Addressing Space Debris: A Policy Framework for Regulating Private Space Companies

Major Project Report

GROUP 5

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Contents

1. Problem Statement & Project Goals

Space debris mainly includes defunct satellites, discarded rocket parts, and various debris generated by space missions, primarily located in low Earth orbit (LEO). Scientists first highlighted this problem in 1961, pointing out that this debris poses a potential threat to space activities.

As humanity expands its exploration of space, the amount of space debris is growing rapidly. The European Space Agency (ESA, 2024) tracks 35,000 objects in orbit, including 9,100 active payloads and 26,000 large fragments (Fig. 1). Over one million smaller fragments pose significant risks to spacecraft, underscoring the growing challenge of orbital debris.

The rapid growth of private companies in space exploration, satellite deployment, and space tourism has intensified the challenges of orbital sustainability. In the past decade, the number of FAA-licensed commercial operations, including launches and reentries, has increased by over 900% (Federal Aviation Administration, 2023). Space X alone has announced plans for 148 launches in 2024, averaging one launch every 2.5 days, further exemplifying the accelerating pace of private sector activity in space.

These trends highlight the critical need for robust policy frameworks to manage space debris, oversee private company activities, and secure sustainable access to LEO. This report aims to develop a comprehensive policy framework to address the growing challenge of space debris, with a focus on regulating private space companies.

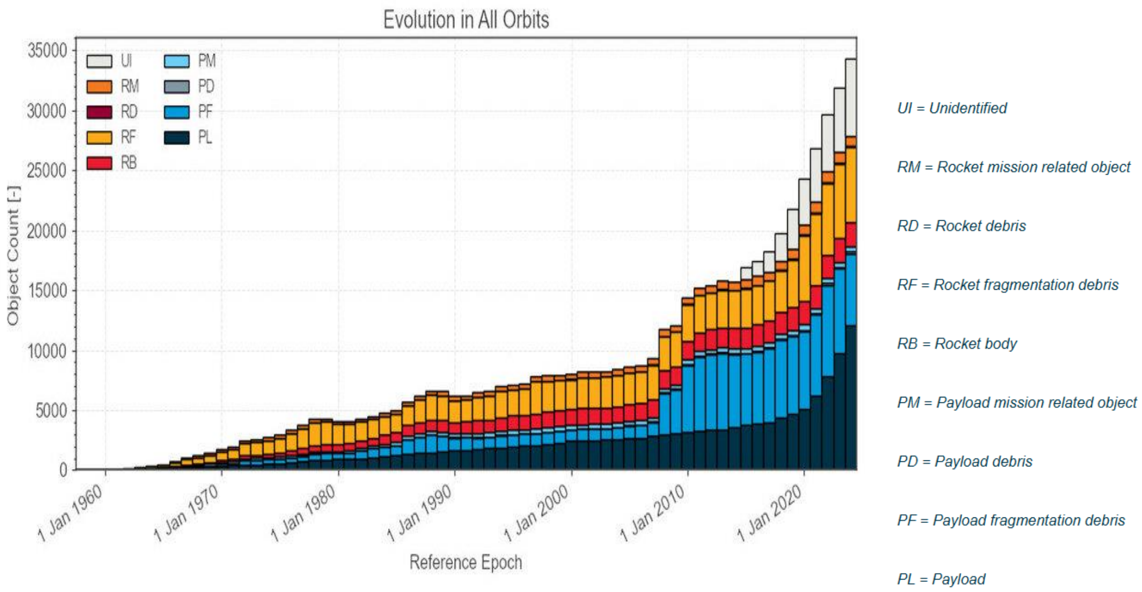


Fig 1: Data from ESA Space Environment Report 2024

2. Literature Review & Data Analysis

2.1 Awareness of the Issue

The dangers of space debris became evident after Sputnik's launch, with Kessler and Cour-Palais warning of the 'Kessler Syndrome,' where collisions create a cascade of debris that threatens orbital sustainability (1978). Since then, the growing urgency of the issue has been highlighted in scientific literature and by organizations such as the United Nations Office for Outer Space Affairs (UNOOSA). This growing body of work reflects the critical need to address space debris as technological advancements and satellite launches continue to accelerate.

