RUBBISH SPACE DUMP

There are **129 million pieces** of rocket and satellite debris above the Earth. Have we reached the limit? Not yet. But the future debris will have to be sustainable. And we'll have to remove the bigger pieces.

by Vito Tartamella

WRECK Space debris in an artistic reconstruction: the most polluted orbits are the low ones, at an altitude of 800-1,000 km. The busiest by communications satellites.

Getty Images

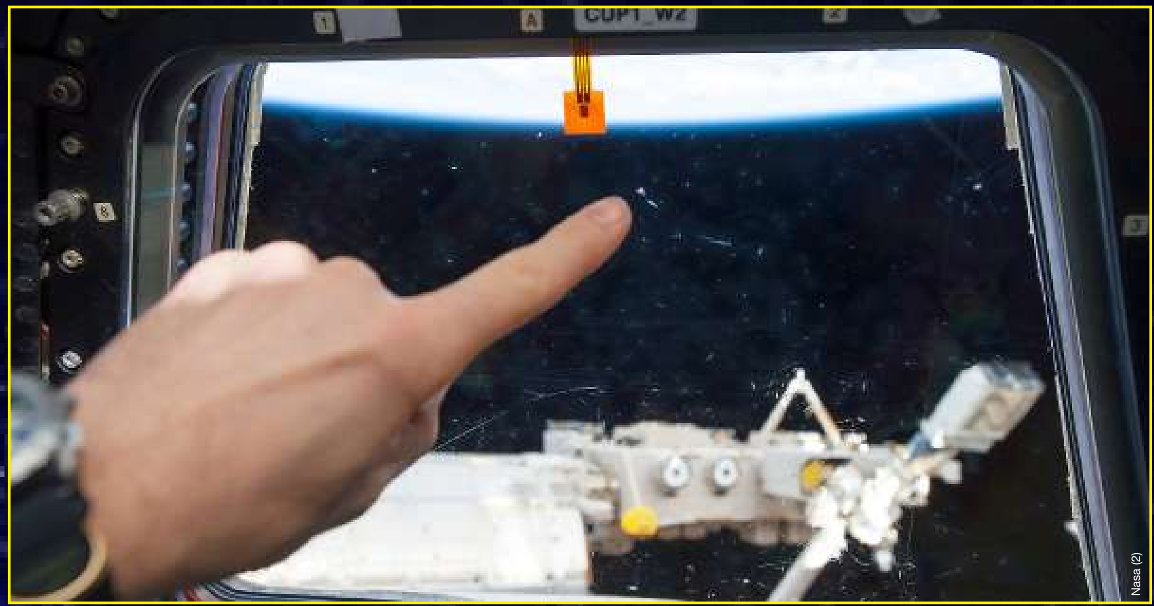
The last time it happened was on 22 September last year. At 22:21, Vandenberg Air Force Base, in California, sent the International Space Station a conjunction data message, a possible collision alert—within an hour it would be in danger of being hit by a piece of stray debris. The three astronauts on board the station, Christopher Cassidy, Anatoly Ivanishin and Ivan Vagner, got to work on the on-board computers to prepare for the emergency manoeuvre. At 22:19 they fired their thrusters for three minutes to move into a safe orbit. Then they took refuge in the Soyuz space capsule, ready to undock and return to Earth in the event of a collision.

They had a narrow escape, as the debris passed by 1,500 metres from the Station, hurtling at 52,560 km per hour over the Pacific Ocean. At that speed, a piece the size of a smartphone has the same impact force as a lorry crashing at 140 km per hour. Only at that point did the military at the Joint Space Operations Center recognize it: it was fragment 2018-084CQ, part of a Japanese rocket that had carried the satellite Gosat-2 into space in 2018. In 2019, this aluminium and carbon fibre stage, weighing more than 100 kilograms, had broken up into 74 parts.

