Space debris: how to clean up space?

Debris: a danger to space activities?

Space Debris and their accumulation

Following the commencement of space activities in 1957, a population of space debris began to form, and continues to grow driven by an increasing number of space missions and rising engagement in space activities. Such an upsurge is expected to be exacerbated in the coming years with the potential deployment of mega-constellations, primarily instigated by commercial actors who benefit from cheaper and simplified access to space solutions.

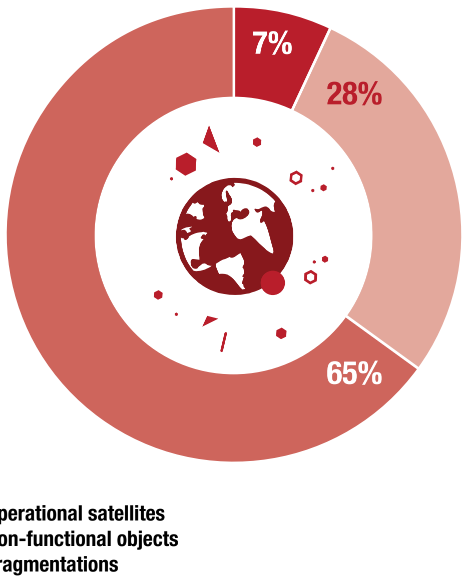
This population includes every non-functional man-made body in space, from non-operational satellites, to break ups from orbital stages, and the fragments of those bodies.

The variety in debris types naturally implies a distinction in their properties. They can usually be classified into three categories: large-sized, medium-sized and small-sized debris.

Large-sized debris are those greater than 10cm and are possible to trace or monitor. They are easier to catalogue, and represent more than 95% of the mass distribution of Low Earth Orbit (LEO) debris[2]. A spacecraft collision with large debris would be catastrophic, and lead to the destruction of both bodies due to the large mass and thus large energy at collision.

Such a collision induces a significant amount of medium-sized and small-sized debris. Medium-sized debris (from 1 to 10cm), which are only partially tracked, and small-sized (less than 1cm) debris, which are completely untraceable, represent the rest of this segmentation.

Figure 1 – Distribution of space objects



A collision with medium-sized debris could cause either complete destruction of the spacecraft or heavy damage, whereas collisions with small-sized debris are only expected to cause minor damage. However, this minor damage could still threaten the functionality of a satellite, or accelerate its degradation, eventually leading to a mission failure.[2]

According to an internationally accepted theory known as the Kessler syndrome, the increase of the debris population will lead to a self-sustained cascading effect where colliding debris in turn creates additional debris and consequently additional collisions. This means that the debris cloud in space is expected to expand continuously and exponentially if no sufficient control measures are taken, given that the critical debris density has been exceeded. Therefore, the future of space activities has become endangered due to the threat of collisions and destruction posed by space debris.

Another major concern due to debris is the risk of debris re-entry. Every year, around 40 random orbiting space objects with a mass inferior to 800kg re-enter Earth's atmosphere[6]. Random re-entries are completely uncontrolled; therefore, there is no telling where the body is going to land precisely and what damage it will cause. Such damage can be minor if for example the object lands in the ocean; however, severe damage can be caused if the object lands on someone's property, not to mention the risks it would impose on human life.

A major concern of the global space community

The international space community agrees that the most critical regions due to debris are currently in the LEO and the GEO orbits. Together, these two regions contain around 82% of the total population of functional satellites in space[6]. LEO orbits alone are home to around 500 functioning satellites exploited for different operations of scientific, commercial and defence purposes and they additionally host the International Space Station (ISS).

THE LEO REGIME IN JEOPARDY

- About 400,000 debris of all sizes are scattered over a wide range of low Earth orbits.
- In LEO, debris and satellites orbit at very high speed. Collisions among such bodies could result as being destructive and thus create additional debris.
- An increase of this population would be extremely difficult to avoid should no actions be taken.
- An excessive increase of the space debris population would eventually lead to a non return point known as the Kessler syndrome and would compromise all space activities conducted in LEO.

The partial or complete loss of the LEO region will endanger launches to higher orbits (GEO, MEO) and will have significant consequences on the global space economy, spanning from the upstream, including satellite manufacturers, to the downstream such as value-added companies using space-based data. It would impact wider industry sectors such as transportation that uses satellite navigation technologies and telecommunications that depend on communication satellites for example.

A call for action: damage control of space debris?

Mitigation measures from the UN/IADC

In response to the threat that space debris poses to space missions, the Inter-agency Space Debris Committee (IADC) developed mitigation measures that were adopted by a UN resolution in 2007. Such measures include limiting or minimizing debris released intentionally from operational space systems through an enhanced design of the spacecraft.

