Forum: Environmental Commission

Issue: Mitigating the Environmental Impact of Space Debris on the Upper Atmosphere

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Position: Deputy President

Personal Introduction

Dear Delegates,

My name is Philip Archontovasilis and I'm currently a 12th grade student at HAEF-Psychico College. Even though I started MUN only last year, I quickly came to love and appreciate MUN conferences, fruitful debate, and the vibrant MUN community. This year I have been handed the utmost honor of being selected to serve as a Deputy President in the Environmental Commission.

I am more than delighted to welcome you to the 9th session of ACGMUN. The EC was the first committee in which I was a delegate, and I am glad it will be the one that I will also serve as a chair. It is a committee well-suited for both beginners but also experienced MUNers, where crucial ecological and political issues are being thoroughly debated.

The third topic: "Mitigating the Environmental Impact of Space Debris on the Upper Atmosphere", which I have chosen to address in this guide, is more than significant in assessing the impact that space debris, either from natural (e.g. comets) or man-made (e.g. satelites) origin has on the environment. This guide should provide you with an overview of the topic. However, in order to be adequately prepared for our conference, you are encouraged to conduct your own research on the matter and learn about your delegation's policy as well as diplomatic involvement in this issue.

If any inquiries about the topic or the conference in general arise, please don't hesitate to contact me through the following e-mail address: farchontovasilis@athenscollege.edu.gr I will be more than happy to answer any questions that you may have, delegates.

I look forward to meeting you all in February!

Sincerely,

Philip Archontovasilis

Topic Introduction

As our reliance on space tech continues to rise, so does our need to protect our upper atmosphere from the pollution of space debris. When these come back down, they pollute our air, and if we don't address this problem, our future explorations and our very survival on Earth may be compromised. By guiding our space governance towards responsibility, innovation, and international cooperation, we can make sure that our progress does not compromise our environmental stability. By addressing this problem, we can leave our future generations with a cleaner and more sustainable space environment. It is our responsibility to "Shape Tomorrow".

As humanity, it is crucial that we assess The entry of these debris into the atmosphere will result in the shedding of harmful by-products, such as what might be found in aluminum oxides and very fine pieces of metal, that could very well affect the chemistry in the upper parts of the atmosphere. In those high altitudes, changes could influence radiative forcing as well as temperatures, with potential environmental impacts that researchers aim to better understand. Specifically, when a large amount of space debris accumulates in the atmosphere, it could potentially interfere with communications, satellite signals, rocket launches, and make telescope usage much more difficult for astronomers, as they will not have a clear and unobstructed view of the night sky.

Protecting our planet from the detrimental effects of space debris gathering in the atmosphere is a matter that requires international collaboration, given the increasing commercialization of space. As nations and companies continue to explore space, it means it is becoming a congested region, making debris a challenge that we must collectively overcome, as it poses a serious threat on the environment. Space junk can move around the Earth at very high speeds, often reaching even 18,000 miles per hour.[1] High speeds, along with the high volume of it concentrated around the globe can pose serious threats to space exploration missions, space-based services (worldwide communications, space station, etc.), and also falling debris which can enter the Earth's atmosphere and pose risks to people and properties on the ground.

Definition of Key Terms

[1] European Space Agency. *"Space Debris by the Numbers."* ESA Space Safety Programme https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers

Active Debris Removal.[2]

Active Debris Removal comprises systems and methods like robotic arms, tethered devices, lasers, and nets developed for capturing, redirecting, or deorbiting hazardous debris.

Kessler Syndrome.[3]

The Kessler Syndrome describes a scenario in which debris collisions generate even more debris, triggering an exponential explosion of fragments, self-sustaining in nature, threatening all space operations.

Space Debris.[4]

Space Debris refers to human-made objects orbiting Earth that have reached the end of their useful life. These include bits of shrapnel from explosions, aged satellites, and retired rockets.

Upper Atmosphere.[5]

That would be the stratosphere, mesosphere, and thermosphere-the layers of the atmosphere starting around 50 kilometers up-where pieces of re-entering debris burn up and release various chemical compounds.