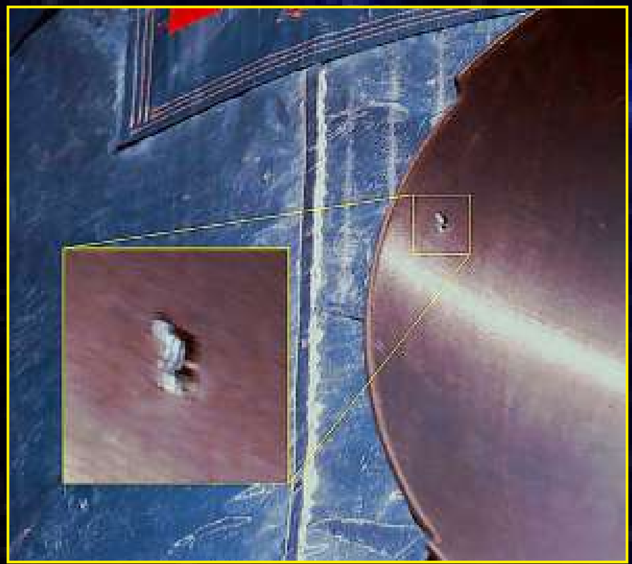
HALF-FULL?

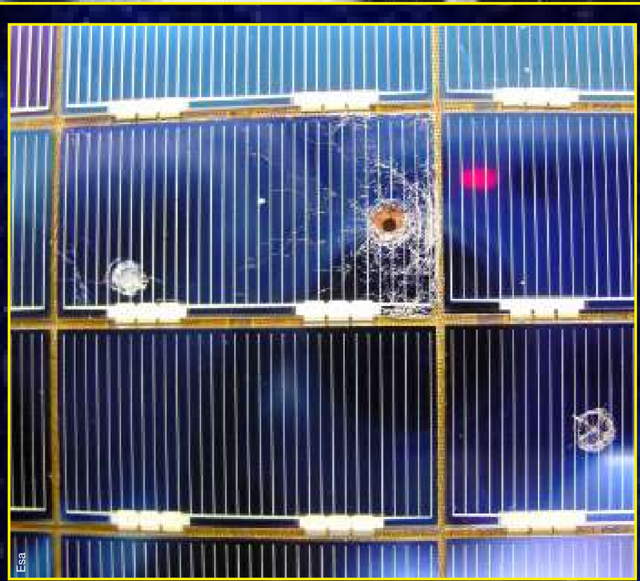
It was the 28th time in 20 years that the Station was forced into a correction manoeuvre to dodge space debris, with the previous three occurring in 2020. «The situation is getting worse», commented the then Head of NASA, Jim Brindestine. It is hard to argue with him: since the launch of the first satellite 64 years ago, the Earth's orbit has turned into a dump site. There are an estimated 129 million fragments larger than 1 mm: rocket stages, bolts, engine slag, paint flakes and retired satellites. The Envisat wreckage alone is the size of a double-decker bus. A worldwide network of orbiting telescopes, radars and sensors has so far surveyed 28,600 fragments larger than 10 cm: they have a total mass of more than 9,400 tonnes, the same as 19 train carriages.

Even if space is immense, it still has a limit. In 1978, NASA scientist Donald Kessler hypothesised a dreadful scenario: as space launches intensified, the density of objects would be so high that they would trigger chain collisions,



TRACES
The sign of a micro impact on a window of the International Space Station: in recent years it has had to make several maneuvers to avoid space debris and to avoid much more serious damage.





DAMAGES
The damage caused from small space debris to the Hubble Space Telescope: here on the right, the impacts on solar panels: left, on the antenna.

Estimated objects

129 millions
1 mm-1 cm fragments (flakes of paint, residues of ignition dust from solid propellant engines, drops of coolant).

900,000
1-10 cm fragments.

34.000
fragments larger than 10 cm (including 1,950 rocket stages and 2,850 dead satellites. There are 200 critical objects of 3-9 tons).

Cataloged objects

Ground-based telescopes can detect debris from 10 cm upwards in Geo orbits. Ground radars can see debris a few millimeters in low orbit. Detectors mounted on satellites can also identify objects of a few micrometers.

To date, **28,600** fragments larger than 10 cm have been cataloged, for a total mass of over 9,400 tons, as **19** high-speed train convoys (1 locomotive and 18 carriages).

