Forum:	Environment Commission
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Introduction

As humanity ventures further into outer space, the issue of space debris has emerged as a critical challenge to both current and future exploration and development. Space debris, which includes defunct satellites, spent rocket stages, and fragments from collisions, poses significant risks to operational spacecraft and the sustainability of space activities. According to NASA, there are over 25,000 trackable pieces of debris larger than 10 cm in Earth's orbit, and greater than 100 million smaller fragments between 1 mm and 10 cm, traveling at speeds up to 15 kilometers per second[1] depending on orbit level (NASA Orbital Debris Program Office). Even small pieces of debris can cause catastrophic damage to operational satellites, space stations, and future crewed missions.

The problem has escalated in recent decades with the increase of commercial mega-constellations, anti-satellite testing, and an increase in satellite launches. Addressing the impact of space debris is essential for ensuring the long-term sustainability of space exploration and development. Without effective mitigation, space debris could lead to a much more problematic scenario in which space infrastructure is frequently damaged, generating more debris exponentially and further multiplying the difficulty of redressing the issue. This report attempts to provide an overview of the history and challenges surrounding space debris, as well as suggestions for future solutions and development.

Definition of Key Terms

Satellite

Any object, natural or artificial, that orbits around a larger celestial body. Natural satellites include objects like the Moon orbiting Earth; artificial satellites are man-made objects launched into space for various purposes, such as communication, weather monitoring, scientific research, or navigation.

Space Debris / Space Junk

Refers to defunct satellites, spent rocket stages, and fragments from collisions that remain in Earth's orbit.

Low Earth Orbit (LEO)

An orbital region ranging from 160 km to 2,000 km above Earth's surface. LEO is heavily used for satellites, particularly those involved in communication, Earth observation, and scientific missions, making it a high-risk area for space debris accumulation.

End-of-Life (EOL) Disposal

The process of safely deorbiting or relocating a satellite or spacecraft at the end of its operational mission to avoid contributing to space debris. This often involves moving a satellite to a graveyard orbit or ensuring it burns up upon re-entry into Earth's atmosphere.

[1] Over 10 times the speed of a bullet.

Atmospheric Drag

A force acting on objects in low Earth orbit that causes them to lose altitude and eventually re-enter Earth's atmosphere. A reduction in atmospheric drag will cause objects to remain in orbit for longer periods.

Satellite constellations / Mega-constellations

Large networks of hundreds or thousands of small satellites deployed in low Earth orbit to provide global services such as internet coverage.

History & Developments

The origin of space debris

Sputnik 1 & the Space Race

The launch of *Sputnik 1* by the Soviet Union (USSR) on October 4, 1957 was a historic moment. As the first artificial satellite to orbit Earth, it marked the start of an innovative spacefaring age for humanity, but also the introduction of human-made objects into space and Earth's orbit. Although the satellite was small, weighing just 83.6 kg, its launch created the first two pieces of artificial orbital debris - the rocket stage used to propel it into orbit, and *Sputnik* itself **(Aerospace)**. After its batteries running out just 22 days later, it drifted back to Earth, re-entering the atmosphere the following January and burning up **(Uri)**. This event directly prompted both the creation of the National Aeronautics and Space Administration (NASA) and Project Space Track, a system under the United States (US) Air Force which documented both foreign and domestic man-made objects in orbit.

The longevity of orbital debris

Launched on March 17, 1958, Vanguard 1 is the oldest human-made object still in orbit today. Though it ceased functioning in 1964, it continues to circle the Earth, weighing only 1.5 kg and smaller than a standard basketball. Due to its high orbit, the result of a three-stage launch vehicle test, its expected orbital lifespan is about 240 years (Betz). A number of scientists who worked on Vanguard ended up joining NASA when it was formed in 1958, transferring from the Navy to NASA along with the project. Though by itself it is quite harmless, Vanguard presents an obvious example of how long objects can persist in space once launched, even when from primitive technology compared to what modern capabilities can manage.

As the Space Race of the 1960s progressed, contributing rocket stages, satellites, and anti-satellite (ASAT) testing debris to the atmosphere, there were further attempts to document orbital objects. For example, the now defunct North American Air Defense (NORAD)'s Space Detection and Tracking System (SPADATS) was built in 1960 to integrate defense systems separately built by the Navy and Air Force, including Project Space Track (NORAD).