Background Information

Historical Context

Space debris, also known as orbital debris, refers to a category of objects in space that are of human-made origin and are not in use by us today. Examples include old satellites, rocket boosters, collision fragments and other byproducts of space operations. The first evidence of space debris was recorded in 1967, when Sputnik 1 was first launched. Since then, the activity in space has been

[2] Liou, J.-C. *"An Active Debris Removal Parametric Study for LEO Environment Remediation."* Advances in Space Research
https://doi.org/10.1016/j.asr.2011.02.003
[3] Kessler, Donald J., and Burton G. Cour-Palais. *"Collision Frequency of Artificial Satellites: The Creation of a Debris Belt."* Journal of Geophysical Research
https://doi.org/10.1029/JA083iA06p02637
[4] European Space Agency. *"Space Debris by the Numbers."* ESA Space Safety Programme.
https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers
[5] Vignon, Élodie, et al. *"Atmospheric Effects of Spacecraft Reentries: Pollution, Chemistry, and Climate Impacts."* Nature Geoscience.
https://doi.org/10.1038/s41561-023-01155-9

continuously increasing, resulting in tens of thousands of tracked objects which orbit our planet, excluding of course many more fragments not tracked at all.[6]

Previously, space debris was not considered a threat to space facilities and astronauts.[7] However, in recent times, the impact of space junk on the environments, specifically concerning the interactions between space junk and the upper atmosphere, has alarmed the scientific community. The main concern is that, when debris descends back to the atmosphere, it heats up and creates large quantities of particles and chemical substances at high altitudes.[8]

The problem's origins trace back to the first manned rocket missions to space, specifically when they started taking place in the late 1960s, with the most notable example being the moon landing in 1969. Rockets function in a certain way, where they commence their journey fully intact as a single body aircraft, disintegrating slowly and leaving parts behind, with the only part that completes the journey being the one that contains the passengers. Meanwhile, the torn pieces burn up as they descend into the atmosphere, releasing the aforementioned substances, which usually interact with the ozone, weakening its protective layer.[9] Research has shown that collected aluminum oxides and heavy metallic vapors could alter the chemical composition of the upper atmosphere, impacting long-term climate trends.

Other than rocket parts, the concept of a mega-constellation that will increase the numbers of satellites by thousands, causing low Earth orbit to become more crowded and augmenting the odds of collisions, is another challenge involving space debris. This concept is called "The Kessler Syndrome"[10], and it was first proposed in 1978 by NASA scientists Don Kessler and Buton Cur-Palais. It explains that from a certain point and onwards, the population of space debris will only increase from collisions of the current space debris that exists in orbit around the earth and not from new launch activities.

In the next decades that followed, new programs were established in order to monitor debris-related space activities. In 1979, NASA created the Orbital Debris Program (OPDO), after Cosmos 954 (1977) and Skylab (1979) were launched again for orbit, and the amount of space debris they left behind

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[6] European Space Agency. Space Debris by the Numbers. ESA Space Safety Programme, 2023. www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers

[7] NASA – *Orbital Debris Quarterly News* orbitaldebris.jsc.nasa.gov/quarterly-news/.

[8] Vignon, Élodie, et al. "Atmospheric Effects of Spacecraft Reentries." Nature Geoscience, 2023. https://doi.org/10.1038/s41561-023-01155-9

[9] Boyd (2019) – *Environmental Impacts of the Space Industry* https://doi.org/10.2514/1.A34302.

[10] Kessler & Cour-Palais (1978) – *Collision Frequency of Artificial Satellites* https://doi.org/10.1029/JA083iA06p02637

was consequential. The OPDO, in order to better comprehend and face the growing problem, conducted discussions with the European Space Agency along with other organizations in 1987. After a series of discussions and conferences which involved a plethora of organizations from various countries, in 1993, the Inter-Agency Space Debris Coordination Committee (IADC) was founded[11]. Its main purpose is to develop frameworks and arrange international operations that seek to mitigate the ramifications of space debris and its associated risks on the environment.