By mass, spacecraft are **55%** of the total, rocket stages **41%**, fragmentation debris **2%** and **2%** mission debris.

State of the orbits

36.000 KM
GEOSTATIONARY ORBIT (GEO)
Satellites remain in this orbit indefinitely, even for millions of years. Objects orbit at the speed of 11,000 km per hour. Here is **5%** of the total mass of debris, and beyond this orbit another **5%**.

2.000-35.000 KM
MEDIUM EARTH ORBIT (MEO)
The time spent by the satellites is equal to that in Geo orbit. Here the objects orbit at 14,000 km per hour. In this orbit there is **15%** of the total mass of space debris.

160-2.000 KM
LOW EARTH ORBIT (LEO)
From an altitude of 1,200 km, satellites take about 2,000 years to fall to Earth; at 800 km it takes 100-150 years and at 500 km less than 25 years. Here the objects orbit at 28,000 km per hour. In this orbit (especially between 800 and 1,000 km of altitude) there is **75%** of the total mass of debris.

36000 KM/H THE AVERAGE SPEED OF IMPACT IN LOW ORBIT
A 10-cm, 300-gram object, which collides with another with an impact speed of 36,000 km / h, has the same strength as a **truck** that crashes at **94 km / h**.

So far 11,670 satellites have been launched: 7,200 are still in orbit, 4,300 still functioning. 56% are from the USA, 12% from China, 5% from Russia.

Over 560 events of fragmentation have taken place in the past 60 years Most are higher stage bursts; collisions were 7.

with an exponential increase in debris and the risk of further impacts. To the point of making space exploration and the use of satellites impossible for many generations. How close are we to this scenario, known as the "Kessler syndrome"?

In a study published this year in *Acta Astronautica*, Luciano Anselmo and Carmen Pardini from the Institute of Information Science and Technology of the Italian National Research Council in Pisa, calculated that «we have already filled a third, if not half, of the capacity of low orbit, the level most crowded with satellites. We obtained this figure by considering the scenarios that would have been unacceptable 25 years ago as reference points. We have gone from 150 to 1,500 satellites launched each year, all concentrated in the same volumes of space», said Anselmo.

Kessler himself, recently interviewed, is even more drastic: «We have now reached the tipping point: debris will continue to increase even if all launches are stopped». Space waste, then, would be like carbon dioxide emissions: even if we stopped them, we could no longer stop global warming.

ANTI-SATELLITE MISSILES

What can be done about it? To answer this question, we need to take a step back: how did we get here? In recent years, there has been an assault on space, not only to observe the Planet, but above all to bring the Internet to every corner of the globe—the signal is provided by satellites in low orbit, which circle the globe in an hour and a half. But even then, an area the size of Italy would only receive this signal for 8 minutes at the most. Therefore, huge constellations are needed to guarantee a constant signal: OneWeb is going to launch 850, Kuiper 3,200 and Starlink 12,000. And the sky has also become more crowded due to the spread of CubeSats, miniature satellites. On top of this, there are military tests. In 1963, the US launched 480 million thin copper needles that created a 15-km wide, 30-km thick doughnut around the globe at an altitude of 3,700 km: they would act as radio repeaters in the event of an enemy attack on submarine telecommunications cables. It was the "West Ford" project: 36 clusters of those needles are still in orbit today.

Today, however, what is of concern are anti-satellite weapons—in 2007 alone, space debris increased by 30% after China launched a missile to destroy an old weather satellite, the FengYun-1C. The Chinese missile was used to test the ballistic capability of shooting down an enemy spy satellite. The US and Russia had carried out dozens of such tests in previous years, and in 2019 India joined them, too.

This is why space is so polluted. It is estimated that today the probability of a catastrophic collision in low orbit—i.e. one capable of destroying a spacecraft by generating thousands of pieces of debris—is one every 20 years; this probability drops to one every five years in the case of a collision between a piece of debris larger than 10 cm and a satellite.

The first such collision occurred in 2009, between the decommissioned 950-kg military satellite Kosmos 2251 and a 560-kg Iridium 33. They collided at an altitude of 789 km above Siberia at over 42,000 km per hour, producing almost 2,000 fragments. Iridium operators had ignored collision alerts because "so many were coming in that we would have to interrupt the service too often, making it commercially unviable".