Challenges in space development

The Kessler syndrome

Proposed by NASA scientist Donald J. Kessler in 1978 in his seminal paper "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt", the "Kessler syndrome"[2] describes a scenario where the density of objects in LEO becomes so high that collisions between pieces of shrapnel generate even more debris. This creates a cascading effect, exponentially increasing the likelihood of future collisions. Over time, collisions between the resulting small

[2] Also referred to as the "Kessler effect", "collisional cascading" or "ablation cascade".

pieces of shrapnel increase in frequency, each time breaking pieces of debris into smaller fragments, until eventually only a disc of dust (a “debris belt”) remains around the Earth.

Due to Earth’s atmospheric drag, it has been concluded that an actual ring of this type is highly unlikely to ever form around Earth (Kessler). However, atmospheric drag does not remove larger pieces of debris faster than they are being generated, so we will still see a continuous increase in collisions and fragmentation until the current debris population is reduced.

The movie Gravity (2013) depicts this situation: after a defunct spy satellite is shot down, the resulting cloud of debris moves at 50,000 miles per hour, eventually consuming the $100 billion the International Space Station (ISS) (Yarlagadda). Of course, this is not entirely accurate to how it might play out in reality - the entire process would take decades, not a matter of minutes - but it serves as a not unrealistic imagining of our future without addressing the clouds of space debris in orbit.

The effect of CO_2 on atmospheric density

Carbon dioxide (CO_2) being a destructive contributor to global warming and a factor which expediates climate change is well understood, but it also has a harmful effect on the longevity of satellites in orbit. Its presence in the thermosphere lowers the atmospheric density, prolonging the time that debris stays in orbit. Though this could be potentially positive for artificial satellites, over time, it will cause collisions to increase and prove expensive for manufacturers and governments.

In orbits below 500 km, objects typically drift back to Earth within 25 years. At 800 km, it can take over a century; at 1200 km, about 20,000 years; and at 36,000 km, geostationary orbit (GEO) is reached, where satellites may stay in space indefinitely (ESA). The increasing presence of CO_2 causes every level of orbit below GEO to be extended, making the natural cleanup process of debris exiting orbit and re-entering the atmosphere much slower.

Without taking measures to reduce the levels of CO_2 pollution and production, the effects of Kessler syndrome could be accelerated, causing increased damage to property and a growing amount of small debris fragments.

Impact on future space exploration missions

Space debris also presents a significant challenge for crewed space missions and future exploration plans, including missions to the Moon, beyond, or even simple maintenance procedures in orbit around Earth. NASA cites micrometeoroids and orbital debris (MMOD) as the number one concern for NASA’s human spaceflight programs: many pieces of shrapnel are large enough to be tracked and avoided through spacecraft maneuvering[3], but MMODs are too small to be monitored and at orbital velocities, even tiny objects can be fatal to humans **(Howell)**.

For example, in 2016 European Space Agency (ESA) satellite Copernicus Sentinel-1A was hit by a millimeter-sized particle in orbit, causing a power loss and creating a 40 cm hole in a solar panel **(ESA)**. Fortunately, the event did not negatively impact the satellite’s operations, but what if the impact had been on a component less disposable than a solar panel? What if it had been on not a satellite but a manned vessel? The sheer volume of untrackable debris in orbit makes further development space risky not only for humans but for other costly infrastructure.

Current legal & regulatory issues

The Outer Space Treaty

The foundation for space law was laid by the Outer Space Treaty of 1967[4], which remains the most significant legal document governing the activities of nations in outer space. Signed by

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[3] the ISS has course-corrected 32 times since its launch in 1998 to avoid satellites and debris.

[4] It was considered by the Legal Subcommittee in 1966, agreed on by the General Assembly in the same year (resolution 2222 (XXI)), and entered into force in January 1967.

over 110 countries, the treaty outlines broad principles[5]: Article I indicates that “the exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit of […] all mankind”; Article IV forbids countries from deploying “nuclear weapons or any other kinds of weapons of mass destruction"[6] in outer space.