2.2 Milestone Events

The growing issue of space debris has been underscored by several milestone events. In 2007, China conducted an anti-satellite test, intentionally destroying one of its weather satellites and generating over 3,000 trackable pieces of debris, significantly increasing collision risks (Jones, 2023). Two years later, the collision between Iridium 33, an active commercial satellite, and Cosmos 2251, a defunct Russian satellite, highlighted the vulnerability of operational spacecraft to orbital debris (Palmer, 2022). The 2020s have seen the rapid deployment of mega-constellations by private companies, adding urgency to the need for debris mitigation as thousands of new satellites crowd LEO (Buzzo et al., 2024). In October 2024, the unexpected explosion of Intelsat 33e, a Boeing-built communications satellite, underscored the risks associated with satellite operations and the need for robust debris management protocols (Tangermann, 2024). These events collectively demonstrate the escalating challenges of preserving the sustainability of space operations.

2.3 Addressing the Problem

Addressing the issue of space debris involves three main approaches.

Mitigation: Efforts to mitigate space debris focus on preventing the creation of new fragments. International bodies, such as the Inter-Agency Space Debris Coordination Committee (IADC), have established guidelines recommending that satellites be deorbited within 25 years after their missions are completed. Many companies are incorporating designs that enable satellites to burn up upon re-entry, while collision avoidance maneuvers have become a standard operational practice (Jones, 2023; Smith et al., 2024).

Remediation: Active debris removal (ADR) technologies are under development to tackle existing debris (Long & Huang, 2024). Examples include the European Space Agency's ClearSpace-1 mission, which aims to capture and deorbit a single debris object using robotic arms, and Japan's JAXA efforts to deploy electrodynamic tethers to remove debris. However, these solutions remain expensive and technically challenging, limiting widespread implementation (Onyibia, 2023).

Monitoring: The global space community relies heavily on tracking and monitoring systems to manage space debris risks. Organizations like the U.S. Space Surveillance Network (SSN) and private initiatives, such as LeoLabs, provide real-time data on debris locations and movements. Enhanced collaboration and data sharing between public and private entities is critical for improving situational awareness and collision avoidance (Onyibia, 2023).

3. Key Challenges of Solving the Problem

Addressing the problem of space debris involves tackling several interrelated challenges spanning legal, political, technical, and financial dimensions (Fig.2).

Fig 2: Orbital Debris contradicting interests (Maier et al., 2020)

3.1 Legal and Political Challenges

Legal and political complexities significantly hinder debris removal efforts. A major issue lies in the diverging interests of nations, making orbital debris a contentious topic on the international stage. Space laws present additional hurdles, such as the perpetual ownership of space objects by their launching states and the lack of explicit liability rules for debris removal.

3.2 Technical Feasibility

Technological challenges include developing and deploying active debris removal (ADR) systems. Current ADR techniques vary in effectiveness and cost-efficiency. Additionally, scaling up these solutions for remediation in LEO presents a significant technical hurdle.

3.2.1 Capture Technologies

Sweepers: Sweepers use rotating blades to capture or deflect particles.

Nets: Nets are designed to entangle and capture debris objects in orbit. They are a simple yet effective option under consideration for ADR.

Single-Arm and Multi-Arm Robotics: Robotic systems equipped with single or multiple arms can grapple and secure debris for removal. These systems offer precision in handling debris of varying sizes.

Fig 3: ADR Capture Technologies

3.2.2 Deorbiting Technologies

Electromagnetic and Moment Exchange Tethers: These systems alter the orbit of debris by leveraging electromagnetic forces or moment exchange principles, guiding debris to re-enter the atmosphere.

Inflatable Balloons: Foam-filled inflatable balloons increase the area-to-mass ratio of debris, allowing atmospheric drag to facilitate natural re-entry.

Solar Sails: Solar sails utilize sunlight pressure to adjust the orbit of debris, enabling atmospheric re-entry over time.

Chemical Propulsion Deorbiting Systems: Particularly effective for large debris, these systems use chemical propulsion to deorbit debris. They are considered the most viable option for handling extra-large debris objects.

