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Space Debris

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Summary

- *Since the launch of Sputnik in 1957, humans have sent an ever-increasing number of satellites into space. However, the number of launches, particularly into low Earth orbit, has rocketed in recent years, bringing the issue of space debris into even sharper focus.*
- *Once satellites are no longer in service, not all of them quickly re-enter the atmosphere. Many continue to orbit the Earth for years, decades, or potentially even centuries. The debris from these either whole or broken up out-of-service satellites pollutes space and can collide with still-operational satellites.*
- *Some initial solutions for managing this debris are emerging.*

Jean-Luc Fugit, MP   Ludovic Haye, Senator

Background to space congestion

Outer space was for millennia immune to any form of terrestrial interference, but human incursions began in the second half of the twentieth century. Over time, these have become commonplace and have left behind an ever-increasing amount of debris.

The European Space Agency (ESA) has counted one million man-made objects in orbit around the Earth,[1] limiting its analysis to debris larger than one centimetre. Now is the time for those involved in space operations to address the risks posed by these objects.

Constellations: a new challenge

This issue applies equally to satellites in **low Earth orbit**, **medium Earth orbit** and **geostationary orbit**. In geostationary orbit, approximately 36,000 kilometres above the Earth, the satellites complete their circular orbit in 24 hours, which means that they are always above the same point on the Earth's surface. However, it is possible to cover the Earth's surface continuously at lower cost by launching smaller satellites, but in much greater numbers, into low orbit, forming what are known as **constellations**.

The oldest telecommunications constellation is Iridium. It consists of 66 satellites placed into low earth orbit at a height of 780 kilometres and belongs to the US Department of Defense. The OneWeb constellation, launched by the United Kingdom but taken over by Eutelsat in 2023, comprises 624 satellites. Starlink has the largest constellation, with 4,000 satellites at the time of writing, at altitudes of between 350 and 500 kilometres. It will have 8,000 by the end of 2024 and has received authorisation to deploy 42,000 satellites. Amazon's Kuiper constellation will have 10,000 satellites.

There were just 540 active satellites orbiting the Earth in 2003. This rose to 900 in 2013 and now stands at 8,700.

Satellite collisions: a real risk

On 10 February 2009, the Kosmos 2251 and Iridium 33 satellites collided over Siberia at an altitude of 789 kilometres. The Kosmos satellite was Russian, decommissioned in 1995, while the Iridium satellite was part of the operational Iridium constellation.

Even though the risks have increased, no collision of this magnitude has occurred since that date. However, the United States, Russia, China and India have carried out tests to destroy satellites by blowing them up, creating thousands of new pieces of space debris.

Other adverse effects

- *Negative impact on astronomical observation*[2]

The growing number of satellites is disrupting astronomical observation. For optical astronomy, which uses ultraviolet to infrared rays, the main problem is the reflection of sunlight by the satellites, which causes streaks in the images, destroys sensors and leads to interpretation errors. For radio astronomy, it is the radio waves from the satellites, whether intentional or from on-board electronics, that interfere with the quality of the signal. At the insistence of the International Astronomical Union, Starlink is now using a less reflective paint for its constellations and is making every effort to switch off its satellites as they pass over the locations of the main radio telescopes.

- *Increased risks on re-entry into the atmosphere*

Objects in low Earth orbit eventually fall back to Earth because the atmosphere, even though very thin at high altitude, slows them down and causes them to spiral downwards.[3] However, these objects do not burn up completely during this process: between 10% and 40% of their mass survives re-entry and crashes to the Earth's surface.

Admittedly, the risks are extremely low. For example, the European Space Agency estimated that the risk of an individual being hit by its 2.3 tonne ERS-2 satellite re-entering the atmosphere was less than 1 in 100 billion.[4] The residual debris crashed without incident into the Pacific Ocean on 21 February 2024.[5] However, the risks are bound to increase as the number of satellites in low Earth orbit grows.

Growing number of debris objects

First pollution from Sputnik

The first telecommunications satellite weighed just 87 kg, but its story set a sad trend in terms of the debris it generated. When the Soviet Union launched Sputnik on 4 October 1957, its payload was just 1.3% of the total mass sent into orbit, since the core stage of the Semiorka rocket used as the launch vehicle (6,500 kg) ended up in the same orbit, as did the satellite's protective fairing (100 kg). Sputnik was active in orbit for 21 days, but re-entered the atmosphere after 92 days because it had been placed in a relatively low orbit, with its closest point to Earth (the perigee) only 225 kilometres away. Even though it re-entered the atmosphere relatively quickly (the core stage had done so a month earlier), it was nevertheless orbital debris for three quarters of its life.[6]

Sources of debris

Space debris comes from a variety of sources:

- Decommissioned spacecraft, such as satellites that are no longer operational. Satellites have an average lifespan of only about 15 years, mainly because of the radiation they receive in space.