Moreover, there were more organizations developed to address the issue. For instance, the Aerospace Corporation manufactured a collision hazard assessment tool called DEBRIS in the late 1980s and early 1990s. This endeavor greatly assisted the Aerospace Corporation in accurate predictions of possible collisions between space junk orbiting the Earth. After that, the first reported crash between two tracked objects occurred[12], specifically between a French satellite and debris from a French rocket that had exploded almost a decade ago. Following this collision, more coordinated efforts were carried out to address the issue that was rapidly developing. The Aerospace Corporation established the Center for Orbital and Reentry Debris Studies (CORDS) in 1997, which focused on tracking debris and predicting when they would restart orbiting in Earth's atmosphere .[13] From a political perspective, the U.S. government, in 2001, publicly published the Orbital Debris Mitigation Standard Practices (ODMSP), which provided detailed guidelines on as to how the growth of debris can be mitigated and prevented from causing environmental damage.

The release of the IADC Space Debris Mitigation Guidelines by the IADC and, consequently the their presentation to the UNCOPUOS Scientific & Technical Subcommittee in 2002,[14] made way for great progress. Since then, this document has been implemented as foundation for national legislation, non-binding policy documents, and technical standards. To combat the worldwide issue of space debris, a consistent set of policies is fundamental, but their implementation cannot be forcefully applied to individual countries, operators, and manufacturers, as it could result in case-by-case differences. As a result, the creation of safety standards and particular rules, compatible with IADC's efforts, has been promoted on a global scale by various member states.

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[11] IADC – *Space Debris Mitigation Guidelines*
www.unoosa.org/oosa/en/ourwork/topics/space-debris
[12] Anselmo & Pardini (2010) – *Cosmos–Iridium Collision*
www.iadc-online.org/documents/
[13] NASA / Johnson et al. (2001) – *EVOLVE Breakup Model*
https://doi.org/10.1016/s0273-1177(01)00423-9.
[14] UNCOPUOS – *Space Debris Mitigation Guidelines (2007)*
www.unoosa.org/oosa/en/ourwork/topics/space-debris.

However, regulating and implementing mitigation strategies is essential to reaching a consensus of shared knowledge of the necessary activities, which will result in important processes that are comparable and will promote transparency on similar issues. Normative international standardization organizations like the International Standards Organization (ISO) with ISO/WD 24113 Space Debris Mitigation have contributed to this aspect of the issue. The United Nations Committee on the Peaceful Uses of Outer Space, UNCOPUOS, has started research on developing a set of globally accepted criteria for the long-term sustainability of spaceflight operations[15] as to solve the problems perpetrated by space debris. The policy and regulatory guideline for space activities, the safety of space operations, international cooperation standards, capacity-building and awareness and scientific and technical progress and research are all key parts of these guidelines, as well as some of the most important goals that these guidelines aim to complete.

Environmental Impact of Space Debris

When Space – Debris re-enters the Earth, it plays a significant role in the upper atmosphere. Specifically, metallic debris and chemical compounds are released in the mesosphere and thermosphere.[16] Furthermore, by the burning of satellites, aluminum oxides are produced, and they can alter the upper atmosphere's chemistry by affecting the Earth's radiation balance and ozone concentrations.[17]. The temperature and density of air in the upper atmosphere can also be affected by the re-entry of more debris, causing the disruption of natural phenomena and satellite orbits[18].

Space Law

The body of legislation controlling space-related activities is known as space law[19]. Similar to general international law, space law is made up of several international agreements, treaties, conventions, resolutions of the United Nations General Assembly, and rules and regulations of international bodies. The norms, standards, and principles of international law included in the five international treaties and five sets of principles controlling space that have been established under the auspices of the United Nations are most frequently referred to as "Space Law."

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[15] ISO / UNCOPUOS – *Long-Term Sustainability Guidelines (2019)*
www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities
[16] Foreman et al. (2023) – *Aerosol Impacts from Re-Entering Space Debris*
[17] Ross et al. (2014) – *Climate Impact of Reentry Emissions*
[18] Vignon et al. (2023)
https://doi.org/10.1038/s41561-023-01155-9
[19] United Nations – *Outer Space Treaty (1967)*
www.unoosa.org/oosa/en/ourwork/topics/space-debris

States have created national regulatory frameworks to control the conduct of space-related [20]activities in addition to implementing international space law instruments. States that have passed national space laws have approached national space operations in a variety of ways. Unified acts or a collection of national legal instruments may comprise national space legislation. Additionally, several states have modified their national legal frameworks in accordance with the particular requirements and pragmatic considerations of the variety of space operations carried out and the degree of non-governmental entity involvement.

