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Space Debris as a Threat to Space Sustainability

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Aim: The issue of space debris (or space junk) is an important aspect of the sustainability of space. If not properly managed, the accumulation of space debris could make some orbital paths too dangerous to use, potentially limiting our ability to explore and utilize space. This study aims to gain a better understanding of the space debris problem.

Design / Research methods: This article is based on a review of official statistics, policy papers, and media coverage related to the topic of space debris.

Findings: The data shows that intentional and non-intentional debris-creating events are still occurring. The increasing amount of debris brings higher risks to functional satellites and missions. While there are new projects to mitigate debris, these are challenging to put into action due to their high cost and high level of technology.

Originality: This paper presents an overview of the space debris problem in the context of the sustainability of space, by focusing on legal and technological aspects. The paper also touches upon different ways to mitigate space debris.

Keywords: Space debris, space sustainability, satellite, debris mitigation
JEL: Q56, Q57

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1. Introduction

More than 4000 active satellites are orbiting around the Earth and are providing important benefits to humankind. On the other hand, almost the same number of inactive/decommissioned satellites are still in the orbits of Earth. Besides, there are thousands of rocket and satellite parts, which are called space debris or space junk. It is notable that even a few millimeter-long junks can destroy important satellites, as space junk travels at the speed of thousands of km/h (SWF 2014). As the number of satellites increases year by year, the possibility of collisions with either other satellites or space debris is deepening as well. Earth's orbital sustainability is critical for planetary environmental protection, as well as for the safety of humans in space and on Earth. It is important to indicate that Earth's orbits are actually gateways to reach and explore space, so it is essential to keep these points open and safe. To achieve sustainability in Earth's orbit, it is necessary to mitigate space debris. In this paper, the author will show what are the current challenges of debris mitigation and what are the possible solutions to the space junk problem.

2. Space sustainability as a concept

The term "space sustainability" is getting more and more visible in academic and political discourses. Even though there are some differences in the description of sustainability in space, the key aspects can be summarized in the definition enhanced by the UN Committee on the Peaceful Uses of Outer Space (2018):

"[…] the ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, in order to meet the needs of the present generations while preserving the outer space environment for future generations".

In 1978, NASA scientist Donald Kessler proposed a scenario called "Kessler Syndrome" (Kessler, Cour-Palais 1978). According to the scenario, the density of space debris would be high enough in Earth's orbits that finally a chain reaction would start; the collisions between debris would create more debris, resulting in more collisions and more debris. Even though the situation is not that bad for now, the risks are increasing. Consequently, the cooperation about the sustainability of space mainly derives from the worry that if space gets unreachable because of a debris cloud. Such a situation would mean that humans would be stuck on Earth (Newman, Williamson 2018).

3. The roots of space debris

The space debris problem started in 1957 when the first human-made spacecraft Sputnik 1 was sent to space. The current oldest spacecraft in Earth's orbits, Vanguard I, celebrated its 50th birthday in 2018 and it will stay in space for around 2000 years more (Naval Research Laboratory 2018). Until today, an average of 60 spacecrafts were launched annually (Bombardelli, Pelaez 2011). During this period, more than 500 collisions and break-up events happened (ESA 2022). All these events caused significant numbers of space debris to spread all around the Earth's orbits. Most of the debris is concentrated in orbits where vital satellites are active:

- the Low Earth Orbit (LEO), between 800–1400 km of altitude,
- the navigation satellite orbits of 19 000–23 000 km,
- and Geostationary Orbit (GEO), around 36 000 km of altitude, where communication and weather satellites are found (Undseth et al. 2020).

Previously, only a few large nations (such as the United States and the Soviet Union) were involved in space affairs, and the space junk problem was not on their agenda due to their concentration on short-term advantages rather than shared long-term goals. There are now new state actors, as well as numerous private actors, who have recently developed their space projects and participate in space governance (May 2021; Cheney et al. 2020). However, due to issues in the space environment, new actors must face further challenges to attain their objectives, thus creating a "tragedy of the commons"[1] scenario. According to the European Space Agency's database,

[1] The theme of "tragedy of commons" is first described in the essay written by Garrett Haydin in 1968. According to the concept, a shared resource would be degraded as each individual

there has been a steady increase in the number of launches since 2000. These include even small educational vehicles built by middle school students. Such data clearly shows that space affairs are no more the affairs of few major powers (Undseth et al. 2020).