In fact, the problem with space debris is first and foremost to determine its orbit. Most of them are small, irregularly-shaped objects whose orientation, size and material are unknown: companies and governments are reluctant to provide space agencies with data on their satellites, which are protected by trade or military secrets. Thus the probability of a collision between two orbiting objects is established by complex calculations and is dominated by uncertainty—the most precise estimates are only possible when impact is imminent. All these calculations result in hundreds of alerts every week, which in turn take hours of work by an analyst. However, in case of risk, only the largest satellites have propellant on board to change orbit.

Today, rules require that satellites are removed when they reach the end of their service life: those in higher orbits must be moved to higher "graveyard orbits", from which they will never fall, while the closer satellites are moved to lower altitudes, so that they disintegrate due to atmospheric drag, or are dropped into the Pacific. According to an ESA survey, however, only 50% of satellites in low orbit meet these requirements. And less than 20% of satellites with an end of life scheduled in 2017 were actually deorbited.

SUSTAINABILITY RATINGS

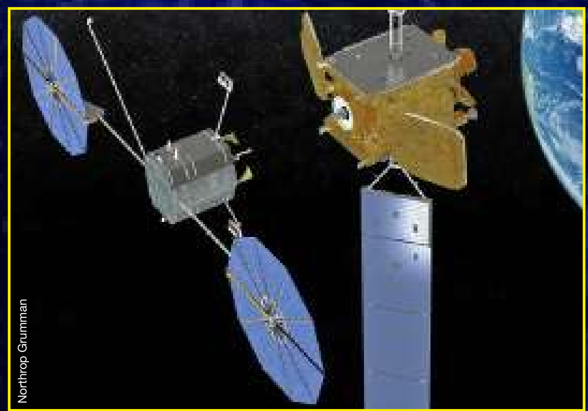
This is why last June, the World Economic Forum took the first steps towards measuring the sustainability of space missions: in 2022 the Polytechnic Lausanne Space Centre, Switzerland, will ▸

7 ways to clean up space

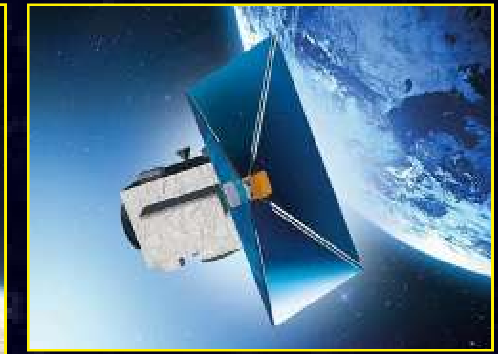
1 ClearSpace-1: a 100 kg probe with 4 robotic pincer arms to capture the Vespa, a part of the 112 kg Vega launcher. Esa project of 100 million euros with launch scheduled for 2025.

2 Elsa (End-of-Life Services Astroscale): mission of the Japanese space company Astroscale. It features a satellite equipped with a magnet to hook debris. A prototype was launched in March 2021.

3 RemoveDebris: removing space debris by catching it with a net or harpoon. Successful in-orbit tests conducted in 2018 and 2019. University of Surrey project with a consortium of companies.



4 Mission Extension Vehicle (Mev): a rescue satellite hooks up to another to supply it with propellant, repair it or bring it back to a correct orbit. Northrop Grumman technology already tested.



5 Adeo (Drag Augmentation Deorbiting Subsystem): sails system from 3 to 100 m² that pushes the disused satellite into a lower orbit to make it disintegrate. it is applicable to new satellites up to 1.5 tons of mass. Esa project.

6 Electrodynamic Tether (Edt). Satellites equipped with a long conductive cable: if unrolled, it captures the earth's magnetic field generating a current that slows the satellite down to lower orbits until it reaches the atmosphere, burning itself. Under study by Nasa and Jaxa (Japanese space agency).