These measures aim at minimizing the capability of a system to suffer break-ups after its lifetime (e.g. by depleting on-board energy storage after the system has served its purpose and is no longer needed), and also by redirecting satellites within 25 years post-mission towards earth atmosphere re-entry or a graveyard orbit. In addition, the United Nations Office for Outer Space Affairs (UNOOSA) has compiled and made public a set of space debris mitigation standards.[3]

Protecting satellites from immediate threats

To protect satellites from colliding with debris, a few measures are taken depending on the debris types:
Large-sized debris (10cm) are already mostly catalogued and traced, and so the risk of collision with a functional satellite can be detected ahead of time. In such cases, collision avoidance manoeuvres are performed by the operational satellite.
As small-sized debris cannot be traced easily, satellite designs sometimes include shielding to protect the spacecraft from potential damage, whether minor or critical, that collisions with small debris might induce. However, shields are heavy, expensive, hard to integrate in the satellite design, and do not protect from medium-sized debris.

Mitigation measures are not enough

Despite the existence of mitigation measures, and the emergence of new concepts to protect operational satellites from collisions, the proliferation of space debris cannot be fully controlled. IADC studies concluded that even if 90% of space activities complied with mitigation guidelines set for the LEO regime, the population of large debris would increase by about 30% in the next 200 years, mainly due to space debris collisions among themselves.

According to NASA and ESA simulations, actually stabilizing the LEO environment would require, in addition to post mission disposal (PMD), the removal of at least five large-sized debris bodies per year over the next 100 years[1]. Therefore, it appears that mitigation measures alone are not sufficient to sustain the LEO regime, and hence additional initiatives such as Active Debris Removal (ADR) and In Orbit Servicing (IOS) should be undertaken.

Furthermore, debris mitigation guidelines are not strictly implemented and followed, since none of them are legally binding. In other terms, it is currently difficult to issue any type of sanction against a satellite owner and operator who have voluntarily refused to apply debris mitigation measures.

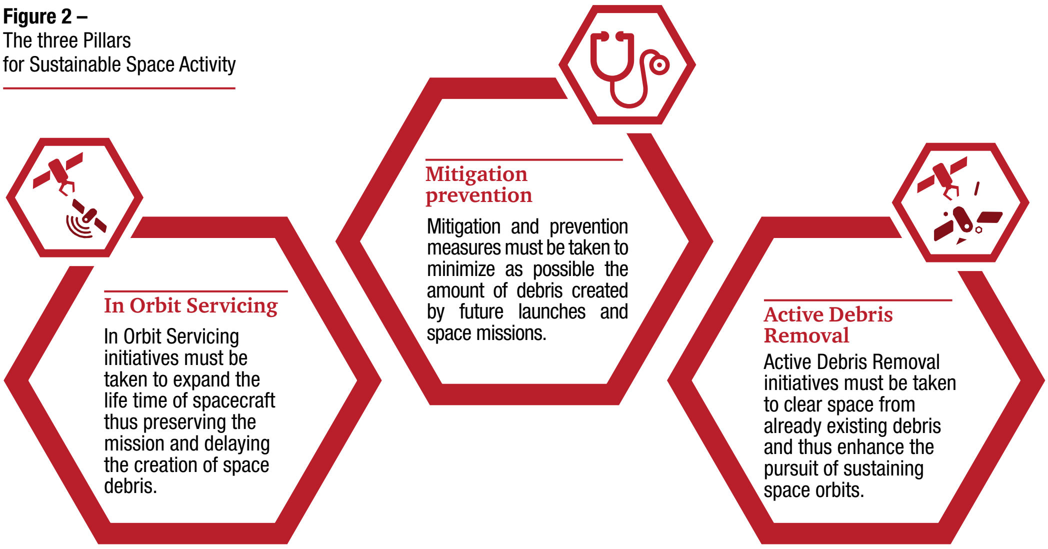
Key Concepts of ADR and IOS

Overall, Active Debris Removal (ADR) and In Orbit Servicing (IOS) mission concepts are currently at a conceptual and demonstration phase, with several initiatives, being led mainly by North American, Japanese and European players, to develop different methods and technologies. The general approach involves sending a servicing spacecraft in orbit and perform operations within the vicinity of the debris. For ADR, these proximity operations would consist of either de-orbiting the debris into Earth's atmosphere, or sending it to a graveyard orbit. These activities can be performed by the means of a net, a tether, a robotic arm, or by attaching equipment that would gradually lead the debris to burn in re-entry.

As for IOS, proximity operations would be used to service the dysfunctional satellite by refuelling it, repairing it or performing maintenance. IOS activities would thus aim at extending the lifetime of spacecraft, which would eventually slow down the increase of space debris.