4. How serious space debris problem is?

The US Air Force Space Surveillance Network is one of the biggest data collectors about space debris. Currently, the Network is tracking more than 20,000 pieces of space debris. Unfortunately, most of these are just bigger than 10 cm, as smaller objects are not visible in radar systems. The number of untracked debris is estimated to be 130 million (Undseth et al. 2020). Avoiding such big numbers of space debris is a serious concern for satellite operators. Between 2010 and 2014, two European meteorological satellites had to do five maneuvers to avoid collisions (Undseth et al. 2020). While it seems rather less important, we should also note that while doing those maneuvers, spacecrafts burn fuel and release chemicals into the atmosphere which are detrimental to the space environment.

Besides commercial and public satellites, we should also note that the International Space Station (ISS) as a manned mission is in danger as well. In 2012, a junk piece of a Russian rocket was detected when it was too late to maneuver the ISS. So, the crew was ordered to stay in escape capsules until the threat ends. A piece of debris chopped off a window as well (BBC News 2012). Similarly, after an anti-satellite missile test done by Russia in 2021, the crew of the ISS had to move to escape capsules once again (United States Space Command 2021). Even though there are shield systems on the ISS, there are almost 700 000 pieces of space debris that can penetrate the ISS's body (Carpineti 2016).

As the number of actors in space is increasing, the number of spacecrafts is also increasing. For example, SpaceX already has more than 200 Starlink satellites in space which makes SpaceX the biggest commercial satellite operator. Yet, this is just the

would act in their own self-interest and use as much as they can from the resource (Haydin 1968).

first part of the plan: SpaceX got permission to place 12 000 satellites while the placement of another 30 000 is on agenda. Another mega-corporation, Amazon, got permission to place more than 3000 satellites in 2019. It is estimated that in the next 20 years, there will be tens of thousands of satellites in Earth's orbits (Undseth et al. 2020). As space is getting "crowded", the cleaning of space debris is getting more important to open up new places.

5. Legal/official framework about space debris

The first official regulation of space governance was the Outer Space Treaty of 1967 (UNOOSA 1967). According to the treaty, all countries are free to use and explore space. In the treaty, the orbits of the Earth were considered a "limited natural resource" and a "common pool resource"[2]. These terms indicate that none of the actors can exclude other actors from using that resource, and the usage of the resource by one actor results in reducing the availability of that resource for others (Undseth et al. 2020).

The UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) is one of the most important organizations about the space debris problem. The committee prepared important guidelines for space debris mitigation. Another critical actor which regulates guidelines is the Inter-Agency Space Debris Coordination Committee (López 2016). These committees are important not only to protect the space environment but also to give a common ground between actors (especially states) to cooperate, to promote peaceful solutions, and to increase awareness of the intents of the actors to cease misperceptions (López 2016).

In the terms of "space politics", we can say that there is a very developed notion of "property". According to the Outer Space Treaty and Liability Convention of 1972 (UNOOSA 1971), no nation can collect or salvage another nation's spacecraft (SWF 2014). As these agreements were prepared during the Cold War, the main concern of

[2] "The term "common-pool resource" refers to a natural or man-made resource system that is sufficiently large as to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use." (Ostrom 2015: 30).

states was security. Such kind of property notion can be easily linked to the fear of "reverse engineering" by other states on spacecrafts (Undseth et al. 2020; Aganaba-Jeanty 2016). These agreements present legal problems for cooperating against space debris efficiently, as in the case of small debris, it is almost impossible to find out who is the "owner" of that debris.

Even though there are universal guidelines, we can not say that these are binding rules (SWF 2014). Countries are still free to do whatever they want with their satellites, as Outer Space Treaty assures. As an example, the FengYun 1-C event can show how unbounded the states are. FengYun 1-C was an active Chinese weather satellite. In 2007, China intentionally destroyed the satellite to test a kinetic anti-satellite missile. While the weapon test was successfully executed, the explosion doubled the number of space debris at 800 km altitude and increased total space junk by 30%. Few satellites belonging to the Italian Space Agency had a severe risk of collision with debris due to the weapon test (Pardini, Anselmo 2009). Similar tests were done by India in 2019 and Russia in 2021, which posed a serious threat to the International Space Station and Starlink systems (Undseth et al. 2020; Business Insider 2021).

