# Strategies for Mitigating and Remediating Space Debris in the Geostationary Orbit

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How can we reduce the likelihood of spacecraft being damaged by hitting small pieces of space debris that are difficult to spot in the geostationary orbit?

## Abstract

As space exploration continues to grow rapidly, there is a problem halting this development—space debris. Every year, an increasing amount of space debris accumulates in Earth's orbit, trapping us inside our own planet. It is becoming increasingly difficult for spacecraft to enter Earth's geostationary orbit (GEO), a circular orbit 35,800 km (or 22,300 miles) above the Earth's equator, without contacting space debris. Pieces of debris less than 4 inches in length, often referred to as micrometeorites, complicate this matter further, as they cannot be seen with the current technology we have and, when coming into contact with spacecraft, can cause immense damage. Here, we investigate different companies' (such as Northrop Grumman, Astroscale, OrbitFab and Arcsec) engineering solutions for this problem, some of which are soon to be implemented, whilst others are in beta testing. The solutions presented in this paper fall under two broad categories: mitigation and remediation. Solutions under mitigation focus on new engineering designs to aid spacecraft in avoiding and surviving collision with space debris, i.e., motion tracking technology, heat-sensing cameras, and a stronger body. Solutions under remediation aim to clean Earth's orbit of debris to make spacecraft less likely to ever encounter debris while in the GEO, i.e., adding a docking station for spacecraft low on fuel, sending spacecraft with the sole mission of collecting debris, robotic arms to pick up the debris, and the elimination of the practice of abandoning spacecraft. A combination of strategies from both these approaches can secure spacecraft missions in the future and enable humanity to reach new limits in space exploration.

## Introduction

The Geostationary orbit, or GEO, is a vital region where 580 satellites currently orbit Earth at about 22,300 miles or 35,800 kilometers above the equator. Satellites in this orbit contribute to essential parts for day-to-day life, modern communication, Earth observation, and various other space-based activities. Thus, these satellites must be safeguarded from damage, as their malfunction could lead to massive societal harm.

However, a looming threat puts these imperative satellites at risk: space debris. According to Britannica, some objects can be up to 20m long, whilst others, micrometeorites, can be as small as 50 micrometers in length – but in its essence, it encompasses a wide array of objects that float around space. Some of these fragments can be characterized as natural debris, which implies an origin from an asteroid or a meteor; most debris in GEO, however, is human-made, which can include fragments from disintegration, collisions, and paint chippings. In a paper written by C.P. Mark 2019, he states that space debris collides with satellites, the outcome is usually terrible for the satellite, and he suggests that the likelihood of this contact has exponentially risen over the past couple of decades. The total weight of debris currently in Earth's atmosphere is estimated to be 9 thousand metric tons.

This paper also refers to the popularly coined Kessler Syndrome, first stated by Kessler et al. 1978, who said that there is an immense multiplication of space debris and that in GEO, this syndrome seems to worsen. It is also essential to add that space debris can travel up to 30,000 km/hr, a speed at which immense damage can be done to a spacecraft. Thus, to mitigate these challenges, steps ought to be taken to ensure spacecraft safety in future space missions. Although scientists have been aware of space debris for some time, no space missions have successfully removed space debris yet. This is because reliably capturing debris without creating more is a daunting task for most agencies, as when these clean-up spacecraft come into contact with the debris, they must not be hit by debris, causing even more particles to enter GEO. A paper from Alex Ellery 2019 supports the urgency of this mission. He adds that we currently have all the technology and resources needed to mitigate this crisis effectively; however, having that tech might not be enough. One of the most significant factors that seems to be holding space exploration back is the economics and whether debris mitigation can be financially viable for companies in the space debris mitigation business.

Given the challenges expressed in the literature, to prevent smaller debris from hitting satellites in GEO, it is crucial to implement solutions to this problem.

Through exploring these solutions, this paper intends to inform space agencies and industries alike on how we can ensure that space is a safe environment for years to come. By addressing the issue of space debris, we can contribute to the longevity and safety of spacecraft and ensure that future space missions go smoothly without any worry of a possible collision.

