Menace of Space Junk around Earth

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Abstract -- **Since beginning of space flights, collision hazards in Earth orbit increased as the number of artificial objects orbiting Earth has grown. Spacecrafts performing communications, navigation, scientific, and other missions now share Earth orbit with spent rocket bodies, nonfunctional spacecraft, fragments from spacecraft breakups, and other debris created as a byproduct of space operations. Millions of tiny pieces of junk orbiting Earth could have a major impact on space exploration.**

Orbital debris removal has become a very critical part of the commercial and scientific space management. It is an aggregating risk which needs to be addressed to prevent loss of spacecraft to debris collision.

NASA and ESA studies show that the only way to stabilise the orbital environment is to actively remove debris items. Innovative techniques have been proposed to solve the problem.

Keywords: Orbital graveyard, Orbital debris removal, Space garbage trucks, Recycling satellites, Space pods

I. INTRODUCTION

FROM almost the first moment that man started traveling beyond Earth's atmosphere, all sorts of debris in space has been left. Not only it is wasteful, but space junk can be dangerous as well - to satellites, to space stations, and when some of it plummets back to Earth, to human life on the ground.

This year, an 18-ton Chinese rocket plummeted toward Earth and landed in the Atlantic Ocean on May 11, becoming one of the largest pieces of space debris to fall uncontrolled back to Earth.

Earth's orbits are becoming increasingly cluttered with so-called *space debris*. This waste is composed of spent boost stages, collision fragments; human discards, inactive or defunct satellites, rocket bodies, ISS construction material, or other parts of spacecraft that have been left behind.

Some space junk results from collisions or anti-satellite tests in orbit. When two satellites collide, they can smash apart into thousands of new pieces, creating lots of new debris. This is rare, but several countries including the USA, China and India have used missiles to practice blowing up their own satellites.

There are estimated to be over 128 million pieces of debris smaller than 1 cm. There are approximately 900,000 pieces from one to ten cm. The current count of large debris (defined as 10 cm across or larger) is 34,000.

Space debris is mostly concentrated in the near-Earth space region, in the Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO) regions. Low Earth Orbit is defined as the region of space around Earth within an altitude of 160 to 2,000 km wherein a large number of active satellites operate. This causes a substantial operational risk, ranging from the need to perform evasive maneuvers to defects, or even obliteration of spacecraft due to collisions with pieces of debris, which at orbital speeds of approximately 7.5 km/s can cause considerable damage. NASA estimates that currently there are some 21,000 pieces of space junk larger than a softball orbiting the Earth that can damage a satellite or spacecraft.

According to experts, the problem is projected to get worse. By 2025 as many as 1,100 satellites could be launching each year. The number of satellites orbiting Earth is projected to quintuple over the next decade.

The estimated 8,800 tons of objects that humans have left in space are becoming a danger. Near misses are common these days: In September 2019, there was one near miss between Elon Musk's SpaceX satellite and one from the European Space Agency. But so far, there has been just one major collision: In 2009 American satellite Iridium 33 and Cosmos 2251, a Russian satellite, crashed, destroying both over northern Siberia. In January 2020, a satellite run by AT&T's DirecTV was found to be in danger of exploding and needed to be moved, or else it could harm other satellites. Meanwhile, in April 2020, the FCC of USA voted to require more disclosures from satellite operators seeking licenses but declined to introduce any new laws governing the removal of orbital debris.

Space debris is emerging one of the main threats for an affordable and safe space exploration and exploitation.