The design and production of spacecraft, the use of space science and technology, exploration activities and research, the operation of a launch or re-entry site, the The body of legislation controlling space-related activities is known as space law[21].

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operation and control of space objects in orbit, and the launch and return of objects into and out of space are just a few of the issues that states may take into account when establishing regulatory frameworks for national space activities.

[20] Weeden & Samson (2021) – *Global Space Governance*
[21] United Nations – *Outer Space Treaty (1967)*
www.unoosa.org/oosa/en/ourwork/topics/space-debris
[22] Weeden & Samson (2021) – *Global Space Governance*
swfound.org.

In light of the growing involvement of non-governmental organizations in space activities, national space legislation is also crucial. Appropriate national action is required, particularly with regard to the authorization and oversight of space activities.

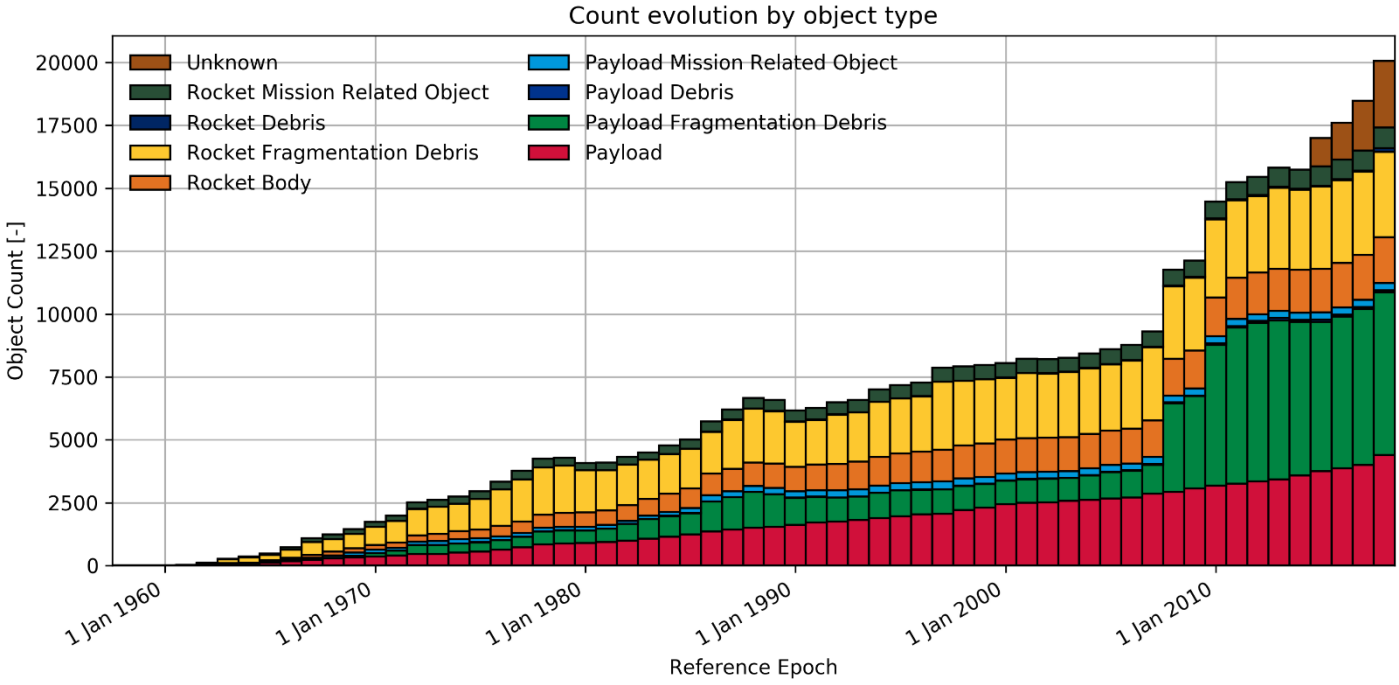

Figure 1: An overview of the timeline of space debris accumulation[23]