As it is shown, there is an anarchical situation exists in space governance. There are rivalrous relations between actors in space. While multilayered/multilateral institutions could promote cooperation, the complexity of space affairs negatively influences the efforts to make space a more sustainable place. The economical and political benefits and the number of investments can be seen as very important for many actors at the individual level. The lack of mutual trust between actors and the high incentives of acting independently result in lower levels of cooperation in the governance of large common pool resources, like space (Olstrom 2015). Additionally, actors are more prone to maximize their gains individually as currently there are no "coercive options"[3] to cease the "tragedy of commons" (Haydin 1968).

[3] Like privatization of shared resources or centralized regulation with coercive tools (Haydin 1968).

6. Disposal of decommissioned spacecrafts

Currently, there are 3 options to dispose of a spacecraft out of its orbit and each poses different risks: controlled reentry, the "Graveyard Orbit", and uncontrolled entry (Wertz et al. 2011). Even though now we have some solutions to clean the orbit and avoid space debris, we can not say that these solutions are so sustainable.

Controlled reentry is a preferred option to deorbit and dispose of spacecrafts. In this way, the spacecraft has to make certain maneuvers at certain times to find a correct angle to fall to a certain unpopulated place on Earth. Despite this option seeming preferable, there are some challenges. First, these maneuvers have to be calculated precisely. As remote control systems have to be used to maneuver the spacecraft, the mechanisms on the spacecraft must be strong enough to survive collisions with space debris and the radioactive effects of solar storms throughout service time. Also before maneuvers, ships and planes around the world have to be warned about the possible crash of the spacecraft (Wertz et al. 2011).

Another problem with controlled reentry is the fuel for maneuvering. To deorbit the spacecraft, capable thrusters are needed. It means that the spacecraft has to carry a significant amount of fuel. Consequently, the launch weight of the spacecraft increases acutely (Wertz et al. 2011). These challenges affect the designs of spacecraft as well.

The unpopulated crash area for controlled reentry is called the "Oceanic Pole of Inaccessibility", a place in the middle of the ocean between New Zealand and Antarctica, thousands of kilometers away from the closest populated area. Since 1971, hundreds of spacecrafts are buried in this "Satellite Cemetery", including the MIR Space Station. After its decommission around 2028, the ISS will also crush into the ocean. At that time, the ISS will be the biggest spacecraft in this cemetery with the size of a football field and weight of 500 tonnes (Stirone 2021). While this option seems like a solution to keep space "clean", it is questionable how right and sustainable is it to use the ocean as a dump for a huge amount of metal and chemicals.

The second option to deorbit spacecraft is using the "Graveyard/Storage Orbit". This orbit is used as a storage for decommissioned satellites and is between LEO and GEO. When a spacecraft finishes its service time, with the help of thrusters, it can increase its orbit to reach the storage region. Yet, the same challenge from the controlled reentry is visible here as well: to maneuver toward the storage orbit, the spacecraft must have enough fuel and strong thrusters, which results in extra launch weight and cost. Also, the spacecraft should be close to the storage orbit. Avoiding other satellites during maneuvering is perhaps a bigger challenge. GEO is mainly used by navigation and communication satellites. To reach a safe orbit in the storage area, a spacecraft has to pass these satellites (Wertz et al. 2011).

Uncontrolled reentry is another option to dispose a spacecraft. Satellites without thrusters are mostly located at 600 to 700 km altitude. After long years, atmospheric drag would deorbit these and they would fall to Earth unrestrainedly. Currently, there are certain rules to launch such types of spacecraft. Space agencies have these rules to reduce the possibility of uncontrolled reentries harming humans. According to the rules, the spacecraft has to be designed in a specific way so that when it reenters the atmosphere, it will burn up and decay enough that those falling pieces won't harm anyone. To the rules of NASA, any project has to prove that the spacecraft's reentry into the atmosphere would pose less than a risk of 1 in 10,000 injuring any one person (Wertz et al. 2011).