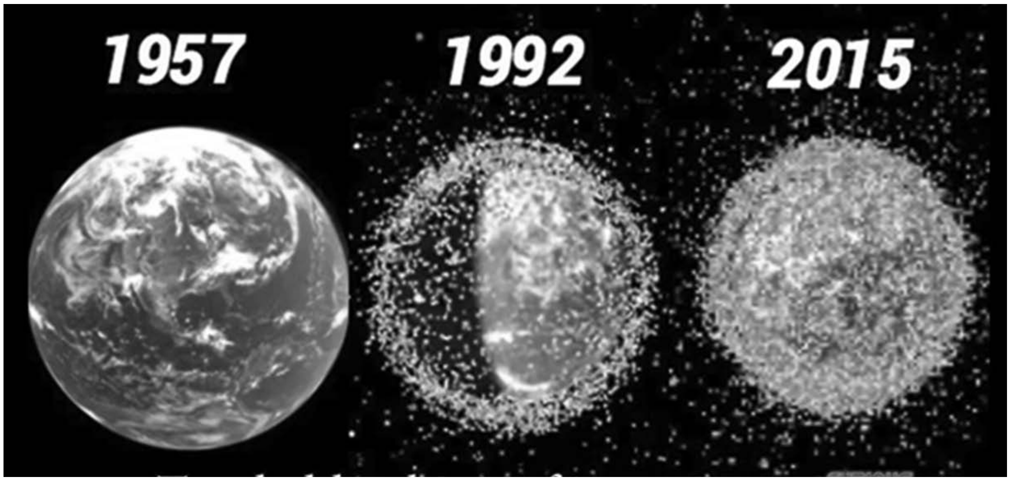

Figure 1. Since humans first went up in space in 1957, we've done a poor job of keeping it clean. The amount of space junk around Earth has hit a critical point.

II. OVERVIEW

One may ask, "What is Orbital Debris?" Though one doesn't see space junk in the sky, beyond the clouds and further than the eye can see, it enters low Earth orbit. LEO has become an orbital space junk yard. There are millions of pieces of space junk flying in LEO. Most orbital debris comprises human-generated objects, such as pieces of space craft, tiny flecks of paint from a spacecraft, parts of rockets, satellites that are no longer working, or explosions of objects in orbit flying around in space at high speeds.

Most "space junk" is moving very fast and can reach speeds of 18,000 miles per hour, almost seven times faster than a bullet. Due to the rate of speed and volume of debris in LEO, current and future space-based services, explorations, and operations pose a safety risk to people and property in space and on Earth.

There are many reasons why LEO has developed into an orbital graveyard. For instance, the deliberate destruction of the Chinese Fengyun-1C spacecraft in 2007 and the accidental collision of an American and a Russian spacecraft in 2009 alone have increased the large orbital debris population in LEO by approximately 70%, posing greater collision risks for spacecraft operating in low Earth orbit.

There are no international space laws to clean up debris in LEO. LEO is now viewed as the World's largest garbage dump, and it's expensive to remove space debris from LEO because the problem of space junk is huge. The NASA Orbital Debris Program officially began in 1979 in the Space Sciences Branch at the Johnson Space Center (JSC) in Houston, Texas. The program looks for ways to create less orbital debris, and designs equipment to track and remove the debris already in space.

Space junk is no one countries' responsibility, but the responsibility of every space-faring country. The problem of managing space debris is both an international challenge and an opportunity to preserve the space environment for future space exploration missions.

Imagine how dangerous sailing the high seas would be if all the ships ever lost in history were still drifting on top of the water. Humanity has generated a global problem that can only be solved with the help from other countries. The space around our planet is filled with rubbish. It's time to take out the trash!

III. MITIGATION STRATEGIES

Lockheed Martin announced construction of a Space Fence on the Marshall Islands in the central Pacific Ocean to track and identify space objects. Astroscale, one of the few companies whose mission is to clean up such space debris, is leading the charge to clean up space pathways and avoid collisions among the objects that humans recently have left in space. The Japanese company is currently working with Japan's Aerospace Exploration Agency (JAXA) to carry out the agency's Commercial Removal of Debris Demonstration (CRD2) project. The JAXA mission plans to complete its first phase by the end of 2022. The goal of the mission is to launch a satellite that will observe and acquire data on the rocket upper stage that the second phase will seek to deorbit. The idea is to find out how the debris moves in space and set up a safe and successful removal.

Northrop Grumman launched its first Mission Extension Vehicle spacecraft (MEV-1) in 2019 to prove it could intercept falling satellites, repair them, remove them from traffic and put them back in orbit. Swiss start-up ClearSpace, meanwhile, has a more specific goal: to remove a 100kg Vega Secondary Payload Adapter (Vespa) upper-stage rocket orbiting around 400 miles above Earth. It plans to do that in 2025. The ClearSpace-1 'chaser' will be launched into a lower 500-km orbit for commissioning and critical tests before being raised

Figure 2. Lockheed Martin has announced construction of a Space Fence on the Marshall Islands in the central Pacific Ocean to track and identify space objects.

to the target orbit for rendezvous and capture using a quartet of robotic arms under ESA supervision. The combined chaser plus Vespa will then be deorbited to burn up in the atmosphere.

