How to Solve the Problem of Space Debris...

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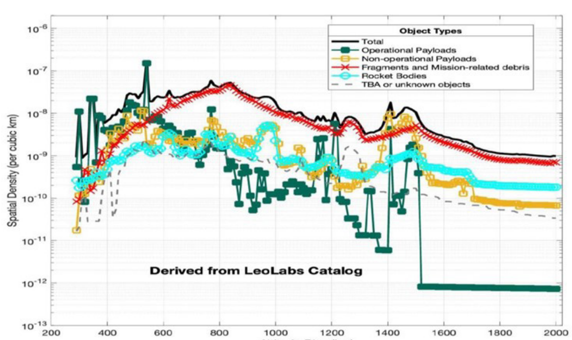
The space debris question can be looked at on three different levels: today, yesterday, and tomorrow.

Today: Critical, but Manageable

Some orbital zones are already severely affected by space debris – mainly those between 700 and 1100 km altitude, where the amount of debris is two or three orders of magnitude higher than the number of active spacecraft. This situation results from the indiscriminate deployment of satellites into low-earth orbit (LEO), polar orbit, and heliosynchronous orbit – all of which are fundamental for Earth observation, communication, and defense – mostly during the Cold War years and following decade. Satellites were launched several times a week, and were left abandoned together with their upper stages, often exploding after some time. The following figure, from LEOLABS[1], shows that current operations in space tend to take place above or below the most congested zone, abandoning the 700-1100 km orbital region.

Figure 1: Typology of Orbital Objects in LEO



Identifying the Statistically-Most-Concerning Conjunctions in LEO, M. Stevenson, D. McKnight, H. Lewis, C. Kunstadter, R. Bhatia, AMOS Conference 2021

It progressively led to the preparation of a set of space debris mitigation rules, at the space agency level first (NASA in 1995, NASDA (Japan) in 1997, and CNES (France) in 1998), then internationally with the Inter-Agency Debris Coordination Committee (IADC) in 2002[2] and the United Nations Committee for Peaceful Use of Outer Space (UN COPUOS) in 2007. After that followed the standards, guidelines, codes-of-conduct, and recommendations applicable to operators such as the European Cooperation for Space Standardization (ECSS) and the International Standardization Organization (ISO)[3]. The five high-level rules prescribed in these documents are quite simple and straightforward:

- Do not generate new debris knowingly (do not destroy orbital objects voluntarily).
- Avoid explosions in orbit by passivating the objects left after operational missions.
- Limit the duration in "Protected Regions" (low-earth orbit and geostationary orbit) to 25 years after operational period.
- Avoid collisions when possible, i.e., when equipped with a propulsion system and correctly informed of the position of potential upcoming collisions.
- Limit the casualty risk to populations associated to uncontrolled atmospheric reentries by aiming at uninhabited zones (South Pacific Ocean for instance) or by adopting a "Design-for-Demise"

These rules are unfortunately not correctly complied with today. More than 1,000 additional objects are left in orbit every year; there is one orbital fragmentation per month on average; the twenty-five-year rule is very badly applied. In addition, most atmospheric reentries are uncontrolled.

The only domain where significant progress has been achieved is that of collision avoidance. Several networks of sensors – run by the American, European, Chinese, and Russian governments and composed of radars, telescopes, lasers, or ad-hoc satellites – provide information on the ever-increasing orbital population, enabling computation of avoidance maneuvers. This collision avoidance operation appears sufficient today to contain the current population.

Yesterday: Countering Kessler Syndrome

"Kessler Syndrome," an effect identified by Donald Kessler of NASA as early as 1979 and quantified and published[4] in 1991, expresses the spontaneous increase in number of orbital objects associated with collisions between non-maneuverable objects. Each collision generates new debris, which, in turn, pose a future collision risk to resident space objects. This effect is balanced thanks to residual atmosphere that induces a dynamic pressure, lowering the orbit of every orbital object; there is therefore a natural cleaning effect. However, when the generation rate of new debris exceeds the level of atmospheric cleaning, there is a chain reaction effect, which can be uncontrolled. NASA has published several simulations showing that even if we completely stopped all space operations, i.e., no more launches, no new satellites, etc., the number of objects in space would continue to increase exponentially.

This effect can clearly be seen today between 700 and 1,100 km in altitude, where the number of objects has increased by a factor of four over the last twenty years, even with a reduction by a factor of four of active satellites in the same time period. Kessler Syndrome was widely publicized by the 2013 film Gravity, directed by Alfonso Cuarón.