- Spent stages of the rockets used to launch satellites into orbit.

- Objects jettisoned in space during missions, such as the waste dumped by space shuttles.

- Small fragments caused by collisions, explosions or damage to active satellites or larger debris.

Classifying debris: size and dangerousness

Debris is generally classified into three categories, depending on its size and how dangerous it is:

- Debris larger than 10 cm is already monitored in low Earth orbit, so action can be taken to avoid collisions; the same applies in geostationary orbit for debris larger than 1 metre.

- Debris between 1 and 10 cm, sometimes called the "lethal population", is so named because it is large enough to cause significant damage, but too small to be monitored.[7]

- Debris smaller than 1 cm is not normally large enough to destroy the satellite it hits. Shielding may protect satellites against such debris.

There are 36,000 large man-made objects in orbit (over 10 cm) capable of completely destroying a satellite, including around 8,713 active satellites (approximately 550 in geostationary orbit and 8,000 in low Earth orbit). There are more than a million objects larger than 1 cm capable of partial destruction. Lastly, there are 150 million pieces of debris smaller than 1 cm.[8]

Probability of collisions

For now, debris comes mainly from the break-up of obsolete satellites in an environment that is particularly harsh on equipment.[9]

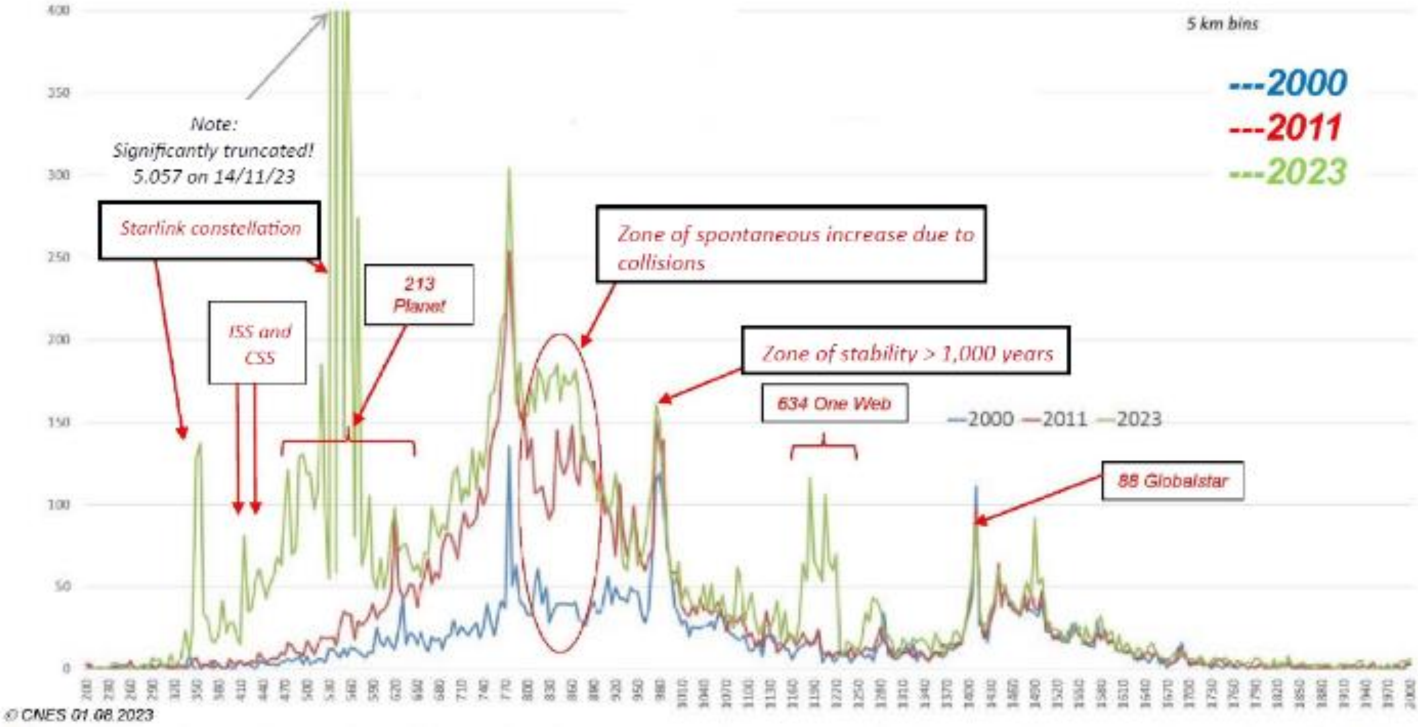
However, as the probability of collisions grows, they could become the main source of debris unless effective measures are taken. One NASA scientist, Donald J. Kessler, has even speculated that there could be a "chain reaction" in which the amount of debris and the number of collisions both increase exponentially. This scenario, known as the **Kessler Syndrome**, has not yet occurred. If it were to happen, it would be crucial to know exactly when it might be triggered, as the members of the French Academy of Sciences interviewed by the rapporteurs pointed out.

