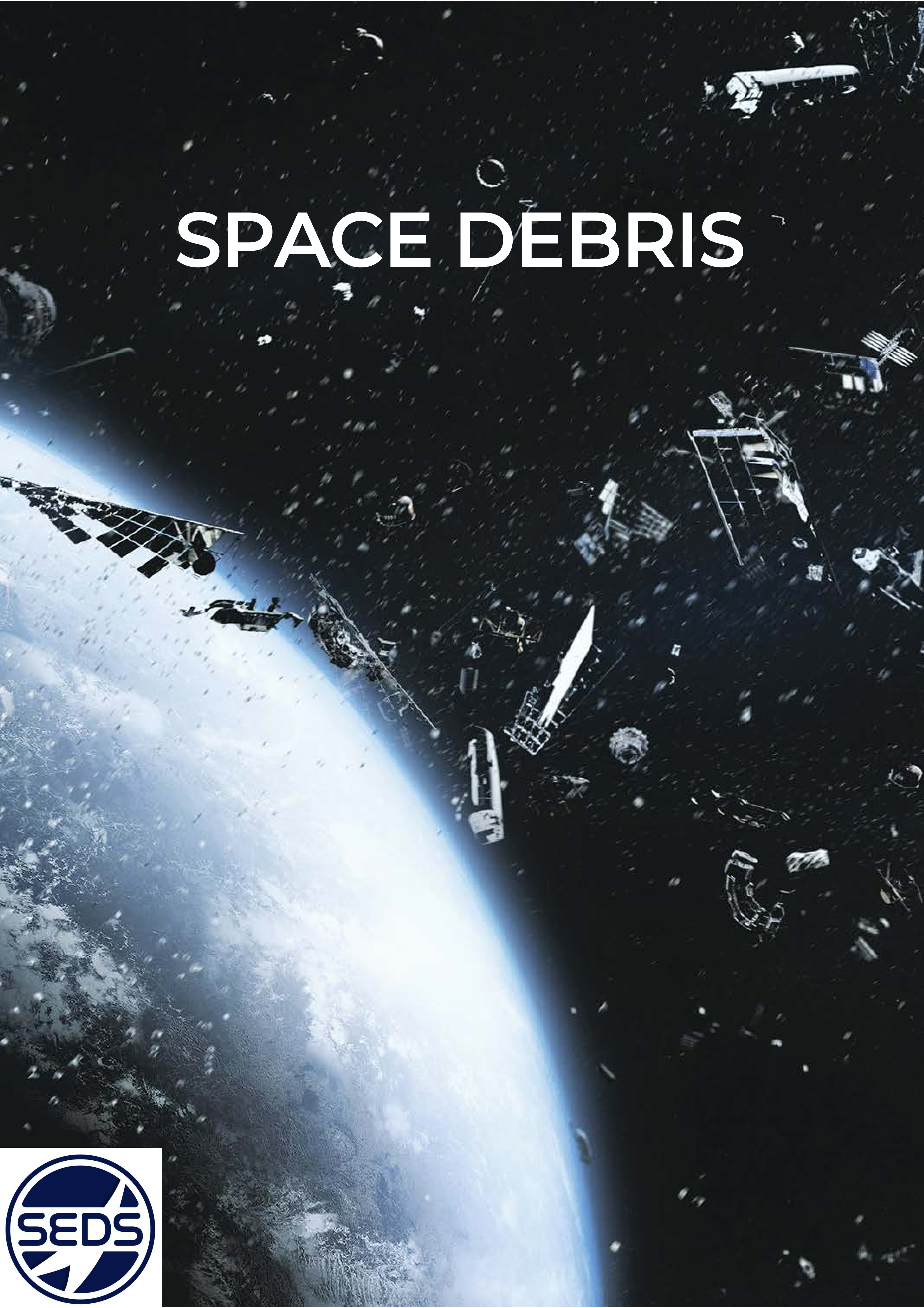
SPACE DEBRIS



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SPACE DEBRIS: ORIGIN, PROBLEM AND HOW TO SOLVE IT

I. Introduction

In this paper, we want to give a brief overview of the current space debris situation in our space and the possible solutions that many parties are trying to discover and apply.

What is space debris? With this term, we can include both natural meteoroids and artificial (human-made) orbital debris. The first ones are in orbit around the Sun, while most of the second ones are in orbit around the Earth, and they are also called orbital debris.

Orbital debris is any human-made object in orbit around the Earth that no longer has a utility function such as inoperable spacecraft, abandoned launch vehicle stages, mission-related debris, and fragmentation debris.

The debris is tracked by the Department of Defense's global Space Surveillance Network (SSN) sensors.