Notably, it is also written that space “shall be the province of all mankind”. This gives rise to the *tragedy of the commons*, a theory coined by American biologist G. Gardin asserting that the unregulated use of a commonly held resource - in this case, space - will inevitably lead to the ruin of that resource ***(Gurova)***. In practice, this means that as more countries and companies use low Earth orbit (LEO), the availability of orbital space diminishes, limiting future access due to increasing congestion[7].

The Liability Convention

The Liability Convention[8] was considered by the Legal Subcommittee from 1963 to 1972 and entered into force in 1972 after being agreed on by the General Assembly. Expanding on Article VII of the Outer Space Treaty, it provides that “a launching State shall be absolutely liable to pay compensation for damage caused by its space object on the surface of the earth or to aircraft in flight”[9]. It is the main basis for outer space damages and reparations law, but it is flawed and vague, perhaps due to its age and lack of updates based on modern advancement.

As suggested by the Chicago Journal of International Law, the Liability Convention has several issues: it relies too heavily on the good-faith cooperation of all parties to determine proper remedy for damage caused, and if the conflict extends over the period of a year, claims will likely never be compensated since the damaged state’s claim will expire ***(Kehrer)***. What this means in practice is that if the damaging state is hostile to the damaged state, or otherwise unwilling to provide recompense, it can simply refuse to participate in the dispute resolution process and in this way prevent any effective action[10].

The only case in the past where the Convention has been formally applied (in some way) was in 1978, when the Soviet-issued Cosmos 954 satellite disintegrated over Canadian territory. The Canadian government then successfully claimed a settlement of 3 million dollars from the Russian government in 1981. It is significant that the Liability Convention itself was not mentioned in the final document and was only explicitly referred to in the claimant’s statement, making this invocation of the Convention more *ex gratia*[11] than out of strict adherence to legal standards[12].

Another important consideration for any amendment or redraft of the Convention is situation which arose in the Iridium-Cosmos collision of 2009. On February 10, Iridium 33 and Cosmos 2251 collided over Siberia - the first time a collision between two intact satellites had occurred ***(Listner)***. Cosmos 2251 was a derelict military communications satellite owned by the Russian Space Forces while Iridium 33 was a U.S.-made privately owned telecom satellite from

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[5] Full text can be found here.
[6] The term “weapons of mass destruction” is not defined here, but defined elsewhere by the UN as including nuclear, chemical, and biological weapons.
[7] Specifically, there is an inherent contradiction between personal interests (the interests of individual countries and corporations) and the public good (humanity’s future expansion in space and maintaining the health of the environment) causing LEO to become less and less available. The supply of literal space in space reduces too fast to meet the demand due to the number of suppliers being functionally unlimited.
[8] Full name: Convention on International Liability for Damage Caused by Space Objects. Full text can be found here.
[9] The term “launching State” is defined in the convention as a State which “launches or procures the launching of a space object” and/or “from whose territory or facility a space object is launched; attempted launching is included.
[10] See the Chicago Journal article here and more specifically sections III and IV for further elaboration.
[11] “Ex gratia”: (of payment) given as a favor or from a sense of moral obligation rather than because of any legal requirement.
[12] A detailed legal analysis of the Cosmos 954 by the McGill Law Journal can be found here.

Iridium LLC, part of a constellation used for satellite phones. Cosmos had been deactivated prior to the collision after its launch in 1993.

Russia, the damaging party, correctly contended that it did not have an obligation under international law to dispose of Cosmos 2251 after it became derelict, and in fact the satellite did not have any maneuvering capabilities, so the obligation fell upon Iridium LLC to avoid the collision. Iridium LLC asserted that it also did not have any obligation to maneuver the satellite, even if it was aware that a collision may occur. In such a situation, under the Liability Convention, an issue regarding the term "launching State" transpires: straightforwardly, Cosmos 2251 was launched by Rocosmos, but Iridium LLC itself has no link to the State of the U.S. other than its nationality - a factor which is not mentioned at all in the Convention. Additionally, the U.S. did not consider itself to be a launching state in this incident, and it would clearly be unfair to hold it responsible for the actions of a governmentally unregistered satellite manufactured and launched by a private corporation[13]. The Convention thus insufficiently addresses corporations and non-state parties, the importance of which will only increase with the growing commercialization of space ***(von der Dunk)***.