The three Pillars for Sustainable Space Activity

Figure 2 –
The three Pillars
for Sustainable Space Activity



It is important to note, that as crucial as ADR or IOS are for the reduction of space debris population, performing them without applying mitigation measures on future missions would be useless, and not sufficient to sustain space activities in the long term.

Current ADR market and its Challenges

Space agencies are taking initiatives towards the reduction

With the global community's awareness of the undeniable need to protect space missions from debris, initiatives have flourished around the world. For example, the US established its Orbital Debris Program Office that aims at monitoring space debris. ESA has launched the *CleanSpace* initiative, which is built upon three main pillars: reducing the environmental impacts of space activities; encouraging the design of spacecraft that would incorporate debris mitigation objectives; and promote and support Active Debris Removal initiatives. As part of this initiative, ESA is designing a mission called e. Deorbit, which aims at removing large-sized debris, and also involves the use of a robotics arm that would enable servicing operations. This mission is planned to be launched in 2023.

Private industries are marketing ADR concepts

As ADR has grabbed the attention of the global community, private companies race to take part in its market. For example, a consortium led by the Surrey Space Centre has developed the RemoveDEBRIS mission that uses on-board net technology to remove space debris. In September 2018, the RemoveDEBRIS spacecraft successfully performed in-orbit operation, becoming the first ADR demonstration in history. In Italy, the company D-Orbit has developed an optimized satellite engine that facilitates a satellite's end of mission redirection (re-entry or graveyard orbits) manoeuvres in terms of cost and time, thus complying with space debris mitigation guidelines. Astroscale, a company based in Singapore, won private-public funding for its space mission from the Innovation Network Corporation of Japan (INCJ), JAFCO Co. Ltd and third party investors. This Asian company is expected to progressively demonstrate and test new technologies and systems in the field of space debris removal.

A gap in legal and policy frameworks

ADR has not yet been incorporated into international space policies and legal frameworks. First and foremost, there is yet to be a legal definition of a space debris in international space laws. There are also uncertainties as to which parties are responsible for retrieving the debris and definitions provided by international law do not clarify this ambiguity. In addition, during an ADR process, any accidental damage will generate additional legal risks. Political concerns also exist, as ADR could be used against military satellites or any spacecraft using sensitive technologies. A legal framework has yet to be devised in order to facilitate, or support ADR projects.[1]

Challenges in systematizing ADR and IOS activities

To have a real impact on the reduction of space debris proliferation, ADR and IOS systems must go beyond the concept-demonstration phase to become mainstreamed and operated on a regular basis. Given the technical complexity of ADR and IOS missions, and the fact that nearly all mission attempts need to be prepared and operated on a case-by-case basis, these mission carry many risks factors. In addition, should ADR activities become systematized, the full scope of these activities needs to be cost effective, while a sufficient revenue stream should be secured. Hence, ADR and IOS ventures must define a sustainable business model to ensure the long term viability of their operations.

Our vision: assessing the impact of space-debris mitigation and removal activities

Our approach to measure this impact

A starting point to assess accurately the importance of space-debris mitigation activities would be to value and monetise the socio-economic impacts of the loss of space infrastructure on space and non-space activities. The results and findings of such an exercise would indicate the worldwide social and economic dependence on space assets and would identify and locate which specific service-oriented space infrastructures are the most sensitive.

Such impact assessment should be performed in parallel with a thorough risk analysis of the current and anticipated debris population in order to determine the potential occurrence of a collision with an operational spacecraft, as well as the collision of two debris with each other provoking a chain reaction of collisions. This should be performed based on existing and previous assessments led by the IADC and space agencies.

The combination of these assessments would inform the level of severity and likelihood of the different sets of plausible catastrophic scenarios triggered by debris collision. The strategic, social, economic and environmental benefits of conducting space-debris mitigation and removal activities would thus be highlighted and enable the design and implementation of appropriate measures.

Performing a deeper Policy and Legal Framework analysis

Further analysis should be performed to support the emergence of international policy and legal frameworks aiming at managing space debris removal. To analyse and potentially establish a framework, a starting point would be to perform a thorough review of the international space law, as well as regional and domestic space laws of countries performing space-debris removal activities. In parallel, all the laws and regulations regarding space policy should be reviewed, including: the Outer Space Treaty, IADC/UNOOSA guidelines, Space Liability Convention, Registration convention, current legal safeguards and pertinent jurisprudence.

From those reviews, a group of fundamental stakeholders can be identified and thus consulted for further deeper analysis of the issues. Once those inputs are gathered, ambiguity in jurisdictions, obligations, and responsibilities, as well as all potential liability claims and their risks, could be identified, analysed and derived to a set of recommendations to complete the policy and legal frameworks around space-debris removal.