How much debris is in our space? The smaller it is, the more popular it is. About 23.000 pieces of debris larger than a softball are in Earth's orbit. They travel so fast that a single relatively small piece of orbital debris can damage a satellite or a spacecraft. There are half a million pieces of debris the size of a marble or a bit larger and about 100 million pieces of debris 0.04 inch. Not talking about micrometre-sized debris, which is even more numerous. The last type is the most dangerous one and it represents the highest mission-ending risk to most robotic spacecraft operating in low Earth orbit.

Figure 1 - Space debris

Not only, the growing amount of all types of space debris equally increases the potential danger to all spacecraft, including the International Space Station and other spacecraft with humans on board, such as SpaceX's Crew Dragon. In a few decades, if the build-up of space debris continues, some regions of space might become unusable.

In order to find a solution to this problem and coordinate all the activities related to these issues, it has been founded an international governmental forum for worldwide coordination named Inter-Agency Space Debris Coordination Committee (IADC). The main objectives of the Committee are to exchange information on space debris research activities among member space agencies, to provide facilitation of cooperative opportunities in space debris research, to examine the progress of ongoing cooperative activities, and identify debris mitigation options. Among the member agencies, there is ASI (Agenzia Spaziale Italiana), an Italian government agency that has been established in 1988. It is responsible for preparing and implementing Italian aerospace policy.

Furthermore, nowadays, to prevent the creation of hundreds of thousands of dangerous debris, there are international guidelines and standards to follow, with the objective of making it clear how we can reach a sustainable use of space. Systematic analysis of the evolution of behaviours in space regarding the adoption of debris mitigation measures provides reasons to be cautiously optimistic unlike a decade ago.

II. History – How did space get cluttered?

Debris around the earth has been accruing since humans started exploring space in the 1950s. After the launch of the first artificial satellite, Sputnik 1, the North American Aerospace Defense Command (NORAD) started a database to keep track of all rocket launches and other objects reaching the earth’s orbit. Over the years, tons of rockets, satellites, spacecraft and instruments have been launched, with only a few items returning to earth. Additionally, natural and human-made ejecta can also be found in space, such as particles from massive volcanic eruptions or nuclear bomb tests. As reusable, returning rockets have been under development for only a couple of years now, the most dangerous share of leftovers is made up of old fuel and batteries, that randomly cause further explosions in orbit.

Diving deeper into history, there have been a few noticeable events.

During the Cold War, the United States military tried to create an artificial ionosphere above the earth to solve a major weakness in military communications. To mitigate the threat of signals breaking down in case of Soviet interference with underwater cables, Walter E. Morrow at MIT started Project Needles. Shooting 480 million copper antennas with a length of 1.78 cm into medium earth orbit (3,500 - 3,800 km) came to be known as the first deliberate release of space debris.

Figure 2 - Size of released "needles"

The first crash of two satellites has been recorded in 2009 when the US communication satellite Iridium 33 collided with the inactive Russian satellite Cosmos 2251. The crash occurred above Siberia at an extremely high speed of around 35,000 km/h, causing thousands of pieces of debris. In 2007, China tested an anti-satellite missile to destroy one of its old weather satellites. Until today, this created the largest number of debris during a singular event.

III. Why is this a problem?

Space debris is a typical example of a negative externality of space travel – it creates costs that the organization initiating the initial action does not have to carry. Therefore, participants in the space travel industry have little to no incentive to avoid it. Rather, the consequences of the problem affect other space missions and – in the end – all of the human race and our technological progress.


Figure 3 - Impact of debris on spacecraft

First, space junk can be a hazard to all spacecraft. The high speeds at which the pieces move could lead to severe damage. Even a very small object, no bigger than a coin, could destroy a spacecraft. The earliest satellite that is suspected to be lost due to a debris collision disappeared as early as 1981. It contained no elements that could have caused an explosion in itself, except the battery, which is the only alternative hypothesis that could explain why it broke into pieces.

Even more worrying is that experts estimate that the so-called «critical mass» of an object orbiting could only be a few decades away. This theoretical scenario is also known as the Kessler syndrome, as NASA scientist Donald J. Kessler proposed it for the first time in 1978. In a scenario where this amount is reached, one piece colliding with another could cause an uncontrollable chain reaction. The theory refers in particular to low earth orbit (<2,000 km above ground). According to a NASA study from 2006, especially the band between 900 - 1,000 km has already reached supercritical density, which means that a satellite will collide with a piece of debris larger than 1 cm every five to six years. That this threat is already having an impact on missions, can be easily told by looking at the ISS. The station alone has performed three manoeuvres to avoid debris. Although it has a Whipple shielding to resist damage from small objects, such manoeuvres are carried out to evade known debris with a chance of collision of 0.01%. Furthermore, micro-pieces can also cause damage in the form to sandblasting, a type of surface erosion that is especially harmful to solar panels and optical equipment.