According to Dr. Holger Krag, head of the Space Safety Program Office at the European Space Agency, the agency is looking into using lasers to gently push the objects off the path. So far, every year, humanity leaves dozens of objects behind in orbit without disposing of them. This is either because disposal was not foreseen or did not work, or the contact to the spacecraft was lost. This number is far too high. Chris Blackerby, group COO and director, Japan for Astroscale, said awareness is rising that there is too much junk in the Earth's orbit. "I think the idea that space debris is an active threat to our current satellite population is becoming more widely accepted," he says. Another worry is the Kessler Syndrome, in which NASA scientist Donald Kessler proposed that an exploding chain of space debris can make exploring space and the use of satellites impossible for generations. The fear is that we get to a level of unsustainability of orbit.

An active debris removal mission, if successful, has a positive effect (risk reduction) for all satellites in the same orbital band. This may lead to a dilemma: each stakeholder has an incentive to delay its actions and wait for others to respond. This makes the space debris removal setting an interesting strategic dilemma. As all actors share the same environment, actions by one have a potential immediate and future impact on all others. This gives rise to a social dilemma in which the benefits of individual investment are shared by all while the costs are not. This encourages free-riders, who reap the benefits without paying the costs. However, if all involved parties reason this way, the resulting inaction may prove to be far worse for all involved. This is known in the game theory literature as the tragedy of the commons.

To counter this risk, mitigation strategies are now implemented in newly launched satellites such as end-of-life de-orbiting or graveyard orbits [1]. However, researchers doubt that these measures, even if applied to all newly launched spacecraft, are sufficient to prevent a potential exponential build-up of debris[2]. Active space debris removal, though very costly, may offer a solution [3].

Figure 3. ClearSpace-1 will be the first space mission to remove an item of debris from orbit, planned for launch in 2025. The mission is being procured as a service contract with a startup-led commercial consortium, to help establish a new market for in-orbit servicing, as well as debris removal.

Following a competitive process, a consortium led by Swiss startup ClearSpace – a spin-off company established by an experienced team of space debris researchers based at Ecole Polytechnique Fédérale de Lausanne (EPFL) research institute – will be invited to submit their final proposal, before starting the project in March 2021.

"This is the right time for such a mission," says Luc Piguet, founder and CEO of ClearSpace. "The space debris issue is more pressing than ever before. Today we have nearly 2000 live satellites in space and more than 3000 failed ones [4].

"And in the coming years the number of satellites will increase by an order of magnitude, with multiple mega-constellations made up of hundreds or even thousands of satellites planned for low Earth orbit to deliver wide-coverage, low-latency telecommunications and monitoring services. The need is clear for a 'tow truck' to remove failed satellites from this highly trafficked region."

At Space19+, ESA's Ministerial Council, which took place in Seville, Spain, at the end of November 2019, ministers agreed to place a service contract with a commercial provider for the safe removal of an inactive ESA-owned object from low-Earth orbit. Supported within ESA's new Space Safety program, the aim is to contribute actively to cleaning up space, while also demonstrating the technologies needed for debris removal.

"Even if all space launches were halted tomorrow, projections show that the overall orbital debris population will continue to grow, as collisions between items generate fresh debris in a cascade effect," says Luisa Innocenti, heading ESA's Clean Space initiative. "We need to develop technologies to avoid creating new debris and removing the debris already up there".

NASA and ESA studies show that the only way to stabilise the orbital environment is to actively remove large debris items. Accordingly, ESA will be continuing development of essential guidance, navigation and control technologies and rendezvous and capture methods through a new project called Active Debris Removal/ In-Orbit Servicing – ADRIOS. The results will be applied to ClearSpace-1. This new mission, implemented by an ESA project team, will demonstrate these technologies, achieving a world first in the process [5].

