A Proposed Policy to address Space Debris

Reports Team 4

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An Introduction to Space Debris

Around the 1960s, the natural meteoroid environment was at the top of researchers' and engineers' worries, but with the launch of several satellites by the 1990s, the man-made orbital environment increased, overtaking meteoroids as the real spacecraft risk driver.

As of November 9th, 2021, the number of debris objects in orbit—statistically estimated by the European Space Agency—amount to over 331 million: 1.1% are greater than 10 cm, 30.2% are between 1 cm and 10 cm, and 68.7% are less than 1 cm but greater than 1 mm. Despite a larger percentage being minimal in size, the risks that they pose are equally dauting: colliding against a satellite or other space object at a speed of 14 km per second, serious catastrophic damage can be caused to satellites and spacecraft. In Lower Earth Orbit (LEO), an acute growth of satellite numbers is occurring, raising an alarm on the growing risk probability of space collisions. Fears of reaching the Kessler Limit, one in which we would not be able to launch anymore satellites because of previous cluttering are founded.

A question is then raised: can the space debris population regulate itself, or is there a need to actively regulate it? While via atmospheric drag and luni-solar gravitational attraction, LEO debris objects can return to the Earth's atmosphere and disintegrate, the exponential growth of the space debris population makes it impossible for natural regulators to effectively keep the number of collision-bound particles in the LEO.

The Economic Impact of Space Debris

Over the last 30 years, the costs deriving from the management of space debris have been rising steadily. The operators of satellites, both national and private, often tend to keep information related to the exact level of expenditure confidential, due to commercial and strategic reasons. However, the National Research Council (2011) estimated that the total set of activities related to space debris' management amounts, on average, to 5-10% of the entire mission cost. As these missions usually cost hundreds of millions of dollars, the economic impact of space debris becomes a real burden on the companies operating in this sector. The costs arising from debris that may be faced by the constructors may be the following.

Debris Related Damage

In case of fatal collisions with space debris, the most obvious consequences are the replacement costs of the spacecraft, related delays of the service offered by the damaged satellite, and data losses. Over the last two decades, in the low-earth orbit, only eleven events related to collisions with space debris have been reported. However, this number is most likely biased because whenever operators do not know the cause behind malfunctions, they will often decide not to consider the event as a collision. Therefore, very little is known about the economic impact of events that involve non-tracked debris below 10cm. Nevertheless, it can be stated that this impact is presumably underestimated.

Satellite Design Costs

Satellites (and related constellations) need to be designed and developed taking into consideration the possibility of collision. They have to be provided with specific features that effectively reduce the likelihood of the occurrence of a similar event (e.g., collision avoidance capabilities, shielding, safehold modes), and this reasonably entails further costs for the operators. Satellite redundancies are planned to avoid jamming and protect against space weather. However, these are eventually responsible for part of the issues related to debris accumulation.

Operations Costs

An operator needs to constantly monitor orbital trajectories. This activity represents a further burden on operators, that are required to put a lot of effort in terms of data analysis and management. When the risk of collision is high, they receive a warning of impending close approach, also named as “conjunction warning”. Unfortunately, the vast majority of these burdens are false / inaccurate, and this makes the procedure even more expensive and time consuming. For instance, between 2015 and 2017, more than 8000 conjunction warnings were reported for just one satellite mission, the European Sentinel-2A – that is around 7 a day. However, over the same period, only 360 events eventually needed collision avoidance manoeuvres from satellite operators, that is nonetheless one every 3 days. The high cost related to these avoidance maneuverers (in terms of data management and fuel consumption) is one of the main reasons behind the delays in the creation of mega constellations of satellites (e.g., SpaceX's Starlink). A similar system of satellites would receive millions of warnings and should conduct thousands of expensive avoidance manoeuvres.