To counter this effect, it is mandatory first to comply perfectly with the space debris mitigation rules described earlier, and, second, to retrieve large debris from orbit. Numerous studies have shown that if ten items of large debris are removed every year from the most polluted orbital regions, then the increase curve would flatten, halting Kessler Syndrome.

Such active debris removal (ADR) operations have been studied for over fifteen years and turn out to be quite challenging. The debris have to be large and heavy; otherwise, the efficiency of the process is low. An internationally agreed list of the fifty debris that must be prioritized for retrieval was published recently[5]: the most critical are nine meters long and weigh nine tons. There are many ADR techniques available. The general principle is to send a "chaser" to catch a "target," attach to it, and deorbit it in a controlled way to the southern Pacific Ocean. The link can be rigid, from robotic arms, tentacles, or large claws; or soft, such as a net, a clamp, or a harpoon at the end of a long tether, with the chaser pulling the assembly up to reentry. There are hundreds of variants with small chasers aiming at one piece of debris, or much larger ones hunting half a dozen targets; some solutions call for the installation of a deorbiting kit on the debris, and so on. The effective development of these techniques is still in its early phases: there have been quite a lot of demonstrations at the laboratory level, then in drop-towers and zero-gravity planes. Several sub-scale experiments have been performed in orbit, but the first "real size" retrieval is expected to be performed in 2026 by ClearSpace, a Swiss startup under contract with the European Space Agency.

ADR raises numerous non-technical problems: such operations may be construed as military anti-satellite actions, and therefore must cautiously and transparently be planned to avoid any misinterpretation. It poses legal and insurance questions, as an operator is not allowed to touch an orbital object that is not under its jurisdiction. However, the main question is the cost of such operations and how they would be paid for. It is hard to define a business plan when nobody is willing to pay for it.

Several ideas are under discussion and evaluation.[6]

- Defining a global ADR program, potentially under the aegis of the UN, with a major sharing of responsibilities and costs among countries; this solution is potentially overly optimistic, considering that not everyone would wish to pay.
- Missions targeted according to financial viability; some missions may bring major economic benefits, such as the removal of dead satellites from geostationary orbit or from large constellations.
- Eco-tax on every operator that fails to comply with debris mitigation guidelines; the money collected would then finance the cleanup. Such a solution, however, is ultimately not realistic, as it would need an internationally enforceable regulation and a "tax collector" recognized by all countries at the international level. A variant of this idea could use insurance with a systematic increase of the costs before the mission, reimbursed after the mission if compliant.
- It is also possible to demonstrate the gain associated to the lowering of the probability of collision.
- Last, and most credible solution today, it is possible to use the new In-Orbit-Servicing (IOS) missions, based on multi-tasks space tugs, to end the missions grabbing a nearby debris, and deorbiting it in a controlled way.

Tomorrow: An Expected Evolution

In 2012, there were 864 active satellites; at the beginning of 2022, there were 4,600 of them. Such an increase is linked to what is nicknamed "The New Space Age," which has seen the launch of both small satellites and large constellations.

- There are roughly 450 cubesats launched every year, and this number is expected to rise in the coming years; some nano-satellites are even smaller than 1U Cubesats, with dimensions in the range of 2.5 cm or less. Such nano-sats are now easy to build and cheap to launch, thanks to the practice of launching swarms of over fifty to 100 satellites in just one mission. These satellites usually do not have on-board propulsion, and they cannot perform collision avoidance maneuvers. Their reliability is not always at the same standard as conventional satellites, leading to a high rate of dead satellites left in orbit. As they are small, they are often hard to track, and it may take months before they are able to be included in space objects catalogues.

- Large constellations, on the other hand, are based on a very large number of identical satellites, generally in the 200-400 kg class, deployed in LEO. The problem comes from their number, as each large constellation can deploy thousands of satellites at a time; a recent proposal was submitted considering up to 325,000 new satellites. These satellites are active, and most of them are equipped with a small propulsion system enabling collision avoidance maneuvers. But their reliability, even if high compared to standards, means that many defunct satellites are left in orbit, causing even more overcrowding in the orbital region up to 600 km. There is no risk of a cascading increase linked to collisions, as the chosen altitude usually enables a natural atmospheric cleaning over the course of fifteen to twenty years, but avoiding collisions is very tricky. It requires on-board autonomous collision avoidance procedures, linked to hundreds of thousands of space objects with poor orbital precision, leading to an incredibly high level of false alarms.