7 Direct infrared laser beams to deflect the orbit of small debris (1-10 cm in size), avoiding collisions with larger objects. It heats one side of the object so as to change its orbit and make it fall into the atmosphere first. At study in Esa.

start assessing the sustainability of space operators based on data sharing, choice of orbit, measures taken to avoid collisions, plans to deorbit satellites at the end of the mission and ease with which satellites can be identified. Spaceships will earn extra points if they have docking devices to facilitate their capture in flight.

In the future, anyone who launches a satellite will pay a security **deposit** for cleaning costs in space

SPACE SWEEPERS

This is not science fiction: in the next few years, the first space sweepers will enter service. The European Space Agency is leading the way in this field with ClearSpace-1. The mission has never been attempted before and consists of sending a satellite equipped with four robotic arms into orbit, capable of capturing a piece of debris in flight. Scheduled for 2025, this probe will pick up Vespa, a piece of a Vega rocket, 2-metres wide and weighing 112 kg, launched in 2013. The probe will then destroy itself and its payload by launching at full speed into the Earth's atmosphere. «Capturing space debris is no joke» warns Luisa Innocenti, Head of ESA's Clean Space Office. «The first critical aspect is to precisely frame the target, which is moving fast and can be backlit: we will have to use infrared cameras and radars on board the probe, coordinating them with ground-based instruments. Then we will have to synchronise the movement of our spacecraft with that of Vespa, approaching it gradually and surrounding it well before closing the clamp arms to capture it. It only takes one wrong move and we risk destroying the target, resulting in more debris. The exact opposite of the mission purpose». This is not the only way to tackle the problem of space junk. Last year, the US company Northrop Grumman's MEV (Mission Extension Vehicle) probe managed to dock an Intelsat satellite and return it to a service orbit, extending its operational life by another five years. «This strategy will become increasingly popular, including in-flight propellant refuelling missions», added Innocenti. «Sending a satellite into orbit and operating it costs around 100 million euro and its planning takes long. Extending its service life, on the other hand, means saving money and time, and not crowding the orbits any more. In the next decade, companies are likely to be required to pay a deposit before launching new satellites, which will be refunded if the satellites are de-orbited at the end of their service; otherwise, that amount will be used to finance the costs of removing space debris. Today, a mission like ClearSpace-1 costs 100 million—we expect to reach a removal cost of between 5 and 15 million euro to remove more than one piece of debris at a time. A sort of space sweeper».

This procedure, however, concerns the military: in this way, spy satellites could be captured. In conclusion, it is a complicated, technical, political, and economic issue. And it is also a legal one: if a satellite causes damage, who pays for it? The country from which it was launched should be held accountable. Moreover, what if it does damage on Earth? Between 200 and 400 dead satellites and rocket parts fall into the atmosphere every year. Most of them disintegrate on contact with the atmosphere, but the rest reach the Earth, falling mostly into the oceans that cover 70% of its surface. The exceptions can be dramatic, such as the fall of the Cosmos 954 satellite, a Russian military satellite powered by a nuclear reactor—in 1978, due to a failure, it crashed in Canada, contaminating an area of 124,000 km². Canada asked Russia for a $6 million compensation. In the end, the Russians paid half.

CHOCOLATE AND RULES

Apart from accidents and pollution, however, prevention will continue to be the way forward. We will need to provide satellites with the propellant needed to deorbit at the end of the mission, and to build them in such a way as not to produce too much debris. «One solution», says Ettore Perozzi, Head of the Italian Space Agency's Space Situational Awareness Office, «is to assemble satellite components like chocolate bars, so that they break easily and their parts are destroyed immediately on contact with the atmosphere». At the same time, «rules of conduct in orbit will have to be set out in the same way we did with the Highway Code on Earth and all countries will have to behave responsibly», said Simonetta Di Pippo, Director of UNOOSA, the United Nations Office for Outer Space Affairs. «We have to tackle this problem on a global scale and we cannot afford to ignore it—we are at the beginning of a long road, but the start is encouraging».

According to Moriba Jah, Director of the Aerospace Engineering programme at the University of Texas, what is needed above all is a change in mentality: «Countries need to understand that the Earth's orbit is an ecosystem like the oceans and forests—it is not infinite and we need to protect it by capping the number of launches».

Will they succeed? F