Orbit Clearance Costs

When it comes to orbit clearance costs, two different situations should be distinguished: geosynchronous orbit and low-earth orbit. When the satellite is in the geosynchronous orbit, it must be moved to a “graveyard” located a few hundred kilometres above the operational orbit. This manoeuvre requires an amount of fuel that corresponds to almost 3 months of ordinary operations. On the other hand, when the satellite is in low-earth orbit, the amount of fuel needed for orbit clearance is a variable. In particular, it is positively correlated with the altitude of the orbit, and the ratio area / mass of the satellite. Finally, for satellites orbiting below 600 km, no manoeuvre is required.

Insurance Costs

Satellites companies can opt for in-orbit insurance to receive protection against different types of risks (from satellite dysfunctions to space environment hazards and third-party liabilities). The annual premium rates are still quite low, accounting on average for the 0.7% of the total amount insured. However, as the probability of collision events is increasing year by year, this cost is expected to rise in the foreseeable future.

Currently active Missions

INTRODUCTRION & OVERVIEW

Earth orbits, and particularly the lower orbits which stretch to approximately 2,000 km above ground, are seeing a growing population of active and defunct satellites as well as debris. There are over 25,000 known pieces of space debris traveling at 17,000 miles an hour in space

Rick Ambrose, EVP of Lockheed Martin Space, suggests that the solution of the problem should be prevention: learning new ways to execute missions. Lockheed Martin has developed several capabilities for this dynamic environment. With robust precision and navigation systems embedded in their satellites, advanced software radar systems like Space Fence detecting objects as small as a marble in LEO, and the iSpace software platform cataloguing space objects and debris, the Company is equipping its customers with greater situational awareness and the tools to act. In the future we can continue to propose diverse mission architectures, when the mission allows, to diversify not only the size of the satellite but also the orbit to alleviate pressure in congested zones.

On the other hand, Chris Kemp, founder, chairman and CEO of Astra is sure that for making a real change is necessary the development of sustainable policies and regulations. His opinion is also shared by Will Marshall, CEO and Co-Founder of Planet. His idea is that an international ban on kinetic anti- satellite destructions would be really useful together with transparent and collaborative space traffic management. Planet’s CEO also suggests satellite and launch vehicle operators must remove their mission hardware as quickly as possible after the end of missions; this could either be achieved by launching to low orbits and relying on atmospheric drag or active end-of-life deorbiting or graveyard orbiting via onboard propulsion or other methods. Moreover, governments must invest in fundamental capabilities to avoid large-scale collisions between defunct objects already in space, such as laser nudging or active debris removal missions.

ACTIVE DEBRIS REMOVAL

Active removal can be more efficient in terms of the number of collisions prevented versus objects removed when the following principles are applied for the selection of removal targets, which can be used to generate a criticality index and the according list:

- The selected objects should have a high mass (they have the largest environmental impact in case of collision).
- Should have high collision probabilities (e.g., they should be in densely populated regions and have a large cross-sectional area).
- Should be in high altitudes (where the orbital lifetime of the resulting fragments is long).

Long¬-term environment simulations can be used to analyse orbital regions that are hotspots for collisions. The most densely populated region in LEO is around 800–1000 km altitude at high inclinations.

High-ranking hotspot regions are at around:

- 1000 km and 82° inclination.
- 800 km and 98° inclination.
- 850 km and 71° inclination.

The concentration of critical-size objects in these narrow orbital bands could allow multi-target removal missions. Such missions could be specifically designed for one orbit type were a number of objects of the same type are contained. Let's have a look at some of these missions:

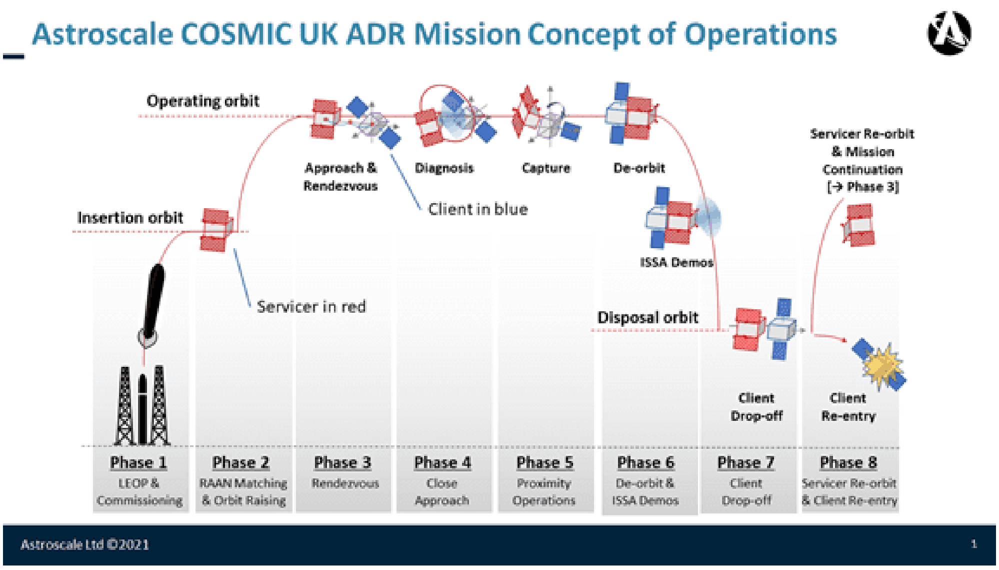
ClearSpace-1

The European Space Agency (ESA) announced plans to launch a space debris removal mission in 2025 with the help of a Swiss start-up called ClearSpace. The ClearSpace-1 mission, is an ESA Space Debris Removal mission. The mission has as objective to demonstrate the complete value chain of Active Debris Removal; the mission will use an experimental, four-armed robot to capture a Vega Secondary Payload Adapter (Vespa) left behind by ESA's Vega launcher in 2013. The piece of space junk is located about 500 miles (800 kilometres) above Earth and weighs roughly 220 lbs. (100 kilograms). Vespa is a reasonable first target for ClearSpace-1 given it is a relatively simple shape, sturdy construction, and about the size of a small satellite. If all goes according to plan, the team can leverage the same technology to capture larger, more challenging pieces of space debris in future missions. The team plans to first test ClearSpace-1 in a lower orbit of about 310 miles (500 km), prior to launching the mission to capture Vespa in 2025. The mission will demonstrate technologies for rendezvous, capture, and deorbit for end of life satellites and builds the path to space junk remediation. Destructive re- entry will destroy both the captured satellites and it.

ESA recently signed a $104 million (€86 million) contract with ClearSpace to accomplish this feat.

Astroscale's Studies

The UK Space Agency has awarded Astroscale's U.K. subsidiary a bid to a study active debris removal project. Astroscale is working on a mission with OneWeb for the European Space Agency's Sunrise program to develop its ELSA-Multi (ESLA-M) spacecraft, which will be capable of capturing multiple defunct satellites in one mission. The CONOPS satellite will be based on the ELSA-M spacecraft.



All this however will need a change of the legal framework in the space sector.

Legal Framework

Let's try answering an apparently easy question: *who is responsible for space debris*? **In order to explain the current situation, we have to start from the difference between "normal territory liability" and "space liability". The former is the one found in daily accidents on Earth, while the latter is the one that seems so far away from us but that has a real impact on us: liability in space.**

For instance, in each country all over the world if you get into a car accident you are protected by the law applied by a judge, in order to determine who is liable for damages. On the contrary, let's consider another kind of situation and imagine that instead of your car you are driving your satellite, and this hits another satellite in space: in this case there are no clear rules to determine who is liable for the accident.

The only legal sources regarding space activities are the Outer Space Treaty (OST) from 1967 and the Liability Convention from 1972. The problem is that in those treaties there is no clear definition of what a "space object" is, and this could be a practical problem to determine who is liable for the removal of space debris. Therefore, what is the actual situation in space? Nations aren't legally required to remove their garbage from space, so there would be the necessity to do that voluntarily, but it would be very expensive for the governments. So, the situation is that more than half of those satellites remain in space, some as still operative but more as decommissioned junk. As they crash into each other, they create more and more space debris around the earth.