Major Countries and Organizations Involved

People's Republic of China[24]

China's national space program, under the administration of the CNSA, is one of the fastest-growing in the world. The country has been expanding its satellite fleets, capabilities, and infrastructure, including the Tiangong space station. However, its history of space debris has been largely marked by the 2007 ASAT test that destroyed the Fengyun-1C satellite and launched thousands of long-lasting debris pieces into space. Since then, the country has been moving in the right direction in accordance with international norms, including adopting post-mission disposal guidelines, minimizing debris from launch vehicle stages, and engaging in UNCOPUOS discussions. Officially, the People's Republic of

[23] European Space Agency. *Space Debris by the Numbers*. ESA Space Safety Programme, 2023. www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers

[24] United Nations Committee on the Peaceful Uses of Outer Space. *Guidelines for the Long-Term Sustainability of Outer Space Activities.* United Nations www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities

China supports the prevention of an arms race in outer space. However, the degree of transparency and the military dimension of its activities in outer space remains questionable.

European Space Agency (ESA) / European Union (EU)[25]

The European Space Agency, in conjunction with the European Union, has made it a point to incorporate the issue of space sustainability and debris mitigation into their key policy areas. Europe has been actively engaged in the development of international space debris mitigation guidelines, including those adopted by the UN. Operationally, the ESA has been at the forefront of promoting key issues that could help address the problem of space debris. For instance, the ESA has been promoting the deployment of satellites that have the capability of de-orbiting after their mission. Furthermore, the ESA has been at the forefront of the Active Debris Removal (ADR) mission, including the ClearSpace-1 mission that aims to demonstrate the capability of removing debris from outer space. The EU also advocates for the establishment of global regulatory mechanisms that could help address the problem of space debris.

Russian Federation[26]

Russia has a long history of space activity that goes back to the Soviet era. Today, they continue their space activity by regularly launching satellites for military, scientific, and commercial use. Recently, in 2021, they conducted a direct ascent ASAT test that destroyed their own satellite, creating thousands of debris fragments in space. This act was highly condemned by other countries in the international arena for posing a potential threat to other space vehicles in LEO. Although they are participating in international forums like UNCOPUOS and are in support of maintaining peace in space, their recent actions are raising many doubts about their commitment towards reducing space debris and maintaining space sustainability.

The United States of America[27]

[25] European Space Agency. *Space Debris by the Numbers.* ESA Space Safety Programme www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers
[26] Anselmo, Luciano, and Carlo Pardini. *"Analysis of the Consequences in Low Earth Orbit of the Collision between Cosmos 2251 and Iridium 33."* Acta Astronautica https://doi.org/10.1016/j.actaastro.2010.06.034
[27] National Research Council. *Limiting Future Collision Risk to Spacecraft: An Assessment of NEO and Orbital Debris Mitigation Options.* National Academies Press

America is the leading player in satellite operations, and it is at the core of space debris governance. The core focus of the United States is space situational awareness and space debris tracking. This focus is spearheaded by the Department of Defense and supplemented by civil organizations such as NASA. The country has developed orbital debris mitigation policies for its government satellite fleet. The country has also initiated a unilateral moratorium on destructive ASAT tests, encouraging other nations to follow suit. Nevertheless, the expanding number of satellite constellations licensed by the United States is causing low Earth orbit congestion, prompting calls for stronger regulation.

The Inter-Agency Space Debris Coordination Committee (IADC)[28]

The Inter-Agency Space Debris Coordination Committee (IADC) is an international governmental forum for the worldwide coordination of activities related to the issues of man-made and natural debris in space. The primary purposes of the IADC are to exchange information on space debris research activities between member space agencies, to facilitate opportunities for cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options.

Blocs Expected

Spacefaring and Commercial Pragmatists (Alliance 1)

These countries are in favor of enhancing existing non-binding guidelines, since this makes it easier to adapt to technological development more quickly. They take a somewhat lenient view with regard to space debris, seeing it as a problem that can be addressed by development policies, rather than seeing it as a dangerous issue that needs to be regulated more formally.