Ever closer monitoring of debris

Space debris can be monitored from Earth using telescopes and, for objects in low orbit, radar. The largest pieces of debris can be tracked and catalogued using these methods.

European Union space programme

The European Union is implementing a debris tracking programme as part of its wider Space Situational Awareness (SSA) programme,[10] focusing on three areas.



The proliferation of objects in low Earth orbit

The first area, known as NEO, focuses on asteroids approaching the Earth; the second analyses meteorological events that can be observed in the natural environment of space; and the third is the EU Space Surveillance and Tracking (SST) system.

The space agencies of 15 European Union member states are part of this network. Run under the aegis of the European Union Space Programme Agency (EUSPA), it pools three types of surveillance resources: three lasers, nine radars and 28 telescopes. This includes France's Graves military radar surveillance system, which tracks satellites orbiting at altitudes of between 400 km and 1,000 km on a daily basis. There are also a host of private systems being developed by French startups such as ShareMySpace, Look Up Space, SpaceAble and Dark.[11]

➢ US surveillance programme

The US military maintains the largest space debris catalogue. Space Track lists more than 28,000 objects over 10 cm in low Earth orbit or over 1 metre in geostationary orbit. Since the 2009 collision between Kosmos 2251 and Iridium 33, the United States has publicly shared an increasingly large proportion of this catalogue.[12]

■ Possible solutions

Solutions are beginning to emerge. Some have already been implemented, while others are in the process of being tested. Often only palliative measures, they sometimes hold out the prospect of finding effective long-term remedies to the current situation.

➢ Protecting satellites against debris impacts

The first solution is to protect satellites from, or help them avoid, collisions.

- *Passive protection through shielding*

Even small pieces of debris can cause serious damage. Objects in low Earth orbit travel at high speeds, typically 7.5 km per second. At this speed,[13] a 1 mm radius piece of aluminium debris will cause as much damage as a bowling ball thrown at 100 km/h, a 1 cm piece of debris will cause the same impact as an average saloon car travelling at 130 km/h, and a 10 cm piece of debris will release as much energy as 240 kg of TNT.

This is why operators now install Kevlar or metal foam shields in front of the most sensitive surfaces of their satellites. However, leaving aside the cost implications,[14] these shields are only effective for debris up to 1 cm in size. They are not a solution for debris between 1 and 10 cm.

- *Active protection by avoidance*

It is possible to avoid collisions if one of the two objects involved is operational and able to manoeuvre. Based on calculations of the orbits of catalogued objects, operators can assess the risk of a collision and take a decision to manoeuvre if necessary. The 2009 collision between Iridium 33 and Kosmos 2251 could therefore have been avoided, as Iridium 33 was still operational and able to manoeuvre.

The French Space Agency CNES's CAESAR (Conjunction Analysis and Evaluation Service: Alerts and Recommendations) can assess the risks and issue collision alerts a few days before the event. This free service is an integral part of the EU SST initiative mentioned earlier. In practical terms, the alerts issued to operators registered with this service enable them to take the necessary evasive action.[15]

Even with the support of artificial intelligence, it is still extremely time-consuming to constantly update the lists of catalogued objects, which are the only ones covered. In 2022, CNES issued 3.5 million collision predictions for 293 satellites, and 17 debris avoidance manoeuvres took place. In 2023, the International Space Station performed six manoeuvres. On average, there is one manoeuvre per year for each satellite in low Earth orbit.