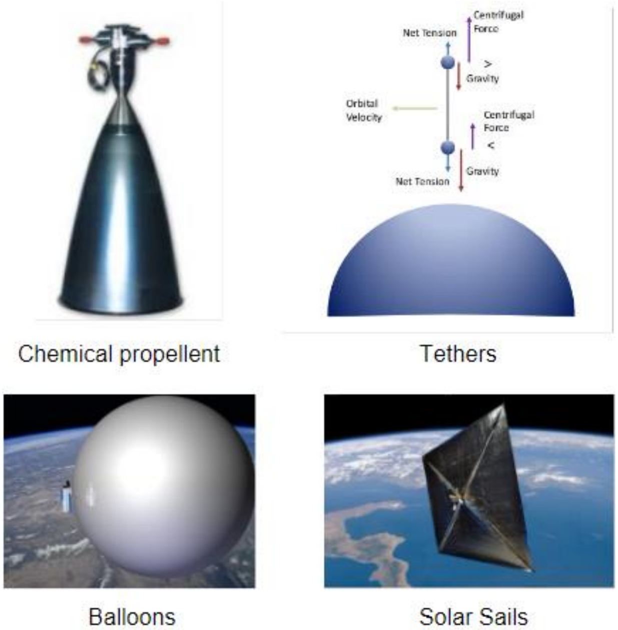
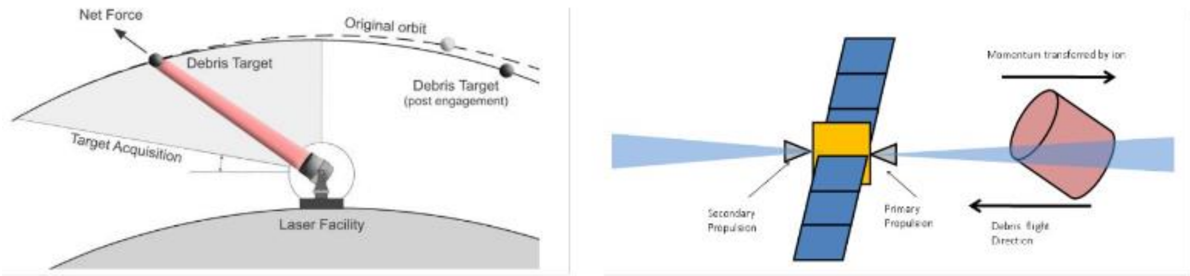


Fig 4: ADR Deorbiting technologies

3.2.3 Contactless Technologies

IBS (Ion Beam Shepherd): IBS employs ion beam propulsion to remotely deorbit debris without physical contact, providing a non-invasive solution.

Ground-Based Lasers: Ground-based laser systems aim to alter debris orbits from a distance, offering a high-tech, contactless approach to debris mitigation.



Laser Technology

Ion beam technology

Fig 5: ADR Contactless Technologies

All technology options for active debris removal should be assessed based on the following key parameters: feasibility, which examines practicality and implementation potential; GEO adaptability, which considers the suitability of the technology for the geostationary orbit environment; reusability, which assesses the ability to reuse components or systems; risk, which evaluates safety and potential hazards; Technology Readiness Level (TRL), which indicates the maturity of the technology; time to deorbit, which measures the speed of debris removal; and total cost, which accounts for the financial requirements for deployment and operation. The selection of the most suitable technology should involve a thorough and context-specific assessment of all these parameters to ensure effective and efficient space debris removal.

3.3 Private Interests vs. Public Interests

The increasing participation of private companies in space exploration has brought to light tensions between their commercial objectives and the broader public interest in ensuring sustainable and equitable use of outer space. While private firms prioritize cost-efficiency and profit, public interests emphasize sustainability and the preservation of the space environment for future generations. Effective debris management requires collaborative policies that incentivize private actors to adopt debris mitigation technologies, such as financial subsidies or penalties, ensuring their activities align with the collective responsibility of safeguarding orbital space.

3.4 Peaceful Use of Space vs. Militarization

Orbital debris management is also intertwined with the dual-use nature of space technology, where peaceful and military objectives often overlap. While nations advocate for the peaceful use of space, concerns about the militarization of debris removal technologies, such as grappling arms or laser systems, complicate international cooperation. Establishing trust and transparency through verification mechanisms and multilateral agreements can help ensure that debris removal initiatives are focused on environmental sustainability rather than strategic dominance.

3.5 Developed vs. Developing Spacefaring Nations

Disparities between developed and developing spacefaring nations further complicate space debris management. Developed nations, with advanced capabilities and substantial resources, dominate space activities and contribute significantly to debris creation. Meanwhile, developing countries struggle to access space and may lack the means to comply with debris mitigation measures. To bridge this gap, international agreements should include provisions for technology transfer, capacity building, and financial support, ensuring that debris management is equitable and inclusive for all spacefaring nations.