The ClearSpace-1 mission will target the Vespa (Vega Secondary Payload Adapter) upper stage left in an approximately 800 km by 660 km altitude orbit after the second flight of ESA's Vega launcher back in 2013. With a mass of 100 kg, the Vespa is close in size to a small satellite, while its relatively simple shape and sturdy construction make it a suitable first goal, before progressing to larger, more challenging captures by follow-up missions – eventually including multi-object capture.

IV. OTHER NOVEL CONCEPTS

There are many possible means of reducing the debris hazard to future space operations [6]. There is no shortage of concepts for cleaning up the junk left behind in orbit, even if some of them seem far-fetched. Here is an overview of some of the ideas being proposed for cleaning up space debris.

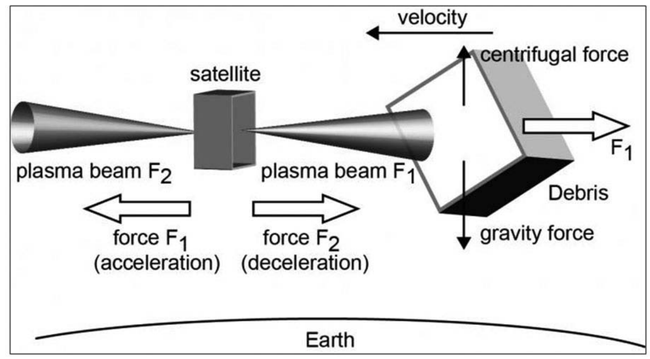

Figure 4. space debris removal by bi-directional momentum ejection from a satellite.

Figure 4 illustrates a novel concept for space debris removal by bi-directional momentum ejection from a satellite. When plasmas carrying momentum fluxes F_1 and F_2 are expelled from two axially opposite satellite exits, the respective forces shown by the horizontal arrows F_1 (pointing to the left and providing the acceleration of the satellite with respect to the orbit velocity) and F_2 (providing the deceleration) are generated and used to adjust the satellite velocity relative to the debris. Continuously imparting momentum flux F_1 to the debris (horizontal arrow F_1 pointing to the right) will cause its deceleration, final re-entry into the Earth atmosphere and natural burn up [7].

Space Garbage Trucks: The US Defense Advanced Research Project Agency (DARPA) is investing in the Electrodynamic Debris Eliminator, or EDDE, a space "garbage truck" equipped with 200 giant nets which could be extended out to scoop up space garbage. The EDDE could then either fling the garbage back to Earth to land in the oceans, or push the objects into a closer orbit, which would keep them out of the way of current satellites until they decay and fall back to Earth.

Recycling Satellites: Instead of just trashing space debris, some dead satellites could be "mined" by other satellites for useable components. DARPA's Phoenix program could create new technology to enable harvesting of some valuable components from satellites in so-called "graveyard" orbits. The program would work to devise nano-satellites that would be cheaper to launch, and that could essentially complete their own construction by latching onto an existing satellite in the graveyard orbit and using the parts it needs.

Self-Destructing Janitor Satellites: Swiss researchers at the Federal Institute of Technology devised a small satellite, called CleanSpace One, which could find and then grab onto space junk with jellyfish-like tentacles. The device would then plummet back towards Earth, where both the satellite and the space debris would be destroyed during the heat and friction of re-entry.

Giant Lasers: Using high-powered pulsed lasers based on Earth to create plasma jets on space debris could cause them to slow down slightly and to then re-enter and either burn up in the atmosphere or fall into the oceans. The method is called Laser Orbital Debris Removal (LODR) and it wouldn't require new technology to be developed - it would use laser technology that has been around for 15 years. It would be relatively cheap, and readily available. The biggest hitch, other than adding more litter to the oceans, is the estimated $1 million per object price tag.

Space Balloons: The Gossamer Orbit Lowering Device, or GOLD system, uses an ultra-thin balloon (thinner than a plastic sandwich bag), which is inflated with gas to the size of a football field and then attached to large pieces of space debris. The GOLD balloon will increase the drag of objects enough so that the space junk will enter the earth's atmosphere and burn up. If the system works, it could speed up the re-entry of some objects from a couple hundred years to just a few months.