Anti-satellite (ASAT) testing

ASAT testing has been one of the main contributors to the exponential increase in space debris in recent decades[14]. In these tests, nations destroy their own satellites using ground-based missiles to demonstrate or test military capabilities. They generate thousands of small pieces of debris quickly because ASAT weapons are often kinetic, meaning they simply collide at high speeds into the target to ensure its destruction. The first major ASAT test occurred in 1985, when the US destroyed its satellite, Solwind P78-1 ***(Grier)***. A more infamous and recent example was in 2007, when China destroyed its defunct weather satellite Fengyun-1C in LEO, generating an estimated 35,000 pieces of debris larger than 1 centimeter ***(David)***.

Other nations, including Russia, India, and the U.S., have also historically tested kinetic anti-satellite capabilities; there is currently no international regulation or standard for banning ASAT testing, commonly considered to be an extreme issue in reducing debris growth. The U.S. announced a unilateral moratorium on testing in 2021, undoubtedly a positive progression ***(McClintock)***. However, Russia has tested ASAT weapons as recently as November 2021; India has also tested ASAT weapons as recently as March 2019. The inconsistency surrounding this matter is obvious[15] ***(Roman)***.

Technological advancements

Active Debris Removal (ADR) technologies

Limiting launch rates would be neither feasible nor helpful due to an inherent inability to mandate such things and would also limit our ability to expand space infrastructure. Therefore, the remaining way would be to actively remove large objects in orbit which have a long lifetime in space. This could also enable removal of critical objects (those that would generate the most fragments in case of collision) and decommissioned objects[16], according to ESA ***(ESA)***. NASA and ESA studies show that with deliberate target selection, the environment could be stabilized when 5-10 objects are removed from LEO every year.

In 2022, engineers at NASA's Johnson Space Center designed an Active Debris Removal Vehicle (ADRV) that can approach and assess a debris object, determine a capture trajectory, and deorbit the object. Due to its small form factor, with this design, up to eight ADRVs can be clustered in a single launch; each ADRV can then be assigned a unique capture target ***(NASA)***.

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[13] See the Nebraska Law Review paper here for an elaboration on the Iridium-Cosmos incident.
[14] A comprehensive spreadsheet of ASAT tests up to 2022 provided by the Secure World Foundation can be found here.
[15] A compendium by the United Nations Office for Outer Space Affairs on space debris mitigation standards, both national and international, can be found here.
[16] This could potentially avoid future scenarios similar to the Iridium-Cosmos collision.

A similar companion to this idea was proposed by Hasseri et. al in 2013: an ADRV or other ADR system could be installed directly into a normal satellite mission's upper stages, which are shed during as part of the launch process ***(Nasseri)***. It could then carry out an ADR mission without necessitating another launch. However, these proposals and other similar concepts are still preliminary and require much development - one of the challenges ADRVs face is the lack of technology enabling precise maneuvering while in orbit, as active capture of moving debris requires ***(Wahl)***.

ElectroDynamic Debris Eliminator (EDDE)

Alternatively, a different approach to ADR could be EDDEs - essentially, vehicles that catch orbital debris in a giant net and then drag it out of the way ***(Wall)***. EDDEs would rely on power from the sun and the Earth's magnetic field rather than chemical propellants, keeping costs down and increasing longevity.

Each EDDE vehicle would be a series of nanosatellites connected by electrically conducting tape up to 3 km in length, with a "net manager" full of nets at each end. The entire system would have a weight of only 100 kg, even with the nets fully expanded to the size of a house. After capturing a piece of debris, the EDDE would be able to drag it to a lower orbit, where it would drift close to and eventually burn up in Earth's atmosphere. According to Jerome Pearson, president of Star Technology and Research Inc., a fleet of 12 EDDEs could potentially de-orbit all 2,500+ pieces of debris in LEO in 7 years. It would take about $84 million per year for 12 years, including 5 years of development and construction time. While this proposal first appeared in 2011 and clearly the orbital debris issue has not yet been resolved (one can assume it was due to a lack of funding), similar designs have been put forth by NASA, and the idea is certainly still viable.

