

SPACE DEBRIS AND MANAGEMENT: A LEGAL STUDY WITH SPECIAL HEED TO DEBRIS MITIGATION

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Abstract

Space debris, conforming of defunct satellites, spent rocket stages, and fractions from collisions or decomposition, has become a growing concern for space operations. As the number of space operations increases, so does the number of debris in Earth's route, raising the threat of inter-collisions that could peril both the being and unborn space conditioning. This article intends to explore the origins, current status, and implicit hazards associated with space debris, emphasizing the critical need for effective operation strategies. From enlisting the various cornerstone and fundamental framework and the articles within it examines both preventative and remedial approaches, including bettered satellite design, compliance with end- of- life disposal guidelines, and the development of active debris junking technologies. Space Debris Mitigation is a crucial and regenerating part of the issue. The article also pays heed on the part of trans-national collaboration and non-supervisor sweats in addressing this global issue. By assessing current challenges and arising results, the study underscores the significance of timely and coordinated action to insure the long- term sustainability of external and outer space. The article also focuses on the future and upcoming trends in the field of debris management. Managing space debris isn't only a specialized imperative but also a strategic and ethical responsibility participated by all spacefaring nations and associations including the private entities.

Keywords: Space Debris, Inter-Collisions, Space Conditioning, Cornerstone & Fundamental Framework, Preventive & Remedial Approaches, Active Debris Junking, Space Debris Mitigation, Trans-National collaboration, Ethical Responsibility, Space Faring Nations.

Meaning of Space Debris

Space debris, commonly known as, Space Junk, entails the meaning of all of the left over stuff in Earth's orbit and sometimes beyond, that we humans have sent up into space. In layman's, it refers to the discarded material or parts of space objects which are of no further use and have no scope of future utilisation, or are immobilised due to any technical malfunction and is beyond repair. For a better

understanding, take space debris as the discarded wrappers, cans, broken tools or any other leftovers from space missions – but instead of being thrown away in a trash bin, these leftover stay floating around, for years and years or even centuries in the dark abyss of space.

This junk is inclusive of things like old satellites that no longer work, bits of rocket stage, and even smaller parts like paint flecks or tiny

fragments from explosions. Some of these pieces are as small, while others are humongous. But what creates a worrisome real problem out of it is that, all these parts, small or big, are speeding around Earth at incredibly high velocities. As a result, even a small speck of debris can do significant damage to a satellite or spacecraft and is therefore a potential threat to property, mankind & environment.

Space Debris Management

Space debris management encompasses all the combination of strategies, technologies, and policies which is used with the motive of monitoring, reducing, preventing, and cleaning up space junk which is present in the space in form of debris. The goal is to make sure Earth's orbital environment remains safe and sustainable for current and future missions which the mankind would carry out.

Without active management, this problem could reach its boiling and tip point, infamously known as the Kessler Syndrome – a chain reaction where due to debris collisions more debris is created and the figure of debris increases in the Lower Earth Orbit (LEO), making the LEO practically unusable and inoperable. This would eventually lead to more dire consequences to Communications satellites, Weather forecasting systems, GPS navigation, Scientific research, the International Space Station & a counting list.

The crux being, a debris filled orbit can have real-world consequences, which are negative, affecting us humans in possibly every single aspect in our life.

Methods Employed Under Space Debris Management

It is pretty clear and understandable now, that Space debris management is a multi-faceted approach that involves some strategic & well-planned activities to resolve the issue of Debris in a more Pragmatic way.

Thus the process Space Debris Management is inclusive of the following steps:

Step 1. Monitoring and Tracking

As the first and initial step, Organisations like the U.S. Space Surveillance Network (SSN), the European Space Agency (ESA), and private companies use radar and telescopes to track objects present in the orbit.

These systems serve the purpose of Detecting small objects, Predict any possible collisions & Alert satellite operators to enable them to take evasive actions a.k.a Collision Avoidance Maneuvers.

Step 2. Designing of Safer Missions

A major part of managing space debris is to prevent more from being created. This step involves changing how companies build & design and operate satellites & rockets. Some of these strategies include Designing Self Deorbiting Satellites which automatically self destructs itself when its purpose is fulfilled, using **Passivation** techniques which prevents leftover fuel or batteries from exploding or blasting, Reducing the number of pieces of objects or parts left in space after a launch.

Step 3. End-of-Life Plans for Satellites

As humans, Satellites don't last forever too, so as an ethical responsibility space activities must include with a plan for what happens when a mission ends. This highly depends on where the satellite is in Low Earth Orbit (LEO) or in Geostationary Orbit (GEO).

