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THE SEARCH TO FIND THE EFFECTIVE MEANS OF CLEANING SPACE DEBRIS: A COMPARATIVE CASE STUDY OF ELSA-D, CLEARSPACE1 AND REMOVEDEBRIS

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ABSTRACT

This paper discusses the challenge faced by the generation and accumulation of debris in space. It explores the causes that lead to the creation of space debris, prominent events that have generated the maximum space debris as well as the top scientific endeavors to solve the crisis. Specifically, the paper explores the cleaning missions ELSA-D, ClearSpace1 and RemoveDebris.

Keywords: Space Debris, Debris Cleaning, ELSA-D, ClearSpace1, RemoveDebris

Introduction

Space debris consists of both natural meteoroids and artificial (human-made) orbital debris. Meteoroids are in orbit about the sun, while most artificial debris is in orbit about the Earth. Orbital debris is any human-made object in orbit about the Earth that no longer serves a useful function. Such debris includes worn out spacecraft, abandoned launch vehicles, and mission-related debris. Space debris began to accumulate in Earth orbit after the first launch of an artificial satellite Sputnik 1 in October 1957. But even before that, beside natural ejecta from Earth, humans might have produced ejecta that became space debris, as in the August 1957 Pascal B test. On July 24, 1996, in the first collision between an operational satellite and a piece of space debris, a fragment from the upper stage of a European Ariane rocket collided with Cerise, a French microsatellite which formed a lot of debris.

Rocket explosions account for 7 of the top 10 debris-creating events. Human presence also creates debris like cameras, pliers, an astronaut's glove, a spatula, even a tool bag lost during space walks. Some space junk results from collisions in orbit. When two satellites collide, they can smash apart into thousands of new pieces, creating lots of new debris. With a limited

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lifetimes, operational satellites can become space debris. Other reasons can be that Satellites run out of maneuvering fuel, batteries wear out, solar panels degrade. Several countries like the USA, China and India have used missiles for blowing up their own satellites creating thousands of pieces of space debris.

It can travel upto 17,500 mph, which is fast enough for small pieces of debris to damage a satellite or a spacecraft. There are half a million pieces of debris the size of a marble and approximately 100 million pieces of debris about .04 inches. Even tiny paint flecks can damage a spacecraft when traveling at these velocities. A number of space shuttle windows were replaced because of damage caused by material that was considered to be pieces of paint flecks. In fact, millimeter-sized orbital debris pose the highest risk to robotic scientific exploration in the lower orbit.

Prominent Debris Crisis

The worst space-debris event took place on January 11, 2007, when the Chinese military destroyed the Fengyun-1C weather satellite in a test, creating more than 3,000 fragments which is equivalent to around 20% of space debris. Within three years fragments had spread out from Fengyun-1C's original orbit to form a cloud of debris that revolved around Earth and would not enter the orbit for another hundred years.

On January 22, 2013, the Russian laser-ranging satellite BLITS (Ball Lens in the Space) experienced a sudden change in its orbit, which caused scientists to abandon the mission. The reason was believed to be a collision with a fragment of Fengyun-1C.

Debris and the Threat it Poses

Given the high speed at which debris moves in space, even the smallest fragments can cause significant damage to a spacecraft or satellite. The amount of space debris is harmful for both crewed as well as uncrewed spacecraft. Debris flux in the Earth's orbit can hinder scientific exploration as well as prompt changes to designs of satellites. Debris present in orbits below 600 km normally fall back to Earth within a few years. The space debris present in the lower orbits can cause an increase in the amount of carbon dioxide which will result in global warming. Debris near the ISS orbits the Earth 15 to 16 times a day, increasing the risk of collision.

There are estimated to be over 128 million pieces of debris smaller than 1 cm (0.39 in) as of January 2019. There are approximately 900,000 pieces from 1 to 10 cm. The current count of large debris 10cm or larger) is 34,000.The European Space Agency (ESA) estimates the total mass of all space objects in Earth orbit weighs more than 9,600 tonnes. There are approximately 23,000 pieces of debris larger than a football orbiting the Earth. There are about a trillion pieces

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which are less than 1mm in size. There are 3000 dead satellites in the Earth's orbit.

To avoid the generation of more debris, space agencies ensure that fuel gets burned up and nothing is left which can explode late and result in debris creation. Precautionarily, satellites which are going to finish the mission are released from the geostationary orbits into the graveyard orbit which is 300 km higher.

In September 2019, the European Space Agency performed its first satellite maneuver to avoid colliding with a mega constellation. Such maneuvers are extremely rare but very important.

