-



| NAME OS SATELLITE | DE-ORBIT TIME (NATURAL) | DE-ORBIT TIME (WITH TERMINATOR TETHER) |
|---|---|---|
| Orbcomm-1 | 100 Years | 11 Days |
| LEO One USA | 100 Years | 18 Days |
| GlobalStar | 9000 Years | 37 Days |

Another project in development (which will soon be implemented) is that of aerodynamic sail installation in satellites which do not contain propulsion systems to either enter graveyard orbits or enter lower orbital range to undergo quick de-orbit. It provides a cheap alternative to letting satellites clog up a heavily used outer space orbit[31]. The sail utilises the principle of aerobraking and increases the surface/mass ratio of an orbiting object which leads to increased drag

and faster de-orbiting. Thus, a lightweight material should be used for making the sail. The aerobraking sail concept will be implemented in the French Microscope satellite and it is believed that the sail will enable the satellite to de-orbit in less than 25 years after completion of its tasks as opposed to the approximately 50 years it would take the same satellite without the sail.
The ESA has been working on a similar project since 2012 and has designed a mission to remove large space debris from orbit. The objective of the mission is to remove debris heavier than 4000 kilograms from LEO and is scheduled to be implemented by 2021. Several capture techniques are being studied, including a net, a harpoon and a combination robot arm and clamping mechanism. The cleaner satellite in question has been christened as the 'Sling Sat'.

Thus, it can be concluded that while steps are being taken in the right direction, the situation of spacefare with respect to space junk is dire and actively working towards acceleration of mitigative measure adoption is the need of the hour.

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