➢ Reducing the amount of debris

Even in low Earth orbit, it can take centuries for debris to be eliminated naturally by falling back into the atmosphere. New technologies have opened up the prospect of dealing proactively with the problem of existing debris, or at least the largest pieces. Active removal demonstrations have already taken place.

- *ESA's RemoveDebris mission (2018)*

This is one of the first active debris removal (ADR) missions. The main RemoveDebris module ejected nanosatellites with no propulsion (and therefore no manoeuvrability) into space to demonstrate how they could be recovered. The mission, which took place from 20 June 2018 to 4 March 2019, demonstrated in orbit the viability of technologies such as **net capture** and **harpooning**. Both methods are based on Vision-Based Navigation (VBN),[16] a technology that uses two optical sensors – a conventional camera and a Laser Detection and Ranging (LiDAR) system – combined with an image-processing algorithm to form an effective navigation system around the main module's immediate environment.

To prepare for the possible future use of the harpoon technique, Eutelsat is now equipping its low Earth orbit satellites with a grapple fixture so that they can eventually be recovered by a grappling system.[17]

- *Two recent Japanese Astroscale missions*

Astroscale, a private Japanese company, has also conducted two debris removal experiments. On 24 January 2024, it successfully demonstrated its ELSA-d magnetic capture and de-orbit system while in orbit. This system features two satellites: a master satellite designed to safely remove debris from orbit and a client satellite acting as prey.[18]

Astroscale's second mission, ADRAS-J,[19] is closer to real-life conditions and aims to demonstrate the feasibility of rendezvous proximity operations (RPO), essential for future on-orbit servicing. This involves making a safe approach to inert debris and facilitating its recovery. On 22 February 2024, the ADRAS-J satellite rendezvoused and synchronised its orbit with a Japanese H2A upper stage rocket body, measuring roughly 11 metres in length, four metres in diameter and weighing around three tonnes. It was able to determine the state and trajectory of this debris, and the risks associated with it. This is the stage prior to a removal operation.

- *ESA's ClearSpace-1 mission for 2026*

Using a **robotic arm**, this mission aims to capture and safely retrieve, for safe re-entry into the atmosphere, a large and particularly damaged piece of debris, in this case the VEGA Secondary Payload Adapter (VESPA), a 112 kg upper stage rocket body orbiting at an altitude of between 664 km and 801 km. Planning for the mission,[20] developed by ESA's ClearSpace team, is taking place in partnership with Swiss startup ClearSpace SA. It is scheduled for launch in 2026.

- *A goal within touching distance?*

According to Christophe Bonnal (CNES), around ten large pieces of debris need to be removed from low Earth orbit each year to stabilise the environment, starting of course with the 50 most dangerous.[21]

- *Controlling the amount of new debris*

Looking to the future, regulations must encourage operators to provide satellites with sufficient fuel (propellant) to push them into a higher "graveyard" orbit at the end of their life. Here, too, cost is an issue.

It is estimated that between 85% and 100% of objects in space that have reached the end of their life in geostationary orbit over the last decade have already attempted to comply with current debris limitation regulations. Between 60% and 90% of them have succeeded in doing so, which is more than half of the total number.[22]

Recommendations

- Step up efforts to monitor, analyse and process tracking data.
- Suspend all satellite destruction tests.
- Only issue launch authorisations if sustainable end-of-mission solutions can be found.
- Begin active removal, as soon as possible, of the most dangerous debris from low Earth orbit, at a rate of at least 10 pieces per year, starting with the 50 most dangerous.

The Office's websites:
http://www.assemblee-nationale.fr/commissions/opecst-index.asp
http://www.senat.fr/opecst

People consulted

People interviewed

- *General Philippe Adam, Air Force Major General, Space Commander*
- *François Baccelli and Jean-Loup Puget, members of the French Academy of Sciences*
- *Christophe Bonnal, Senior Expert, CNES Directorate of Strategy*
- *Astrid Bonté, Director of International and Institutional Affairs, Chehineze Bouafia, Head of Regulatory Affairs – Space & Telecommunications, and Étienne Lesoeur, Institutional Affairs Officer, Eutelsat*
- *Julien Cantegreil, founder of SpaceAble*
- *Juan Carlos Dolado Perez and Michel Friedling, co-founders of Look Up Space*
- *Didier Flaender, Chairman of Numerisat*
- *Stijn Lemmens and Francesca Letizia, analysts at the Space Debris Office, European Space Agency (ESA)*
- *Clyde Laheyne, co-founder of Dark*
- *Pierre Lionnet, Director of Research at ASD Eurospace*
- *Romain Lucken, founder of ShareMySpace*

Références

[1] ESA's Space Debris Office has published an annual report on the space environment since 2016. The latest was published in 2023: https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf.