Major Parties Involved

National space agencies

As the U.S.' national space agency, NASA has been at the forefront of space exploration and, consequently, space debris management. The U.S. government ended all ASAT testing in The NASA Orbital Debris Program Office monitors and researches the debris environment, and contributes to international guidelines on space debris, including the Inter-Agency Space Debris Coordination Committee (IADC)'s and the UN's. Roscosmos, Russia's space agency, notably has not discontinued ASAT testing, but has proved amenable to fair negotiation as demonstrated by the Cosmos 954 Incident. The Chinese National Space Administration (CNSA) has also continued ASAT testing up until relatively recently and has expanded its space infrastructure with ambitious projects such as the Tiangong space station, which counts as one of only two space stations currently operational along with the ISS. All three states mentioned here are party to the Outer Space Treaty.

European Space Agency (ESA)

ESA is a 22-member intergovernmental body with its headquarters in Paris. It was founded in 1975. Historically, it has deals with small, unmanned projects as compared with NASA, which has always deployed more high-profile crewed missions. ESA's Space Debris Office combines all of ESA's efforts in this area and manages part of the Space Situational Awareness (SSA) program, a European space surveillance effort. It also coordinates with national research efforts in European national agencies and in Italy, the UK, France, and Germany, forming in combination the European Network of Competences on Space Debris. In 2025, ESA plans to launch ClearSpace-1, the first-ever mission to remove a satellite from orbit.

Private space companies

The increasing activity of the private space sector introduces mega-constellations, which are formed from thousands of telecommunication satellites launched by companies in LEO. A key player is Elon Musk's SpaceX, which manages the Starlink internet constellation and designed the first reusable rocket, Falcon 9, in 2010, cutting down greatly on launch costs. Other companies include Astroscale, a

Japanese company that has demonstrated the viability of magnetic ADR technology, and commercial mega-constellation managing companies like OneWeb or the proposed SatNet (Jones).

Previous Attempts to Solve the Issue

Over the past decade, space agencies and private companies have explored technological solutions aimed at removing existing debris from orbit, which have included robotic arms, nets, magnetic fields, and harpoons. The first significant attempt came with the RemoveDEBRIS mission in 2018, led by the University of Surrey in partnership with ESA (Aglietti, REMOVEDEBRIS). The mission involved propelling a 100 kg satellite out to the ISS by a SpaceX rocket, where it would then perform a series of experiments on capturing space debris, successfully testing two types of debris removal technology: a net system to capture small debris and a harpoon to target larger fragments (Aglietti, Harpoon successfully captures space debris). While it demonstrated that these technologies could be used effectively on a small scale, scaling them to handle larger debris fields and defunct satellites remains an obstacle.

Another promising development in Active Debris Removal (ADR) technology was the ELSA-d mission launched by Japanese company Astroscale Holdings in 2021. This mission aimed to demonstrate the use of a magnetic docking mechanism to capture defunct satellites and guide them toward deorbiting (Astroscale). It also demonstrated other key capabilities required for on-orbit servicing and extension of GEO orbits[17]. The ELSA-d mission was the first commercially backed initiative to actively remove space debris, indicating a shift toward private-sector involvement in debris mitigation.

Another approach to managing space debris has focused on preventing collisions by improving space traffic management and developing better collision avoidance systems. With the increasing number of satellites in orbit, particularly in LEO, the risk of collisions between satellites and debris has grown. To address this, many new satellites, such as those in SpaceX's Starlink constellation, have been equipped with autonomous collision avoidance systems that can perform evasive maneuvers when on a collision course with debris. Over a period of 6 months, Starlink's satellites made 50,000 collision-avoidance maneuvers, with each satellite maneuvering 275 times per day - about double the number of the year prior (Pultarova). These decisions are made autonomously by onboard AI. Possible issues that may arise include a shortening of operational longevity due to each maneuver using up more propellant. However, SpaceX has committed to a zero-debris policy with Starlink, and only one satellite failed to deorbit in the 6-month period covered (Sheetz).

In addition to satellite-based avoidance systems, efforts to improve debris tracking capabilities have also advanced. NASA's Orbital Debris Program Office and ESA's Space Debris Office use radar and optical tracking systems to monitor the location of debris and provide satellite operators with early warnings of potential collisions. These tracking systems are critical for managing the growing congestion in space, though they primarily offer reactive solutions rather than addressing the root issue of space debris accumulation, which requires more aggressive strategies. The collision-avoidance maneuvers of satellites like Starlink's also throw off these tracking and collision prediction systems by up to days, with satellites' actual positions differing by as much as 40 km from their forecasted ones after movements.