3.6 Global Concerns vs. National Interests

Space debris management involves navigating the tension between addressing global challenges and protecting national interests. While space debris poses a shared threat to all spacefaring nations, individual countries may prioritize their strategic or economic advantages, delaying cooperative action. Achieving effective management requires building consensus through international frameworks that respect sovereignty while emphasizing the collective responsibility to ensure the long-term viability of outer space.

3.7 Sustainable Use of Space vs. Minimal Current Costs

Promoting the sustainable use of outer space often clashes with the desire to minimize current costs associated with debris mitigation. Implementing advanced debris removal technologies or adhering to strict mitigation guidelines can be expensive, deterring compliance, especially for smaller players. Policymakers must balance these competing priorities by developing cost-effective solutions and incentivizing sustainable practices, ensuring that short-term cost savings do not compromise the long-term health of the orbital environment.

3.8 Preservation of the Space Environment vs. Continuation of Space Activities

The drive to preserve the space environment must be reconciled with the growing demand for increased space activities, including satellite launches and commercial ventures. While robust regulations and debris mitigation strategies are essential for protecting orbital resources, overly stringent measures could impede progress and innovation. A balanced approach should encourage responsible practices, such as designing satellites for end-of-life disposal and promoting collaborative debris removal efforts, allowing sustainable growth of space activities without further degrading the orbital environment.

The challenges of addressing space debris for private companies are multifaceted and require a holistic approach. This involves international collaboration, policy development, technological innovation, and substantial financial investment to mitigate the problem effectively.

4. Other Areas Approach to Similar Problems

4.1 Ocean waste management

The ocean, like outer space, is a global commons and has suffered severe environmental degradation due to decades of unrestricted waste dumping by countries and private shipping companies. No single country could enforce standards across international waters. The United Nations Convention on the Law of the Sea (UNCLOS) and the International Convention for the Prevention of Pollution from Ships (MARPOL Convention) were adopted as international treaties to mandate compliance with environmental standards. These treaties also impose penalties for non-compliance and ensure international oversight over private companies operating in international waters. Under the treaties, ships are regulated by the country whose flag they fly (Kantharia, 2024).

4.2 Airspace Regulation

Airspace is another global commons shared by private, military, and commercial aircraft. Its rapid expansion has raised global concerns about congestion and accidents. The International Civil Aviation Organization (ICAO) was established as a UN agency to set international standards for airlines and private aircraft for domestic and international flights (ICAO, 2019). Air traffic control is managed through a complex system of air traffic control zones to ensure safety and reduce congestion.

4.3 Nuclear Non-Proliferation and Disarmament

The spread of nuclear weapons poses a global threat similar to the accumulation of space debris. The world leaders adopted the Non-Proliferation of Nuclear Weapons (NPT) treaty to prevent the spread of nuclear weapons and promote disarmament, the International Atomic Energy Agency (IAEA) was established as an agency to conduct inspections and ensure compliance (IAEA, 2016).

5. Current Policy Evaluation

5.1 Outer Space Treaty (1967)

The treaty, whose full title is “Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies,” was established through United Nations negotiations and came into effect in October 1967, provides the basic framework for international space law (Robert Wickramatunga, n.d.). The treaty outlines ten essential principles governing space activities and has been signed by over 100 countries.

Impact of Private Companies

Although the Outer Space Treaty provides a legal basis for space activities, the treaty does not specify the responsibilities of private companies (Johnson, 2017). With the increase of private companies, existing treaties focus mainly on state actions and are not clear about the specific requirements of private companies in areas such as debris management, decommissioning and orbital sustainability.

5.2 Space Debris Mitigation Guidelines (2002)

The Space Debris Mitigation Guidelines were published by the Inter-Agency Space Debris Coordination Committee (IADC) in October 2002 to provide a set of internationally agreed recommendations for reducing the generation of space debris. The main contents include limitation of debris released during normal operations, minimization of the potential for on-orbit break-ups, post-mission disposal, and prevention of on-orbit collisions (IADC Space Debris Coordination Committee, 2002). These measures are aimed at promoting the long-term sustainability and safety of space activities.