Environmental Protection and Equity Advocates (Alliance 2)

This alliance includes states that care about environmental protection, sustainability of the atmosphere, and universal access to space. Most developing nations, environmental states, and non-spacefaring nations belong to this camp. Members of this camp believe that the threat posed by space debris is a threat and a future environmental issue that might affect the earth's atmosphere and climate systems.

[28] "IADC." *Www.iadc-Home.org*, www.iadc-home.org/what_iadc.

Timeline of Events

Date	Description of Event
1957	The beginning of humankind's involvement with space with the launch of Sputnik[29], thus marking the start of a gradual process of space debris accumulation.
2007	The Chinese successfully destroyed an ASAT[30], producing a massive chunk of debris that highlighted the susceptibility of the low Earth orbit.
2009	The Iridium-Cosmos crash[31] marked the first deliberate satellite on satellite smashup, producing thousands of pieces.
From 2020 to the current period	Ten years of observation has allowed the evolution of the orbital environment to be understood[32], as the deployment of mega-constellations has accelerated launch and re-entry dynamics.

Relevant UN Resolutions, Treaties & Events

Outer Space Treaty (1967)

The Outer Space Treaty, officially called the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, is the foundation for international space law. It affirms that space should be used for peaceful purposes and for the benefit of all humanity. It also asserts that no country may claim ownership of space or any objects in space. It places the onus on states for all activities in space, including those carried out by non-government actors. It requires states to authorize

[29] NASA – *Orbital Debris Quarterly News* orbitaldebris.jsc.nasa.gov/quarterly-news/.
[30] ESA / NASA www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers.
[31] Anselmo & Pardini (2010) https://doi.org/10.1016/j.actaastro.2010.06.034.
[32] Bastida Virgili, Blanca, et al. "Risk to Space Sustainability from Large Constellations of Satellites https://doi.org/10.1016/j.actaastro.2016.03.034.

and supervise all activities in space. Although it doesn't address space debris directly, it has influenced the development of rules on space debris behavior.

Liability Convention (1972)[33]

The Convention on International Liability for Damage Caused by Space Objects builds on the liability provisions established by the Outer Space Treaty. It asserts that the launching state shall be absolutely liable for damage on the Earth's surface or to aircraft caused by its space objects. It asserts that the launching state shall be liable for damage caused to objects in space on the basis of fault. These rules on liability are important for space debris control because collisions between objects in space can result in liability claims. However, the Convention doesn't address liability for the creation of long-term space debris or shared fault.

Space Debris Mitigation Guidelines (2007)

It was back in 2007 when the United Nations Committee on the Peaceful Uses of Outer Space[34] (UNCOPUOS) came up with the Space Debris Mitigation Guidelines, which were meant to address the problem of space debris. Simply put, the guidelines call for space players to follow best practices for mitigating space debris, minimizing the risk of satellite breakups, and safe disposal of satellites and upper stages of rockets after the completion of space missions. Although the guidelines were accepted by all space players and implemented, there is no law requiring any space player to comply. It is purely voluntary.

Long-Term Sustainability (LTS) Guidelines (2019)

In 2019, the UNCOPUOS came up with the Long-Term Sustainability of Outer Space Activities Guidelines, which had the objective of ensuring the sustainability of space for the next generation. This is mainly through the adoption of best practices for the sustainability of space, such as space situational awareness, sharing of information, transparency, as well as the adoption of best practices for the mitigation of space debris. Further, the guidelines call for the support of all the new players in space, especially, as a way of promoting the collective objective of promoting the sustainable use of space.

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[33] United Nations Office for Outer Space Affairs. *Convention on International Liability for Damage Caused by Space Objects*. www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/liability-convention.html.

[34] UNCOPUOS – *Space Debris Mitigation Guidelines* www.unoosa.org/oosa/en/ourwork/topics/space-debris.