The main reason these proposed debris management systems have not been wholly successful is because thus far, they have been mostly relegated to remaining proposals. Projects like RemoveDEBRIS and Astroscale's ELSA-d have shown success in capturing small debris, but scaling these solutions to handle millions of debris pieces and large defunct satellites remains difficult and expensive. Additionally, they have only been tested in controlled environments with plentiful human supervision and guidance, so it remains unknown how they may perform in more volatile situations. ADR technologies in general are still in their early stages, and no entity has committed to the high cost of large-scale cleanup operations. While collision avoidance systems help mitigate immediate risks, they are reactive measures with less than universal adoption. SpaceX's environmentally conscious policies are promising, but very few entities have made similar promises, and it is of course less than ideal to rely on the commitment of a corporation not bound to honor that agreement by law.

[17] See Astroscale mockup video on ELSA-d's aims and capabilities here.

One of the earliest approaches to tackling the space debris problem was the development of international guidelines to promote responsible space activities. In 2007, UNOOSA introduced the Space Debris Mitigation Guidelines[18]. Although these guidelines helped raise global awareness of the issue, they remained non-binding, limiting their effectiveness in fully curbing the growth of debris. They do, however, provide a basis for binding legislation in the future and national regulations. Several countries and space agencies have since implemented their own national policies. For instance, ESA drafted end-of-life procedures for satellites in 2015, requiring them to safely deorbit or move out of active orbital zones. As mentioned above, some commercial companies like SpaceX have adopted zero-debris policies as well. While these policies have had some success in limiting new debris, the lack of legally binding global agreements continues to be a gaping issue.

Possible Solutions

Any successful solution to the proliferation of space debris must involve ADR - at the current state of things, even if any increase in manmade objects is entirely prevented, debris fragments will still increase quickly due to collisions in LEO. Successful demonstrations like RemoveDEBRIS, ELSA-d, and various mockups of more efficient ADRVs show that ADR technologies are maturing, but large-scale implementation faces technical and financial hurdles. Being comprehensive also requires an extremely large amount of long-term funding, likely more than any single company could accrue consistently through just investors. Thus, the support of numerous governments and international cooperation is almost certainly necessary, if not for funding, then for avoiding legal issues, since any technology based in the U.S., for example, would not be allowed to capture Chinese property (even defunct) without express permission.

There are also ways of limiting the creation of new debris through better design and operational practices: it would be beneficial for any and all launching parties to adopt a zero-debris policy and install deorbiting systems onto new satellites and other objects. Other than projects like the ISS, which are designed to stay in space indefinitely with regular maintenance from Earth, all smaller-scale satellites will eventually run out of fuel and as such end-of-life deorbiting procedures are necessary. Alternatively, if the vehicle is unable to perform a deorbit maneuver due to lack of fuel or incompatible velocities[19], it can be reorbited to a graveyard orbit, also called a junk orbit or disposal orbit. These orbits lie away several hundred kilometers from common operational orbits and have a negligible effect on human operations in space; this may be a less effective solution long-term than deorbiting satellites, since it amounts to pushing the problem back when humans will inevitably expand to currently unused areas, but it is still advantageous in the current situation. Other future areas worthy of research could also include designing satellites to be more collision resistant and anti-fragmentary or reducing the number of rocket stages discarded during the launch process.

Additionally, there should be a move to better integrate commercial satellite constellations with tracking systems like NASA's and ESA's to improve collision prediction and ensure adherence to guidelines. There is also a need for binding international agreements that establish clearer responsibilities and penalties for debris generation, especially where private entities are concerned. These agreements could include mandatory requirements for deorbiting satellites after mission completion and assigning liability for debris-related collisions.

Ultimately, solving the space debris problem will require a combination of technological innovation, international cooperation, and regulatory reform. As more nations and companies invest in space exploration, establishing global standards and encouraging responsible practices will be essential for maintaining the long-term sustainability of outer space.

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[18] The Guidelines' full text can be found here.

[19] Deorbiting a satellite requires a velocity of about 1,500 meters per second, while reorbiting to a graveyard orbit only requires about 11 meters per second.

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