Step 4. Active Debris Removal (ADR)

This step of space debris management is somewhat of a futuristic one. Several research companies and entities are consistently working on technologies to which are intended to physically remove debris from space orbit. Though experimental, these ideas include Robotic arms to grab and deorbit old satellites, Harpoons or nets to capture junk and bring it back to earth & Laser systems that thwack small debris into lower orbits and burn it up in the atmosphere.

Though how cool it seems, but on a practical side Active debris removal is expensive and challenging.

Step 5. Policies and International Cooperation

As mandated by the Non-Appropriation Principal, space doesn't belong to any one country, and to manage it international collaboration is required. Several bodies help set & frame rules and to encourage best practices like United Nations Office for Outer Space Affairs (UNOOSA), IADC (Inter-Agency Space Debris Coordination Committee) & International Telecommunication Union (ITU).

Some countries possess their own national policies.

But here the challenge is that of enforcement—there are no strict global laws and most importantly that are Enforceable.

Active efforts are underway to make debris management part of standard licensing for satellite operators.

Legal Framework

United Nation's Treaties to Deal with Space Activities with Articles

• The Outer Space Treaty, 1967

- Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, it is one of the most important and foundational treaty in space law.
- This treaty lays down some very basic and cornerstone principles out of which other treaties and agreements and based on and follow up, like- Non-Appropriation principle, Peaceful Purposes Use, & Freedom of Exploration.
 1. Article-I: Use of Outer Space for Peaceful Purposes.
 2. Article-IV: Prohibition of Weapons of Mass Destruction in Outer Space.

3. Article-V: Cooperation & Information Sharing.
4. Article-VI: National Responsibility for Space Activities.
5. Article-VII: Liability for Damages.
6. Article-VIII: Registration of Space Objects.
7. Article-IX: Avoidance of Harmful Contamination & Harmful effects.

• Rescue Agreement, 1968

- This Agreement Deals with the Rescue & Safe Return of Astronauts & Objects deployed in the outer space by mutual aid or assistance by all the signatory states regardless of boundary/border differences.
- All the signatory states are bound to assist to rescue and bring back any astronaut stranded in outer space. Therefore, the signatory states have a trans-global role when in time of need.
- It supplements the Outer Space Treaty.

1. Article- III: Return of Space Objects.
2. Article- IV: Cooperation in Emergency Situations.

3. Article-V: Liability for Damages.

• Liability Convention, 1972

- As the name suggests, the Liability Convention upholds the nation state launching any object in the celestial reign "Totally Liable" for any threat or damage incurred or posed on earth or mid-air by that object by means of paying compensation as a Penalty.
- On earth, the nation where the space object junk falls and tends to cause any damage, that country can claim compensation for the damage caused.
- This convention concerns itself with mutilation caused by the man-made space entities to other space entities which are assets, but also expands to

any situation where any damage is caused by these entities by gravitating to the earth.

1. Article-I: Liability for Damages.
2. Article-II: Space Object Damage on the Surface of the Earth.
3. Article-III: Damage in Outer Space.
4. Article-IV: Fault Based Liability in Outer Space.
5. Article-V: Claims for Damage.
6. Article-VI: Settlements of Disputes.
7. Article-VII: Joint & Several Liability.
8. Article-VIII: Time Limit for Claims.

• **The Registration Convention, 1976**

- Convention on Registration of Objects Launched into Outer Space, this convention also supplements the Outer Space Treaty and mandates nations to register their space objects with the United Nation.
- This convention aims to bring in transparency in space activities and to effectively facilitate tracking of space objects.

1. Article-I: Definition of Terms.
2. Article-II: Registration of Space Objects.
3. Article-III: Information to be Provided.
4. Article-IV: Registration of Space Objects Launched from the Moon or Other Celestial Bodies.
5. Article-V: Responsibility for Registration.
6. Article-VI: Registration of Space Objects by Private Entities.
7. Article-VII: Notification of Registration.
8. Article-VIII: Access to Information.

• **The Moon Agreement, 1979**

- Agreement Governing the Activities of States on the Moon and Other Celestial Bodies.
- India is a signatory to all five of these treaties but has ratified only four. India did not ratify the Moon agreement.

1. Article-II: Non Appropriation of Lunar Territory.
2. Article-III: International Cooperation.
3. Article-IV: Exploration & Use for Peaceful Purposes.
4. Article-VII: Environmental Protection.