In addition, we must be very clear about the speed and gravity of the cascade. Kessler himself stated in 2012 that we should not think about this as a singular event, rather, the cascade process has already started and slowly increases the chance of further collisions with each contact.

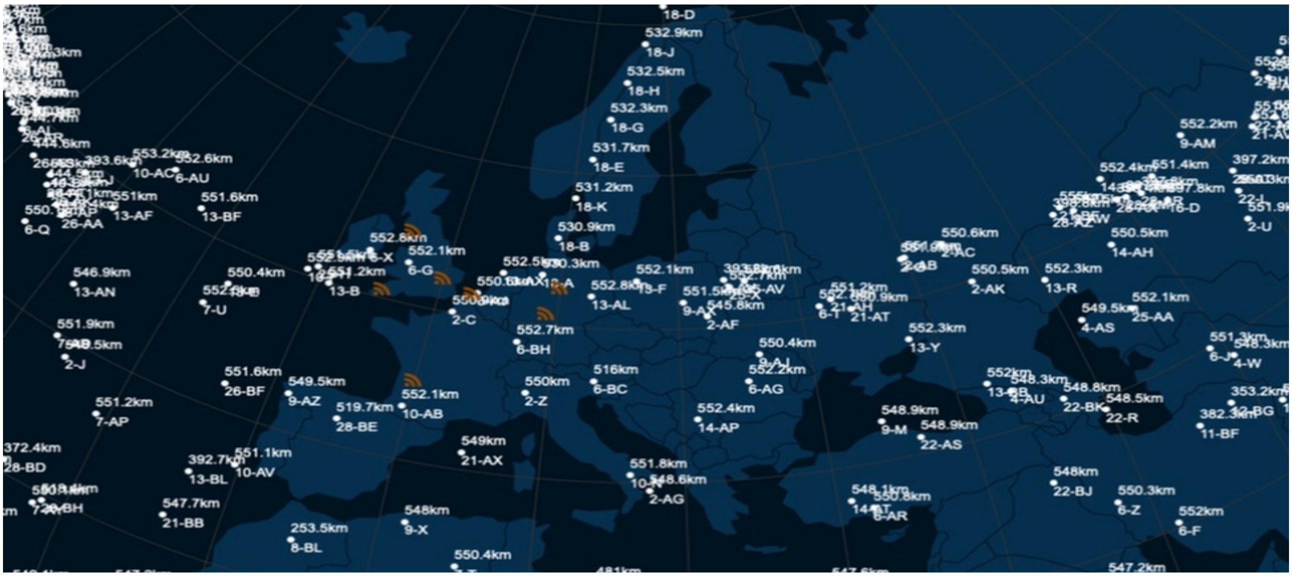


Figure 4 - High density of star link satellites in lower altitudes

Currently, mega-constellations of satellites such as SpaceX’s Starlink project are threatened by debris. Generally, satellites that are supposed to stay and operate in the lower earth orbit are at risk of being destroyed. On the other hand, those massive amounts of new satellites in this area are also a huge threat themselves, as some will inevitably fail and generate debris too. Spacecraft passing through, however, is at much lower risk of being hit due to the short stay in this area. Therefore, there is no evidence at this point that outer space exploration or placing satellites in higher orbit is becoming impossible.

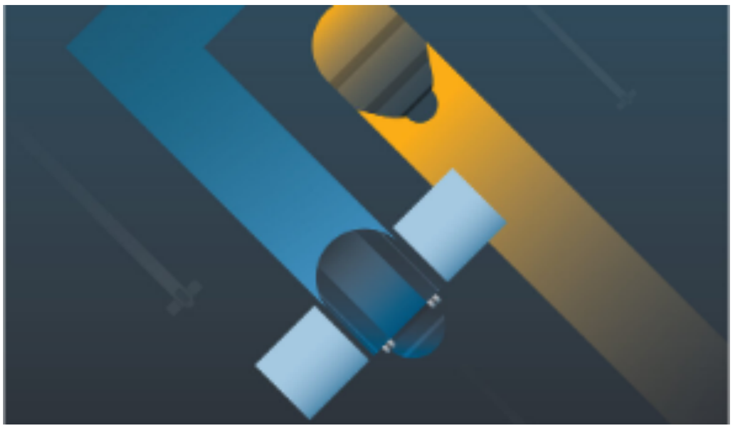
Figure 5 - Debris found in Saudia-Arabia in 2001

Lastly, there are also some hazards on earth, as large pieces can reach the ground without burning. According to NASA, there has been no damage to property so far, however, numerous small tanks to hold fuel have been found. Each day, one catalogued piece of trash has been falling down for the last 50 years. However, this number is expected to increase.