[2] The rapporteurs would like to thank Jean-Loup Puget, a member of the French Academy of Sciences, for drawing their attention to this point when they interviewed him and his colleague François Baccelli.

[3] However, it is estimated that it takes several centuries for debris to fall back to Earth when it is in orbit at an altitude of more than 1,000 kilometres.

[4] https://blogs.esa.int/rocketscience/2024/02/05/ers-2-reentry-frequently-asked-questions/

[5] https://www.esa.int/Space_Safety/Space_Debris/ERS-2_reenters_Earth_s_atmosphere_over_Pacific_Ocean

[6] Presentation by Mr Christophe Bonnal, CNES (French Space Agency) expert, to the Toulouse Air and Space Academy, 19 May 2016: https://academieairespace.com/wp-content/uploads/2018/05/Bonnal-Bdx-2016.pdf. The authors of this briefing would like to thank the author for providing them with the latest update of this panoramic presentation of the space debris issue, in which he is a specialist.

[7] Although its true capabilities are unknown, it is thought that the most modern radar in the US surveillance network, the Space Fence, located in the Marshall Islands, "probably sees objects the size of a centimetre in low Earth orbit". (Michel Friedling, *Space Commander*, Editions Bouquin, Paris, 2023, p. 182). However, 10 cm is still widely considered to be the current upper limit for cataloguing debris.

[8] ESA 2023 Space Environment Report. In a POSTnote briefing from March 2010, the British Parliament Office of Science and Technology reported that there were 19,000 pieces of debris larger than 10 cm and several hundred thousand pieces of debris between 1 and 10 cm.

[9] On the subject of space weather, i.e. variations in solar activity and their effects in space, see scientific briefing no. 43 by Christine Arrighi, which states: "The flow of high-energy particles linked to the activity of the Sun and the magnetosphere can accelerate the aging of the electronics on board the satellites, and cause computer errors or reduce the power of the solar panels that supply them with energy."

[10] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32021R0696 (Regulation (EU) 2021/696)

[11] https://www.eusst.eu/wp-content/uploads/2023/11/SDSC-conference_1nov2023.pdf

[12] "The 2009 collision brought about a salutary reaction within the space community. The Americans gradually made their daily collision alerts available to many commercial space operators, providing levels of accuracy and calculation that were satisfactory for the time." (Michel Friedling, *Space Commander*, Editions Bouquin, Paris, 2023, p. 181)

[13] The speed of a moving object is a key determinant of its kinetic energy (Ec), which is equal to half its mass multiplied by its speed squared: Ec = 1/2 X mass X speed^2.

[14] At an OPECST hearing on 4 May 2023, Mr Yannick Borthomieu, from Saft, highlighted the light weight of the satellite batteries his company produces, explaining that "every extra gram added to the battery has to be carried by the launch vehicle, at a cost of between €50 and €80 per gram. When several hundred kilograms are on board, you can easily imagine the cost savings from reducing this mass by 10% or 20%". The same applies to the shielding added to satellites.

[15] CNES, "Débris spatiaux, un risque à la loupe", interview with Christophe Taillan (in French).

[16] https://inria.hal.science/hal-02286751/document

[17] https://www.youtube.com/watch?v=nTtskTGRr1U

[18] https://astroscale.com/astroscales-elsa-d-finalizes-de-orbit-operations-marking-successful-mission-conclusion/

[19] https://astroscale.com/astroscales-adras-j-mission-starts-rendezvous-operations/

[20] https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/320/SDC8-paper320.pdf

[21] A host of teams from all over the world have identified the 50 most dangerous pieces of debris in low Earth orbit: "Identifying the 50 statistically-most-concerning derelict objects in LEO", *Acta Astronautica*, vol. 181, April 2021, p. 282-291. The 19 co-authors of the article include Stijn Lemmens and Francesca Letizia, analysts at the ESA's Space Debris Office, who were interviewed by the authors of this briefing.

[22] IADC Report 2024, see in particular figure 14.