India's Role in Space Debris Management

India as one of the global leader and possessing a stronghold in the present scenario in almost every domain has proved to play an active and dominant role, suffice in this domain of Space Exploration too.

Recent notable Indian space missions include **Chandrayaan-3**, which achieved a soft landing on the Moon's south pole in 2023, and **Aditya-L1**, launched in the year 2023 with the aim to study more deeply the Sun. ISRO also completed a successful **Space Docking Experiment (SpaDeX)** in 2025.

India's first crewed space mission, **Gaganyaan**, is under scrutiny and planned for launch soon.

Apart from these space ventures, India has also actively taken steps and measures to curb the problem of Space Debris. These administrated steps are:

- **ISRO SSA (Space Situational Awareness) Control Centre:**

Established in 2020, it involves tracking space objects, assessing potential close approaches, and implementing mitigation measures to avoid collisions of space objects. It acts as a hub of Space Situational Awareness to India for the purpose of carrying and ensuring Sustainable Space Operations.

- **ISRO System for Safe & Sustainable Operations Management (IS4OM):**

Launched in 2022, IS4OM is ISRO's comprehensive approach to ensure and scrutinise the safety of the Indian space assets and the continued use of outer space for national development. This programme actively aims to monitor and manage objects that pose collision threats. Another aspect of this programme is to ensure compliance with the international guidelines that are put forth by

International bodies like the U.N in regard to the Post-Mission Disposal & end life programmes of Space Objects..

- **Project NETRA (Network for Space Object Tracking and Analysis):**

NETRA – it acts like a space traffic control system. It helps track debris and satellites in Earth's orbit to avoid collisions, protect important space missions, and ensure a safer, more organized use of space. It is an early warning system launched by ISRO in space to detect debris and other threats to Indian satellites. It can spot, track, and catalogue objects as small as 10 cm, up to a range of 3,400 km.

- **Collision Avoidance Manoeuvres:**

One of the most well-known examples of ISRO's collision avoidance maneuvers was carried out for its GSAT-6A satellite. In 2018, the satellite's orbit was adjusted to avoid a piece of space debris that was predicted to come dangerously close. ISRO has also worked closely with other space agencies, such as NASA and the European Space Agency (ESA), to share data and collaborate on collision avoidance, especially when debris poses a threat to multiple satellites.

In order to avoid collisions with other space objects, ISRO performed 21 collision avoidance manoeuvres of Indian operational space assets in 2022.

Case Laws & Global Incidents

CANADA v. SOVIET (1977)

(Cosmos-954 Satellite Case)

This was the first time the Liability Convention had been used in a real-world situation. The Cosmos 954 case proved that countries could hold each other accountable for space accidents using international law.

In 1978, a Soviet satellite called *Cosmos 954* unexpectedly crashed back to Earth. It was carrying a nuclear reactor, and when it broke apart over Canada—mainly in the Northwest Territories—it scattered radioactive debris over

a wide area. This caused major concern for safety and the environment, and cleanup was both difficult and expensive.

After the crash, Canada asked the Soviet Union to take responsibility for the damage. They based their claim on the international agreement of 1972 Space Liability Convention, which says that if a country's space object causes damage on Earth, that country is *automatically* responsible, even if it didn't mean for it to happen.

Canada calculated that cleaning up and managing the fallout cost about \$6 million. In 1981, the Soviet Union agreed to pay \$3 million in compensation.

SpaceX Starship & the Environmental Lawsuit

In April 2023, SpaceX launched its biggest rocket ever—called Starship—from a site in Boca Chica, Texas. Just a few minutes after lift-off, the rocket had problems and was blown up on purpose in midair. The explosion scattered debris, dust, and concrete fragments across nearby areas, including sensitive wildlife habitats.

Several environmental and Indigenous rights groups took legal action—not against SpaceX directly, but against the Federal Aviation Administration (FAA). That's the U.S. government agency that gave SpaceX permission to launch the rocket.

These groups say the FAA rushed the approval and didn't do a full environmental study, which is required under U.S. law (specifically, the National Environmental Policy Act, or NEPA). They argue that the FAA ignored the risks to local wildlife and sacred Indigenous lands.