Passivating spacecrafts

Passivating a spacecraft means that the energy stored in the spacecraft must be "depleted when they are no longer required for mission operation or post-mission disposal" (Wertz et al. 2011). Even though spacecrafts can be sent to storage orbit, it doesn't mean that now they are safe. It is estimated that deorbited spacecrafts in the storage orbit will spend centuries there before decaying "naturally". In the past, discarded spacecrafts that had intact fuel tanks exploded due to collisions or solar storms and created an enormous amount of space junk. Also, deorbited spacecrafts that reenter the atmosphere will burn up and release chemicals. So, it is important to deplete all additional chemicals before disposing of the spacecrafts to protect the space environment and avoid space debris.

7. Modern solutions

In the 90s, NASA and US Air Force prepared a joint project called Project Orion. According to this project, a ground-based laser could be used to eliminate space debris until 800 km altitude. The main focus of the project was the debris between 1–10 cm, as they pose the most danger and are hard to track. It was estimated that 3 years of service would be enough to wipe off all space debris in a chosen area. Yet, the project is shelved (Bekey 1997). A similar laser project was proposed by a research institution in Japan. In this program, rather than using a ground-based laser, a mobile laser cannon would be integrated into the ISS to clean up the orbits around (Ackerman 2021).

In the 2010s, a new concept called "Ion Beam Shepherd" was designed. According to the concept, ion beams could be used to accelerate the momentum of debris to deorbit them faster or even move them into storage orbit without physical contact (Bombardelli, Pelaez 2011).

In recent years, active debris removal is getting more and more popular. Active debris removal is a method that removing debris by using an external vehicle. This method is important as it gives a way to dispose of small pieces of debris. Currently, most of the debris around the Earth's orbit is considered small debris, varying between 1–10 cm. Despite they are small, they still pose enough concern for scientists. The main danger of small pieces are coming from the lack of awareness about them, as modern tracking systems are not able to track them routinely due to their size (May 2021).

In 2017, the Japanese Space Agency (JAXA) designed a giant space net to collect space debris and sent it to the International Space Station (ISS). The satellite would fire a tether to collect big pieces of debris and then drive them into the atmosphere to burn up. In January 2017, the satellite was released from the ISS but failed to succeed (O'Neill 2017). A similar project was developed by the European Space Agency. The project was called RemoveDebris and the spacecraft weighed only 100 kg. The working principle was simple: the spacecraft would have a harpoon and the harpoon would catch a piece of debris. Then the debris would be pulled into the atmosphere to burn up. On the other hand, there were some concerns in practical terms, like the possibility of the harpoon hitting the wrong place, causing debris to explode, and creating much smaller debris all around (Undseth et al. 2020; Clark 2018).

Additionally, the European Space Agency will launch Clearspace-1, a brand-new kind of junk remover, in 2025. The craft has four robotic arms and can only hold one piece of space junk at a time. The project will cost 120 million euros (Devlin 2019).

As the examples indicate, active debris-removing systems are very complex and technologically challenging. Economically, developing such technology needs a huge amount of investment. The debris-removing market is getting bigger but it is not sustainable yet, due to high cost and “lack of catastrophes” which would increase the need for debris-removal (May 2021). Likewise, there are discussions about “Green Satellites”, which would be designed according to sustainability norms. Namely, these spacecrafts would have certain types of parts that would reduce debris creation (Undseth et al. 2020).

Besides technology and the economy, there are also political concerns. Due to agreements, actors must determine whose debris is it before the removal operation. Also, modern debris-removing systems raise questions about the future of such developments if they turn into space weapons one day, especially in the case of laser systems.

8. Conclusion

Besides Space sustainability is now an important aspect of space governance. There are a few reasons. First of all, the increasing interest and awareness of the general notion of sustainability affect the actors participating in space. Secondly, as humans aim to increase their activity in space, especially in further places like Mars, it is important to achieve sustainability in Earth’s orbits to reach far space safely. Thirdly, the space industry and technologies are developing swiftly and Earth’s orbits present more profit and advantages, as long as we keep these orbits active and clean for long-term use.

Cooperation is vital for reaching a sustainable situation in space. As it was presented in the paper, actors should behave responsibly and cease debris-creating activities, like anti-satellite weapon tests or intentional collisions. As Earth's orbits and generally space are seen as common goods, all actors must accept certain norms and rules. While current systems of international organizations allow states to discuss and present their intents, seems like we should start thinking of an international body that would monitor the actions and punish the actors if necessary. Yet, this is another challenge as especially major states still see space affairs as part of their national security and it is not likely that they would accept binding treaties.

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