Previous Attempts to Solve the Issue

Early International Space Law Frameworks

The first attempt at fixing liability for space activities was the Convention on International Liability for Damage Caused by Space Objects, which was adopted in 1972. This convention was intended to establish who was liable when damage was caused by space activities. For instance, if damage was caused that reached the Earth, absolute liability was applicable. However, if damage was caused in outer space, then fault-based liability was applicable. This was intended to discourage risky behavior by making it clear who was liable. However, this convention has not been very successful and has failed to address the issue of space debris. This was also the first of its kind, and it was intended to establish liability for damage caused by space activities. However, it was not intended to address the issue of debris accumulation, which makes it of little use in this respect. Another convention that was adopted in 1975 was the Convention on Registration of Objects Launched into Outer Space. This was intended to increase transparency in the field of space activities. This was achieved by requiring states that had launched objects into outer space to register them with the United Nations. This helps in identifying the parties when damage or a collision occurs. However, this convention has been of little use due to incomplete information and the delay in registration of the objects. This was also intended to address the issue of debris accumulation, but it was not very successful.

Development of Space Debris Mitigation Guidelines

In the latter parts of the 20th and early 21st centuries, with increasing recognition of orbit congestion, more specific measures were taken to mitigate them. National space agencies, such as NASA in the United States and ESA in Europe, have established guidelines within agencies regarding end-of-life disposal, passivation, or collision avoidance.

One of the biggest efforts to control space debris outside of the UN framework came from the major players in space, NASA and the European Space Agency, in the 1990s and early 2000s. They introduced their own set of debris mitigation guidelines to ensure that their own missions do not contribute to the problem of space debris. These guidelines include things such as passivating a satellite at the end of its life, collision avoidance maneuvers when necessary, and disposing of a satellite via controlled re-entry or transferring it to a graveyard orbit. These guidelines have been incorporated into mission design and licensing. They have been effective in preventing debris from government missions and have become best practices, but their effect is limited. They are primarily in-house, and other stakeholders, particularly commercial entities, follow them voluntarily.

Possible Solutions

Strengthening Space Debris Mitigation Standards

Among the most effective long-term solutions would be to simply halt the problem of creating more space junk in the first place. To accomplish this, there must be tightened and standardized rules on debris mitigation at the international level. This can be achieved by nations taking the existing voluntary rules developed on debris mitigation through the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) and thereby setting them as norms or rules that nations must adhere to or even make them mandatory. These norms or rules can include post-mission disposal, such as de-orbiting satellites within a specific timeframe, as well as minimizing debris generation during nominal operations. In addition, the rules of design and building spacecraft might be updated to include and promote those materials and designs that reduce the fall-out of objects in the atmosphere as they return to the ground. Materials which return to atmosphere in large chunks, thus causing less harm, might be used as a priority.

Controlled and Sustainable Re-entry Practices

Facilitating controlled re-entries is also an effective way of mitigating any possible dangers to the environment. Since re-entering spacecraft can be deliberately directed towards uninhabited zones, such as predetermined oceanic regions, more controlled re-entry can be achieved, which will also enable more accurate modeling of the dispersal of materials in the upper atmosphere. The international community could help create best practices related to the re-entry phase and establish a standard for environmentally responsible behavior by both governments and commercial entities. All debris or rocket re-entries should be meticulously tracked in order to prevent unauthorized entry back into the Earth's atmosphere. Incentives could be provided for the latter to follow such a standard.

Enhancing Atmospheric and Space Environment Research

Better scientific research is required for policymaking. Encouraging greater use of international data sharing can help scientific communities better comprehend the impact of particles on the chemistry of the atmosphere, ozone layer, and radiation forcing. Research collaborations among space agencies, universities, and climate studies offices can fill the current knowledge gaps. The creation of a global system to monitor re-entry material emissions might also help to inform regulatory policy. In this manner, policymakers can use information to create targeted approaches to mitigate material, rather than just working off a precautionary principle.

Economic Incentives and Accountability Mechanisms

Economic instruments might also have an important role to play in promoting responsible behavior in space. Launch licensing costs, insurance premiums, and environmental impact statements might be structured so as to encourage debris-sparing behavior. Conversely, penalties for non-compliance could prevent irresponsible space activities. The 'polluter pays' principle, used in other terrestrial environments, can be extended to space-related activity[35]. This way, companies are incentivized to account for the costs of the generated debris as well as the atmospheric pollution. In these economic incentives, national governments, space agencies, commercial space companies, as well as international organizations will be involved.

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[35] Boyd (2019) -*Environmental Impacts of the Space Industry* https://doi.org/10.2514/1.A34302.

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