Uganda Considers Lawsuit Over SpaceX's Satellite Debris (2023)

In May 2023, fragments from a SpaceX satellite launch fell across several districts in western Uganda, including Kyegegwa, Sembabule, and Kyenjojo. The debris, which spread over a 40-kilometer radius, damaged property but fortunately caused no injuries. A forensic report by Uganda's National Forensic Sciences

University and the Airforce identified the debris as "military-grade equipment" made from durable materials like carbon fiber and specialized alloys, which allowed some fragments to survive re-entry into Earth's atmosphere

The incident raised concerns about the safety and accountability of falling space debris. The forensic report recommended that Uganda consider legal action against SpaceX, citing Article 7 of the United Nations Outer Space Treaty, which holds launching states liable for damages caused by their space objects. Uganda had until May 2024 to file a formal claim under this treaty.

While the Ugandan government did not pursue legal action within the specified timeframe, the incident highlighted the growing risks associated with space debris, particularly as private space exploration accelerates. The report emphasized the need for international cooperation and updated legal frameworks to manage the increasing clutter in low Earth orbit.

This case underscores the importance of ensuring that the benefits of space exploration do not come at the expense of those on Earth. It calls for a balanced approach that considers both the advancement of space technology and the protection of our planet and its inhabitants.

Technology & Futuristic Approach

○ Ground Lasers to Vaporise Space Trash

Japanese startup EX-Fusion is working on a ground-based laser system to address space debris. In partnership with Australian contractor EOS Space Systems, the company plans to install a high-powered laser at the EOS Space Observatory near Canberra.

The project's first phase focuses on using laser technology to track debris smaller than four inches, which has traditionally been difficult to detect.

In the second phase, lasers will be intermittently fired from the ground to slow down debris,

causing it to descend into Earth's atmosphere and burn up. Unlike weapon-grade lasers, EX-Fusion utilizes diode-pumped solid-state (DPSS) lasers, a lower-power alternative for space debris removal.

○ Use of Artificial Intelligence

Artificial Intelligence, which in the hot-talks, undoubtedly has and, as a matter of fact, is playing a very dominant and significant in reshaping the orthodox processes and methods in almost every field of life. Evidently, it is apt to say, that AI has played a very crucial and key role in the realm of Space exploration and in debris mitigation, in particular.

There are two instances where the use of AI has been employed and is close to give the anticipated outcomes. The first one is NASA and the second one is of ESA.

➤ NASA, infamously known as National Aeronautics and Space Association, the most dominant and developed space organisation US based player has inculcated AI-Powered Debris Tracking System. This automated system has highly upgraded the detection and tracking aspects. This became possible by setting up highly advanced and high spec ground and space lasers. These lasers collect data by tracking the space objects, debris & outer space bodies and calculate their space positioning, velocities, and orbital track. It then forecasts these stats and ensure that everything is going in line and is safe and sound. In case, any threat is detected it alerts the association before hand and in real time so that there is ample time left at disposal to deal with the possible disastrous event and dodge the dire consequences.

➤ ESA or the European Space Agency, has employed an autonomous space debris detection satellite. This system is independent in nature and needs no human intervention as it carries out its

work from the space itself. As the name suggests, it detects debris and gives statistics in real time. It is also pertinent to mention that the stats provided are really accurate and can be highly relied upon. As an independent functioning satellite it has really showcased how technology can be useful in the space advent and help us to have a safer condition.

Therefore, by harnessing technology and science research with human conscience we can help to invite innovation which is useful and would give blanket of safety to us for the greater good. Justified to say, technology has a front-foot role in space debris management.

Challenges to Space Debris Management

Though a lot of evident progress has been made in the realm of Space Debris Management and a lot is sure to come, but there are still some challenges that tend to exist which presently stand as crucial barrier and hamper the growth in the progress. These challenges are:

- **Challenge of Legal & Regulatory Gaps**
This challenge concerns itself with the Global Policies and legal framework which are based on Debris Management. There is a no consistent framework which is latest & up-to-date in nature and has binding force over the nation states that advent to the space. This challenge highlights the need to have a firm authority and stringent policies that are specifically dedicated to space laws, and in case of non-compliance, dire penalties must be imposed.
- **Challenge of Finance & Cost**
The methods and technologies opted for space debris removal are very costly and require a high amount of finances to be carried out. These methods are not easily fetched & feasible and it is not possible for every nation to use these technologies. Only the proper financially

sound countries could avail these technologies and it is apt to say that developed nations have access to these technologies and the other developing nations are pretty much distant to avail the same. As a result, due the financial status a disparity bar is created among nations which decides that which country can act and which country cannot when talking about Space Debris Management.