**Evidence**

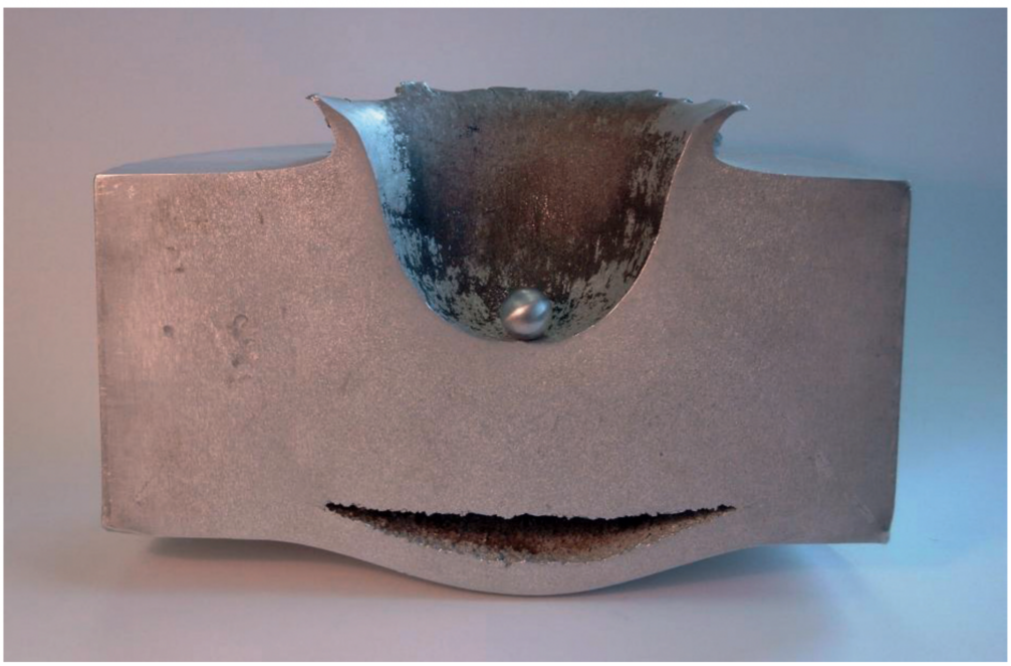
As of right now, there are many engineering solutions to this issue, and they can be split into two different categories, mitigation and remediation. Solutions under mitigation are mostly engineering-related and include innovative shielding materials to protect spacecraft, collision avoidance systems, i.e., motion tracking sensors, and total debris avoidance through creating a debris landfill and programming spacecraft to avoid those areas. This paper's second section will focus on the solutions that fall under remediation. This includes the implementation of robotic arms to pick up the trash, missions involving launching spacecraft to pick up debris, docking stations so spacecraft can refuel, and reducing the abandonment of spacecraft.

*Mitigation*

To restate: solutions under mitigation aim to help spacecraft avoid or protect spacecraft from debris. One solution we can implement is the use of motion-tracking sensors. A Belgian space company called Arcsec has been developing these sensors to put on spacecraft in the future. They explain that when this tracker detects an object that does not look like a shining star or planet in the backdrop of the cosmos, it immediately flags it as potentially being debris. It then calculates the object's trajectory, which space situational awareness companies can use to assess the likelihood of that debris hitting the spacecraft. By using these sensors, spacecraft can detect and monitor pieces of debris in real-time. This heightened sense of awareness can allow them to autonomously maneuver the spacecraft away from the debris, thus evading a potential collision.

Another solution is that pyrotechnic elements, particularly pyrotechnic bolts, must be protected. These elements are imperative in separating spacecraft when launched into space, and when a piece of space debris hits them at the wrong time, they can be triggered. The spacecraft will separate prematurely, thus ruining the space mission and causing further debris from the failed rocket. Therefore, we ought to protect these bolts in order to ensure that the breaking process goes smoothly and that the spacecraft successfully launches into space.