IV. How to deal with and solve Space Debris

Millions of pieces of space debris objects represent a constant and high risk for satellite integrity. Pieces of space debris can often happen to lie in a satellite orbit and eventually damage the satellite in case of collision.

Nowadays it is a normal practice for space operators to manually set "collision avoidance manoeuvres" to put the satellites out of the way in a safe orbit. This means that when the risk of collision is high the operators need to program a deviation of the satellite from the original orbit in order to get around the obstacle. Such manoeuvres can be operated also to avoid collision between two different satellites, but the vast majority of them are due to space debris. On average this happens more than once a year per each satellite in low Earth orbit, but the space agencies receive hundreds of alerts per year and identifying the cases with a significative risk of collision is a process that requires tons of information and a lot of work and analysis, rising maintenance costs up and reducing satellite life itself.



To make this whole process more efficient and manage space traffic in a better and faster way, the ESA is developing an automatic collision avoidance system that should exploit machine learning in order to automatically estimate the risk of collisions and eventually even send orders to the at-risk satellites to change their orbit.

The point of course is that, even if the process of avoiding space debris reaches the most effective level possible, the situation can't be sustainable in the long run. In the very next future, there are going to be more and more objects in space, so the real mission is to keep the number of space debris objects as low as possible and also to reduce it by removing and destroying them.

According to several opinions, the best solution to keep low the number of pieces of debris in space is to prevent the origin of new elements. This can't only rely on the current mitigation measures like the 25-year deorbit rule for missions in low-Earth orbit, but also through an "international agreement to charge operators «orbital-use fees» for every satellite put into orbit".

Space is now crowded by satellites and space debris, but each operator keeps launching satellites until their private collision risk equals the value of the orbiting satellite: this leads to the so-named latest Tragedy of the Commons. Thus, the real key decision that could stop the rise of space debris is to discourage space operators in keeping launching so many objects into space. The implementation of an orbital-use tax on current and new orbiting satellites would exactly work as a disincentive for keeping satellites in orbit for more than the necessary time. The idea behind this strategy would be to force operators to take into account and actually pay the cost of a collision that they impose on other operators.

This is actually an interesting idea, but even with zero new launches in the next years, the space debris situation will get worse since collisions between items generate fresh debris. This is the reason why an orbital fee is not the only solution for space debris the world is currently working on. Space agencies and private companies are also trying to fix the problem with engineering approach solutions to contribute actively to cleaning up space and removing space debris.

Indeed, on 9th December 2019 ESA officially commissioned the world's first space debris removal. ESA has signed a contract for the mission with the Swiss private start-up ClearSpace: an amount of 86 million euros will be paid to the company to cover part of the total cost of the mission of 100 million euros. Commissioning private companies represents a new operating strategy for ESA, and in this case, the aim is not only to clean up the space but also to demonstrate the new technology and to help establish a new market for space services.

The mission, called ClearSpace1, is to develop a robot-like spacecraft equipped with articulated arms which will grab the debris and move it closer to the atmosphere where both the spacecraft and the debris will burn due to the atmospheric friction and ultimately disintegrate.

ClearSpace-1 will target a specific piece of space debris that is the Vespa, in orbit since the launch of the Vega of which it was part in 2013. The Vespa has a mass of 112kg and is close to a small satellite size and this makes its removal relatively easy to achieve. If the mission will be successful the program should progress to a larger and more challenging object, eventually even to multi-object capture.

The launch of the spacecraft is currently set to occur in 2026.

Another relevant engineering project still going on is the RemoveDEBRIS mission whose target is to demonstrate through some in-space experiments the success of various technologies that could be implemented to solve the space debris issue.

The mission is being held by a consortium led by Surrey Satellite Technology and which includes also Airbus. The mission consists in launching a platform equipped with the necessary items to carry out four experiments on four different technologies:

- Net experiment: tests the usage of a net to capture debris;
- Vision-based navigation experiment: tests the possibility of autonomous navigation of satellites to avoid debris;
- Harpoon experiment: tests the usage of a harpoon to be launched against debris to tow them;

- Dragsail experiment: test the usage of an inflatable drag sail to lead back the platform itself inside the atmosphere and burn and destroy it with atmosphere friction.

Many other missions are undergoing to fix the space debris problem, but none has already been proven to be the final solution. One thing is sure: it is needed to find soon a solution to guarantee the development of the space economy.

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