- **Challenge of Tracking & Monitoring**

It is easy to talk and write & Conceptualise about space debris but in actuality it would be a very difficult task to deal with the same and its processes even the tiny ones. One of the most basic of task is that of Tracking & Monitoring. Though we do have technologies to track and monitor space debris present in the orbital space but there is certain limits to it. Not every debris is detectable, the smaller one goes unnoticed and generally these are the one that can cause severe damage because of the unpredictability and untraceable nature. Also there are other factors which decide the extent of tracking and monitoring of this debris like: atmospheric pressure, gravitational pull, orbital ground, collisions, etc.

- **Challenge of Uniformity**

Challenge of uniformity confines itself to the issue that there is no as such a common ground which creates a common basis on the issue of space debris. In other words, the status and stats is somewhat irregular as some countries have achieved a different level of progress and some are still underway, creating a difference in approaches and view points. As evident there is not a common ground which tends to create uniformity amongst the nation states that are participating in debris management which hampers the overall development.

o **Challenge of Privatisation & Militarisation**

The entry of private entities in the space advent has led to a new issue and question of accountability these entities include startups, private players, & mega constellations like SpaceX, OneWeb, Amazon Kuiper, etc. These entities are either contract based or licensed through governmental authorities and have large level of space operations that are either being carried out or are planned for the future. More the plans, more the potential debris. Also the militarisation of space for purpose of nuclear use and weaponisation has baffled the activists and many citizens and has raised question of the limit to it.

Suggestions

1) Technological Enlargement & Development

Technology has always played a crucial role from the beginning of advent into the space exploration. Owing to the technology we humans were able to accomplish this major milestone of space exploration and as far we know the journey is ever-&-on going. Therefore to have progressive growth in the near future, more work should be carried out and improvise with the existing one.

2) International Collaboration & Efforts

Global efforts and standards of mitigation should be employed and worked upon. This means a collaborative effort must be put in by every state with a dignified role to better the conditions and aid in space debris management. As per the Non-Appropriation Principle, the space territory belongs to none, but that does not rule that no state should help in reforming and advancing in betterment of space exploration and debris mitigation.

3) Strengthening Legal Framework

A more heavy focus should be made upon the advancement and reinforcement of rules and regulations related to space laws.

There already exists a loophole in the area of legal framework in regard to space laws and it must be focused on. More sound and up-to-date laws must be made which strikes a perfect balance between steady growth and rule compliance.

4) Scrutiny & Active Compliance

More heed should be paid on the overlooking & scrutinising of all in-line work and progress carried out by individual nation states and private companies and ensure that the work and activities being carried out are with due compliance with existing laws. This would foster positive growth in the realm of Space Activities and Debris Management.

5) Strict Penalties & Sanctions

With more stringent laws, heavy penalties and sanctions should be imposed on the instance of non-compliance by the nation states and private entities. These penalties should have a strict approach so a fear of deterrence must avail over all. Reasoning to do so, is due to the heavy damage that is caused by the debris is irreversible to the nature, environment, & life forms.

6) Redressal Mechanism

Improvements in the periphery of Grievance Redressal System should be made, as noting the global incidents and live examples of debris, for instance of SpaceX in space debris, where debris from their rocket have been found in various locations like Bahamas, North Carolina & Poland. This is an international concern and demands a specific constituted body for the purpose of redressals.

7) Raising Public Awareness

As of global concern, knowledge and bordering issues must be imparted to the general public pan-globally. It is of utmost importance to highlight the problem of Space Debris. This is to ensure that public review is generated and ideas for innovation

and mitigation can flood through all areas of world and demographics.

Conclusion

Space exploration is now a milestone that has been accomplished and also a bar standard or benchmark that resonates a country's developmental and progressive rank in the global competition scenario. But as the exploration takes a rise so does the number of objects present in space. This human intervention has a purpose, but as the old saying goes that 'Everything comes with a Price', which implies that nothing is free and without consequences. The price here is that of space debris.

Though the problem is of somewhat we rarely think or talk about in our daily lives, but global activists and space enthusiasts have paid heed and highlighted the debris problem. Also leading nations have schemed out plans to mitigate space debris. These plans highly rely on technology and science. They are costly and hard to execute too. Therefore only some well financially backed & sound nations can employ such technology and could carry out these methods practically for others, only it only tends to be a theoretical concept.

To conclude, it is understood that debris management is a concerning & worrisome issue which needs collaborative effort to get rid of. It is extravagant & technical. And it is important to impart knowledge about the issue amongst general public so that resourceful and young minds can help to inculcate new ideas to help with the issue.

It is the mutual duty to protect the environment. Because where we humans intervene for our own benefit, we need to fix the damages that comes hand-in-hand.

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