- It is now compulsory to prepare for some form of Space Traffic Management (STM), or at least Coordination (STC). A major effort is devoted to this priority at the international level, structured following the various elements of Figure 2 below.[7]

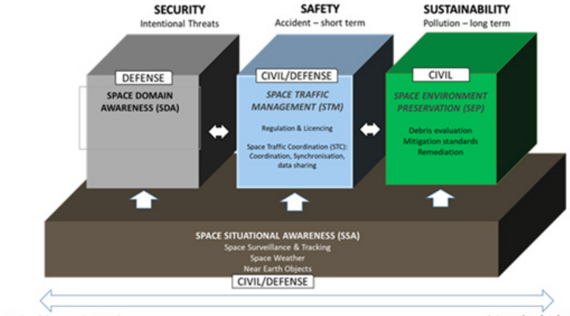
- In terms of general principles, there is no "hard" regulation enforceable at the international level, and it does not appear credible to imagine a form of regulation in place that would be one applicable to all countries, or at least the three biggest "polluters" (97.5% of space debris in LEO originates from Russia, the United States, or China). Each country should instead write its own regulatory framework, laws, standards, and recommendations. This is necessary mainly due to security and defense concerns, which imply national and sovereignty stakes.

- There is nevertheless a very good and efficient coordination at the international level on principles around space traffic management, shared by all but not constraining. The goal is to verify that every actor plays by more-or-less the same rules. This is the domain of international entities such as UN COPUOS, IADC, ISO, ECSS, and others. The main work there is to prepare regulation and licensing rules, shared by all, aimed essentially at improving the collision avoidance process. As an example, IADC published in July 2021 a set of recommendations applicable to large constellations[8].

- The last pillar is that of general work aimed at preserving the future of the space environment. These activities cover a wide range of fundamental work—scientific, technical, and legal—at the international level, in dedicated working groups, and through think tanks. These are, in general, more efficient as they are not constrained by political or industrial considerations. There are numerous committees dealing with these questions around the world – for instance at the International Astronautical Federation, International Academy of Astronautics, International Institute of Space Law, European Space Policy Institute, Air and Space Academy in Europe, Secure World Foundation in the United States and Fondation pour la Recherche Stratégique in France. These activities lead to exchanges during ad-hoc congresses, webinars, and taskforces, and some of the recommendations arising from those conversations have already been efficiently put in place.

- All these activities rely on a solid base, compulsory for every aspect of preparing for the future, called Space Situational Awareness (SSA). SSA covers the question of near-earth objects and space weather, but essentially relates to space surveillance and tracking (SST). The top priority is to determine with precision what is above our head; improve the detectability and trackability threshold; and determine associated orbits more precisely. Numerous initiatives to achieve this are underway, such as the Space Surveillance Network in the United States; the International Scientific Optical Network in Russia; and EU Space Surveillance and Tracking in Europe. There are also more and more private actors working in this space, such as LEOLABS in the United States or Share My Space in Europe.

Figure 2: Relationships between STM, SSA, SDA, and SEP



Conclusion

As a conclusion, there are clearly numerous points of concern when it comes to space debris. The space debris mitigation rules are not correctly respected, by far, with numerous fragmentations each year – some of them voluntary, as in the recent cases of anti-satellite demonstrations. There is a growing number of very small satellites, which are not capable of avoiding collisions, and major growth in large constellations expected: optimistic evaluations say we could have over 30,000 active satellites by 2030 (compared to 850 in 2010).

Priority should be given to international coordination, and to drastically improved observation tools. We must react now to keep the situation under control.

Endnotes

1 Identifying the Statistically-Most-Concerning Conjunctions in LEO, M. Stevenson, D. McKnight, H. Lewis, C. Kunstadter, R. Bhatia, AMOS Conference 2021

2 IADC Space Debris Mitigation Guidelines www.IADC-home.org

3 ISO Space Debris Mitigation Requirements - ISO 24113

4 Collisional Cascading: The Limits of Population Growth in Low Earth Orbit, Advances in Space Research, D. Kessler, Volume 11, Issue 12, Pages 63-66, 1991.

5 Identifying the 50 statistically-most-concerning derelict objects in LEO, D. McKnight et al., Acta Astronautica 181, pp 282-291, 2021

6 Some high level reflections on how to finance Active Debris Removal (ADR), C. Bonnal, IAASS 2021

7 IAF Technical Committee on Space Traffic Management TC.26 WG1. Draft

8 IADC Statement on large constellations in Low Earth Orbit. IADC-15-03. 2021