Wall of Water: Another idea for cleaning up space junk, from James Hollopeter of GIT Satellite, is to launch rockets full of water into space. The rockets would release their payload to create a wall of water that orbiting junk would bump into, slow down, and fall out of orbit. The Ballistic Orbital Removal System is said to be able to be put into action inexpensively, by launching water on decommissioned missiles.

Space Pods: Russia's space corporation, Energia, is planning to build a space pod to knock junk out of orbit and back down to earth. The pod is said to use a nuclear power core to keep it fueled for about 15 years as it orbits the earth, knocking defunct satellites out of orbit. The debris would either burn up in the atmosphere or drop into the ocean. It is claimed to clean up the space around Earth in just ten years, by collecting around 600 dead satellites (all on the same geosynchronous orbit) and them sinking them into the ocean.

Tungsten Microdust: In theory, tons of tungsten microdust put into low earth orbit, on a trajectory opposite that of the targeted space junk, would be enough to slow smaller space debris (with dimensions under 10 cm). The slowed debris would then decay into a lower orbit, where it could be expected to fall into earth's atmosphere within a couple of decades, not the hundreds of years which the debris could remain in orbit at their current altitudes. The biggest problem with this idea is the possible health issue of tungsten entering the atmosphere - tungsten compounds have been associated with stillbirths and abnormal musculoskeletal development in some studies.

Sticky Booms: Altius Space Machines is currently developing a robotic arm system it calls a 'sticky boom', which can extend up to 100 meters, and uses electro-adhesion to induce electrostatic charges onto any material (metal, plastics, glass, even asteroids) it comes into contact with, and then clamp onto the object because of the difference in charges. The sticky boom can attach to any space object, even if it was not designed to be grappled by a robotic arm. The sticky boom could be used to latch onto space debris for disposal.

V. CONCLUSION

The space around our planet is filled with rubbish. It's time to take out the trash! Space debris is emerging one of the main threats for an affordable and safe space exploration and exploitation. Proposed space junk cleanup concepts could potentially help to clear some of the debris which is currently littering the area around Earth, but many of them still have one major drawback - they tend to focus on getting the junk to come back to Earth to land in our oceans, which have enough problems without the added debris. We're still waiting for a decent solution to space junk that not only cleans up the debris, but which also disposes of it in a mindful and environmentally friendly way.

GLOSSARY

Low Earth Orbit (LEO): orbit with a mean altitude of less than 2000 km.

Sun-Synchronous Orbit: retrograde LEO orbit in which the orbit plane processes at the same rate the Earth revolves around the Sun. A spacecraft in SSO experiences the same ground lighting conditions each day; this can be useful for Earth observation missions.

High Earth Orbit (HEO): any Earth orbit with a mean altitude greater than 2000 km. Circular Semisynchronous Orbit — circular orbit (such as that used by the Global Positioning System) with a period of about 12 hours. The mean altitude of such an orbit is approximately 20,200 km.

Highly Elliptical Orbit: orbit with an eccentricity of greater than 0.5, including GTO and the Molniya orbits.

Geostationary Transfer Orbit (GTO): elliptical orbit with an apogee around GEO and a perigee in LEO. This orbit is used to transfer spacecraft from LEO to GEO. The rocket bodies used to accomplish this transfer often remain in this orbit after the spacecraft separates and circularizes its orbit using an apogee kick motor.

Molniya Orbit: highly elliptical orbit with an inclination of 63-65 degrees, a period of about 12 hours, and an apogee above the Northern Hemisphere. Molniya orbits have historically been used to provide communications and early-warning services; they are suited to this task because spacecraft in Molniya orbits spend most of their time above the middle latitudes of the Northern Hemisphere.

Geostationary Earth Orbit: nearly circular orbit with a period of approximately 1,436 minutes and an inclination close to zero degrees. In such an orbit, the satellite maintains a relatively stable position directly above the equator, at a mean altitude of approximately 35,785 km. In practice, "geostationary" satellites exhibit small orbital eccentricities and slight inclinations, resulting in an apparent wobble about a fixed location.

Geosynchronous Earth Orbit (GEO) — roughly circular orbit with any inclination and a period of approximately 1,436 minutes. The ground tracks of inclined geosynchronous satellites follow a figure eight-shaped pattern, completing a full circuit once a day, with the center of the figure eight fixed directly above the equator at an altitude of 35,785 km.

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