In addition, the body of the spacecraft should be thickened. This is the solution that is easiest to implement and understand. By fortifying the outer structure of the spacecraft, it will be much easier to withstand the impacts from smaller space debris and other particles in GEO, reducing damage.
A lab test was done by the European Space Agency (ESA) where a 1.2cm diameter aluminum sphere was fired at 6.8 km/s (15210 mph) into a block of aluminum about 18cm thick. Below is a picture of their results:



According to a paper written by K. Min and Y.H Shin 1999, the average spacecraft's walls are only about 1cm thick. This means that we would need to add at least 7-8 cm of aluminum to ensure safety. However, this would increase the spacecraft's mass, which could lead to greater financial responsibility for those launching and owning the spacecraft.

Finally, an unconventional solution is aggregation. There have been proposals to aggregate all the debris in GEO into one giant "trash pile" in space. This could be done by towing, sending a spacecraft to remove defunct satellites, and dumping them all in the same place. Space debris can avoid these locations by centralizing all the debris in specific areas.

Thus, all these solutions aim to aid spacecraft in avoiding the current space debris present in GEO.

*Remediation*
The second category is remediation, which focuses on actively removing debris and there are many solutions in this class. The first solution involves removal missions. This requires spacecraft to be sent out solely for debris and defunct satellite removal. Spacecraft can remove debris by docking it to the defunct satellite and using propulsion systems to move it to where it needs to be. Alternatively, the satellite can be moved to the lower atmosphere, where it can burn up. Through this process, space debris in GEO can be averted.

The second solution is the use of robotic arms. The development of these devices can be used for the retrieval and securement of space debris. These arms can latch onto debris objects and remove them from GEO, thus reducing collision risks. The third solution is docking stations for spacecraft. Refueling and servicing stations in GEO are essential for spacecraft that are low on fuel. These stations can help reduce the likelihood of the abandonment of aging spacecraft, thus reducing space debris caused by defunct satellites.

Finally, there needs to be a reduction in rocket self-destruction. This is because when rockets self-destruct, it leads to additional space debris from the residue of the destruction. Thus, by reducing the number of rockets self-destructing, we would also reduce the amount of extra debris caused by these explosions.

By implementing solutions from this category, there is a lower chance of spacecraft meeting debris in the first place, thus reducing the risk of collision.

While solutions from both categories are crucial, the solutions under the remediation category are more vital regarding effectiveness in space debris removal. This is primarily because preventing the accumulation of debris is more effective than dealing with the aftermath. Even with the engineering modifications from the mitigation category, the existence and volume of debris will still be an issue and a burden for space agencies. However, mitigation is a better solution for the short term and is much cheaper, as most solutions that fall under mitigation cost less to implement than the latter, since strategies under remediation demand greater resources and usually result in greater changes to the spacecraft and space industry.

**Engaging with Alternate Perspectives**
The main argument against implementing strategies to lessen space debris mitigation is that it is costly. However, it would actually cost more to not invest in space debris solutions. It would also cost companies fines in the hundreds of thousands when they are reckless about littering in GEO. However, these fines would need greater enforcement, and organizations like the UN can help with that.
Companies have started getting fined for negligent practices leading to the abandonment of satellites in orbit. Notably, in 2023, Dish, a satellite television company, was fined $150,000 by the FCC for failing to remove a satellite from GEO properly. As a result, their share price fell 4%, causing the company's valuation to drop by about 100 million dollars, according to the MIT tech review. This incident emphasizes the growing importance of responsible satellite management.

Not only that, but this shows that companies simply cannot be negligent over their satellites, and thus, they will probably employ strategies to ensure they do not spill excess debris in the Earth's orbit. Therefore, this incident would motivate companies to not be irresponsible with their satellites. This situation also emphasizes that it would be much wiser for companies to spend money on space debris mitigation than to be fined for contributing to it, facing a drop in valuation.