Assessing the market for space-debris removal activities

Due to the ambiguity in the policy and legal frameworks as to who is responsible for performing and funding the ADR mission, the addressable market could thus be reduced to the public or private entities willing to pay for ADR services. As it is quite unlikely that a small minority of stakeholders bear the risk and financial burden of conducting space-debris initiatives, the potential market for space-debris removal solution has to be defined based on the incentives of directly exposed entities.

Research on the typology of space entities potentially exposed to the threat of debris collision would allow the identification of entities having a direct interest in space-debris removal solutions. Risk exposure to space debris vs the criticality of exposed space assets would determine which entities have the highest needs for debris removal solutions.

Depending on the nature of the expected impacts (social or economic), public and private entities involved in space activities have dispatched needs and incentives in benefiting from debris removal solutions. Therefore, a role is to be played in assisting entities in clearly determining their needs for solutions. The market for space-debris removal activity will fully emerge when needs for debris removal solutions are expressed by entities who are directly concerned by the issue.

Defining the business model(s)

At first glance, space-debris removal operations bring very little monetary value given that investments for such operations are high whereas direct returns are low or non-existent. The financial question therefore represents a challenge that needs to be addressed by disruptive business models. The first potential financing scheme is based on international cooperation, in which all spacefaring nations would contribute to a budget dedicated to debris removal activities. However, this option would need to be supported by a clear, strong and unanimously adopted international legal framework covering all aspects of space-debris and this is currently not the case.

A second option would be to have space-debris removal activities financed by taxes. Each entity owning an asset launched into space would have to pay a tax on its launched asset. Entities following and respecting space-debris mitigation guidelines would collect the entire or partial majority of the funds paid through taxes while non-compliant entities would see their taxes used to finance debris removal operations. Again, this polluter-payer concept needs to be enforced by a strong legal framework and might be challenged by the question of governance and by a lengthy turnover.

The third possibility is to raise funds for debris removal activities based on the concept of lowering the probability of debris collision. The percentage risk reduction of debris collision with a valuable spacecraft would be translated into a fee, paid by the entity owning the jeopardised spacecraft. The challenge posed by such option is to define the right equation between risk reduction and the charged fee.[6]

A global concern necessitating common alignment

Given the nature and importance of the threat posed by space debris, it is clear that international cooperation, and a common alignment between all players taking part in space activities, should be promoted. Players benefiting from increased access to space opportunities and developing new activities such as mega-constellations should be encouraged in their endeavour, while also being supported to comply with the relevant set of standards and best practices ensuring the security and reliability of their activities. In addition, discussions pooling international space organisations, established and emerging players, as well as players developing and offering ADR and IOS solutions, should be planned and arranged. Such dialogue would aim at reaching a consensus on the most suitable alignment and way forward towards the definition of a sound and sustainable use of space.

Sources

[1] Ram Jakhu, Yaw Nyampong (February 2012). Active Debris Removal — An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space. *A Report of the International Interdisciplinary Congress on Space Debris Remediation and On-Orbit Satellite Servicing 6-17.*

[2] Matteo Emanuelli , Tiffany Chow, Deva Prasad, Giulia Federico, Joshua Loughman (2013). Conceptualizing an Economically, Legally And Politically Viable Active Debris Removal Option. *64th International Astronautical Congress, Beijing, China.*

[3] Inter-Agency Space Debris Coordination Committee. Report of the IADC Activities On Space Debris Mitigation Measures. *41st Session of UNCOPUOS S&T Subcommittee.*

[4] J.–C. Liou. Engineering and Technology Challenges for Active Debris Removal. *4th European Conference For Aerospace Sciences (EUCASS).*

[5] Office of the Director of National Intelligence US, Department of Defense US (2011). National Security Space Strategy.

[6] Christophe Bonnal, Darren S. Mcknight (2016). IAA Situation Report on Space Debris-2016.

Contact

If you have any questions or wish to discuss the space sector and the challenges it faces, please contact our team leader:

Dr. Luigi Scatteia
Director
+33 (0) 6 42 00 71 67
scatteia.luigi@pwc.com

About PwC and the space sector

Data

The information presented in this document provides an analysis of the space-debris mitigation sector. The figures are based on available data as of May 2017, and are subject to change over time.

About the PwC network

At PwC, our purpose is to build trust in society and solve important problems. We're a network of firms in 157 countries with more than 208,000 people who are committed to delivering the highest quality solutions in advisory, assurance and tax services.

About the PwC space sector

The PwC space team is part of the PwC Advisory practice, which includes strategy and consulting. The PwC space team is fully dedicated to the space sector. Our team includes specialists from all space sectors who are supported by consultants from the global PwC network. Our expertise covers the entire space sector and spans the value chain, from upstream to downstream. We help entities, public and private, to face their business, technological and governance challenges in a constantly changing environment.