Impact of Private Companies

Although the Space Debris Mitigation Guidelines have had an important impact on many countries and organizations (such as NASA, ESA, and JAXA) and are incorporated into their space debris management strategies, they are non-mandatory and lack the force of law. As a result, private companies may not strictly follow, with limited practical effect (National Aeronautics and Space Administration & Liou, 2021).

5.3 Space Debris Mitigation Guidelines (2007)

In 2007, the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) adopted a set of Space Debris Mitigation Guidelines that follow the framework of the IADC. These guidelines elevated the non-binding recommendations of the IADC to a broad consensus at the United Nations level, become one of the reference standards for global space behavior, and be more widely applied in more countries and organizations (De Paula & Celestino, 2019).

Impact of Private Companies

Despite support from the United Nations, the guidelines remain non-mandatory, lack legally binding force, and rely solely on voluntary principles for private companies to follow, leading to limited enforcement. In addition, with the rapid increase of large satellite constellations and private company activity in recent years, the guidelines do not have monitoring and feedback mechanisms to assess compliance by all parties, making their effectiveness limited in practice.

5.4 ISO 24113 Standard (2010, 2019 Revision)

The ISO 24113 standard was first published in 2010 and revised in 2019 to establish clear technical requirements and thresholds for reducing space debris generation to improve the sustainability and safety of space activities. The standard requires solid rocket engines in Low Earth Orbit (LEO) to control debris ejection below 1 mm to reduce the formation of small debris. The spacecraft should have a 90 percent probability of successful disposal at the end of its mission to prevent it from becoming a long-term debris threat. The standard also implements a 25-year rule requiring LEO spacecraft to be removed from orbit within 25 years of mission completion and introduces an assessment of impact risk. These quantitative requirements create a systematic mitigation framework designed to protect the long-term security of the space environment (Stokes et al., 2020).

Impact of Private Enterprise

The ISO 24113 standard provides clear technical requirements, but due to its non-mandatory nature, compliance by private companies may vary. Due to the high cost of meeting the technical requirements, many small private satellite companies face huge economic and technical challenges in complying with the standards.

6. Recommendation

6.1 Establish a Special Space Debris Management Department Under UNOOSA

A dedicated department within UNOOSA should oversee private space companies' adherence to standardized debris management protocols. This department would certify private spacecraft before launch using Life Cycle Assessments (LCA), track debris using advanced monitoring technologies, and maintain a global debris database. It would also mandate incident reporting and enforce a ban on intentional destruction of space objects by private operators, reducing debris generation caused by commercial activities.

To implement this, the department would collaborate closely with private companies to ensure compliance with global standards, while national governments integrate these regulations into their domestic frameworks. Success would be measured by private sector compliance rates, reduced debris incidents, and improved coordination between private operators and international bodies.

6.2 Promoting Responsible Practices in Private Space Operation

Governments should incentivize private companies to develop and deploy innovative debris-clearing technologies through tax breaks, grants, or public-private partnerships. Regulations must also require that private spacecraft include self-deorbiting mechanisms or graveyard orbit capabilities, ensuring their responsible end-of-life disposal. Certification by UNOOSA’s debris management department would be mandatory to enforce these standards.

National space agencies would work with private companies to design these incentives and monitor compliance with mitigation requirements. Progress would be evaluated through the number of private missions incorporating mitigation technologies and the deployment of novel debris-removal solutions developed by commercial operators.

6.3 Mandating Space Debris Mitigation Insurance for Private Space Operators

Private space operators should be obliged to have Space Debris Mitigation Insurance that should compensate for the damage that may result from debris created during the operator’s operations. This funded amount would be a function of the risk associated with the mission including the size, orbit, and lifetime of the satellite. This mechanism would help ensure that operators bear the costs of their practices and hence promote safer practices.

Governments would enforce insurance mandates as part of launch licensing processes, with risk assessment guidelines set by UNOOSA. Effectiveness would be measured by the proportion of insured private operators and their responsiveness to debris-related claims, promoting accountability.

7. Conclusion

Space debris poses a growing challenge to the sustainability of outer space, exacerbated by the rapid expansion of private sector activities. Despite existing guidelines and frameworks, gaps remain in regulating private companies, enforcing compliance, and addressing the financial and technical barriers to effective debris management. By establishing a dedicated department under UNOOSA, incentivizing innovation, and mandating liability insurance, the international community can create a unified approach to mitigate, remediate, and monitor space debris. This policy framework is essential to safeguarding orbital environments for future generations while enabling the continued growth of space activities.

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