In the future, the question arises of who will enforce these fines. Firstly, it should be established that contributing to space debris is unethical, as in the Outer Space Treaty, a foundational document in space law, which prohibits the active contamination of celestial bodies and their surroundings. The organization with the most power to enforce this law and fine infractors is the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS). This organization mainly focuses on ensuring peace in outer space and preventing competition between countries. While it might seem a bit out of the scope for this topic, the UN does have the biggest scope regarding how many countries will be affected by a law proposed by them. Thus, if this committee could come together to create a law, it would be the most legitimate. In order for a law to be established and a fine to be mandated, it would require the nations in COPOUS to cooperate and reach a final agreement.
Another viewpoint argues about the issues of docking stations, stating that they are way too expensive to implement and that we are better off not investing in them. While it might seem costly, the reality is that it would cost more money not to implement docking. While it usually depends, most satellites launched cost anywhere north of 100 million dollars, according to the Futron Corporation. While there are currently no stand-alone docking stations in space right now, the fact of the matter is that over time, having one docking station serving satellites multiple times would save agencies millions in having to buy new satellites. This would be because docking stations act as refuel and repair stations, prolonging the life of a satellite. One challenge with docking stations is that it is hard to design a single station that can fit with every satellite, considering that every satellite is unique and different manufacturers make each. Adapters can help with that. In 2019, NASA spent 22.5 million dollars on their docking adapter IDA-3.

Space debris also continues to grow extremely rapidly (mainly from already existing pieces of debris colliding and creating more "Kessler Syndrome"), thus increasing the likelihood of collision with spacecraft. This means that it would cost more to simply not act on space debris mitigation than the latter, as a study by Wataru Nozawa et al. 2023 estimates that the presence of space debris alone can drop the global GDP by almost 2%. As of January 2022, the IMF estimates that the global GDP is at 85 trillion dollars, and a 2% loss is equivalent to around 1.7 trillion dollars. In contrast, this paper's solutions (specifically under mitigation), which are similar in scope and resource use to the NASA IDA 3, are likely in the same ballpark price-wise. This would mean that the average cost of mitigation strategies presented in this paper is in the range of tens of millions per solution. Thus, ignoration will hurt the economy much more than implementing solutions to alleviate this crisis.
The reason critics criticize space debris removal efforts mainly comes down to long-term financial gain and enforcement. Even though companies will have to spend extra to keep their spacecraft safe, they will not have to spend additional capital (which would cost more than the cost of implementing solutions to mitigate and remediate space debris) from the damage caused

by space debris in the future. As for enforcement, while no laws are set in stone, COPOUS can change that to prevent companies from carelessly mishandling their satellites.

## Conclusion

In conclusion, Earth's geostationary orbit (GEO) is a crucial area for satellites that power our day-to-day lives. However, a new problem is emerging that could disturb these satellites: space debris. With 9000 metric tons of debris already in the atmosphere, the numbers are only surging. Collisions and the likelihood of them are increasing along with the amount of debris, thus demanding urgent solutions.

Mitigation and remediation solutions are imperative. Mitigation focuses on avoidance, while remediation focuses on removing and preventing further debris.

This paper argues that solutions under remediation are more vital in alleviating this crisis due to their active role in debris removal. However, economically, mitigation would be easier to implement, as it would be cheaper to do so compared to remediation. While it depends on the current economic circumstances, if there are the funds to do so, then remediation strategies should be prioritized.

This paper also wrestles with alternate perspectives, which argue that efforts to prevent space debris are not economically viable. However, in response, this paper highlights the economic benefits of space debris mitigation, including on-orbit servicing and fines for negligence, which can be enforced by international organizations like the United Nations Committee on the Peaceful Uses of Outer Space (COPOUS).

With the rising popularity and interest in looking into strategies to mitigate space debris, there will be more investment into the solutions mentioned in this paper. Therefore, there will be more concrete evidence of each solution's costs and effectiveness in combating space debris.

Thus, implementing solutions presented in this paper is essential in ensuring the safety and longevity of space activities. The exploration of mitigation and remediation solutions aims to educate space agencies and organizations about the need to create a safe space in GEO. By addressing the ongoing challenges posed by space debris, we are taking one step closer to ensuring that Earth's GEO is a safe place for our satellites to continue operating.

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