So, what could be a possible solution? Perhaps the legal framework might become more uniform and easily applicable if there was an active harmonization of the national legislations. If the ratifying countries of the Liability Convention and the OST implemented the international treaties at a national level, the provisions would be absorbed within the national

legal framework, and they might be better observed. The implementation will need to focus on defining at a national level the concept of "space object", which is nowadays perceived as ambiguous since it is not specified in the treaties. However, this solution would generate several different definitions and there would confusion, undermining legal certainty.

Moreover, another convincing solution would be modifying both legal sources at an international level, developing a more modern network of legal provisions regulating space activities. As a matter of fact, more than 50 years have passed since these legal sources were enforced therefore a partial or complete replacement is necessary. Within these amendments, a worldwide recognized definition of "space object" should be introduced because this would consequently allow the enforcement of new legal provisions on space objects collisions and the respective third country liability.

The time frame is relevant because space debris has gradually become a bigger problem over the decades. Luckily more space activity has been engaged, but it also brought more space junk causing also detrimental effects on the environment. It has become a problem that needs be addressed and that involves each country, especially the ones that are highly invested in these activities.

In conclusion, for these reasons, it is preferable to act at a higher level and find a common policy between all countries.

Other Proposed Policies

Technologies for debris mitigation

LEO altitudes are threatening to become clogged with debris, especially in the popular polar orbits. Compliance with space debris mitigation requirements makes significant demands on LEO satellites, especially large ones.

To help with this, ESA's Clean Space Office has begun the CleanSat project, to support European industry at the design stage in developing future LEO spacecraft that are fully compliant with debris mitigation regulations. The aim is to upgrade LEO platforms in a coordinated European approach through the creation of common technologies and building blocks, fostering shared supply chains, in order to reduce the development costs and recurrent costs.

There are four key areas of interest to CleanSat, below.

Passivation: Explosions of satellites are a major source of debris. Passivation reduces the likelihood of a satellite exploding in the future by deactivating its power systems and batteries and venting any leftover propellant.

Deorbiting systems: International debris guidelines require satellites to remove themselves from LEO within 25 years of their end of life, either to a graveyard orbit or to re-entry. Promising methods to achieve this without detracting from mission efficiency include solid rocket motors or drag sails and tethers.

Design for demise: Many satellites will eventually renter the atmosphere (in either a controlled or uncontrolled manner). The design aim is to ensure that they pose no risk to people on the ground, by using materials and designs that are likely to burn up entirely so that nothing is left to hit the ground.

Design for servicing: Design for servicing involves incorporating standardized features on future satellites, such as grips and handles, that will enable future 'active debris removal' by a mission such as e.Deorbit. It will also enable orbital servicing missions to capture satellites for removal or repair.

Remediating space debris

Because of the tendency of every collision to generate more debris, it is not enough just to minimize debris production by future missions: the current debris population also needs to be reduced. Since 2012, ESA's Clean Space initiative has been designing a proposed mission called e.Deorbit (later CleanSpace-1), which will demonstrate the active debris removal of a large item of space debris from LEO.

The objective of the mission is to use a custom satellite to capture a heavy, ESA-owned item of debris and remove it from an altitude of 800–1000 km and a near polar orbital trajectory. This removal will be performed by moving the item at high speed and high precision into Earth's atmosphere, causing it to burn up. At this stage, the emphasis is on mastering various technologies to make e.Deorbit workable in practice. Some of the most important are described below.

Target characterization: drifting satellites are prone to tumbling in unpredictable ways. The e.Deorbit satellite will have to identify the target – potentially autonomously – and then assess its condition and rate of spin before going on to perform a close approach.

Capture mechanism: The target item of debris next has to be captured and robustly secured. Capture mechanisms under study include nets, harpoons, and robotic arms.

Disposal methods: The combination of the removal craft plus the captured item of debris will then have to be maneuverer in a safe, fully controllable manner, without posing any hazard to other space missions or to populations on the ground as they proceed to deorbit.

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