Case Study: The Remove Debris Platform

The RemoveDebris platform, developed by Surrey Satellite Technology Ltd, consists of low Earth orbit spacecraft avionics systems and structural designs called the X50 series. The platform is based on four side panels, a payload panel, and a separation panel. The X50 series platform is built on 30 years of experience and success in SSTL of breaking low cost barriers and delivering operational level performance in small satellite packages. Developing the net technology took around six years of many tests in drop towers, during parabolic flights, as well as in thermal vacuum chambers. The spacecraft features three Airbus technologies: a net and a harpoon to capture debris, as well as a Vision Based Navigation (VBN) system to corroborate with the debris-tracking techniques in orbit with cameras.

This mission is aimed to perform active debris removal technology demonstrations in order to discover a method to capture the 40,000 pieces of space debris orbiting the Earth. Mission comprises a main satellite of 100kg launched to the ISS by a spaceX rocket and deployed by the NanoRacks Kaber system into orbit. When it reaches, it will perform a series of experiments to catch debris. It was launched in 2018.

The mission was scheduled for 1.5 years however it took 3 years 8 months to be completed.

- Week 1 to 6: Docking and transfer to ISS, payload preparation on ISS.
- Week 6 to 16: RemoveDEBRIS deployment from ISS and commissioning.
- Week 16 to 20: Demo and data download, VBN demo and data download, harpoon demo and data download, drag sail demo.
- Week 20 to one and half years: Passivation, de-orbiting and re-entry to end the mission.

The RemoveDebris experiment cost roughly $18 million and was funded by the European Commission and the groups involved in the project. This is a relatively cost effective sum as far

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as space travel is concerned. The mission started late in 2014 and was sponsored by a grant from the EC.

The RemoveDebris mission has been the world's first Active Debris Removal (ADR) mission to successfully demonstrate, in orbit, some cost effective technologies like net and harpoon capture. The mission has also been successful in bringing various institutions together to tackle a global issue, from large to small companies, universities and research centers. The mission consists of the world’s first 100 kg satellite to be launched from the ISS.

The relative perturbations must be considered when flying in lower Earth orbit as the relative drag effects can be critical when the different orbited spacecraft have dissymmetric structure or design. The mission baseline was revised to take into account feedback from international and national space policy in terms of risk and a potential launch option was found: deployment from the ISS. The RemoveDebris satellite was shipped in a launch box. The launch box serves two purposes: Protect spacecraft during shipping, launch, and handling at the ISS and to Protect astronauts from sharp edges during handling aboard the ISS.

Case Study: ELSA-D

ELSA-d is the world’s first commercial mission. The mission consists of two satellites — a servicer to remove debris from orbit and a client that serves as a piece of replica debris. The first demonstration, where the servicer released the client and performed magnetic docking, was completed on August 25, 2021, validating the capture system, on-board sensors and cameras. Astroscale developed a ”Chaser” minisatellite of 180 kg in its office in Tokyo. In addition, SSTL provided the ”Target” microsatellite of 20 kg. The mission is divided into 7 phases. Between demonstration phases, when the chaser and target are docked, they can enter a routine phase which is power and thermal safe. The phases were designed to increase in complexity provided that less risky demonstrations were attempted first.

The full duration of the ELSA-D mission is expected to last up to 6 months, including non-demonstration period. The first demonstration was launched into a 550 KM orbit from the Baikonur Cosmodrome in Kazakhstan in March 2021 in which the servicer released the client and manually performed magnetic docking was completed on August 25, 2021.

Phases of the Mission

- Phase 1 to 2: Launch and Commissioning. The chaser and target are launched together into the operational orbit of roughly 550 km.The chaser undergoes authorization and The target isactivated using the TAU (Target Activation Unit)

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- Phase 3: Capture without Tumbling A TSM (Target Separation Mechanism) holds the target and chaser together during launch and phase 3 is the first time the target is separated. After separation, the magnetic capture system is used to repeatedly capture and release the target, thus TSM's use is terminated. The majority of the target commissioning has already been completed, so any remaining commissioning is performed.

- Phase 4: Capture with Tumbling The phase also contains two sub-demonstrations - INVD and Diagnosis. INVD (Inertial Navigation Validation Demonstration) tests the full rendezvous sensor. Diagnosis is a fly-around to visually check the target. Diagnosis simulates and images of the target are taken and downloaded for operator inspection before capturing it. After these two demonstrations, tumbling capture is performed.

- Phase 5: Relative Navigation Demonstration The chaser separates and thrusts away from the target until its sensors lose the target which is decently far from it. The chaser moves into a safety ellipse, simulating first approach to the target as in a full service mission.

- Phase 6 to 7: Re-orbit and Passivation In the final phase, the chaser performs a re-orbit maneuver to reduce the altitude of the target. At a lower altitude, the craft is passivated. Both chaser and target undergo unsupervised and uncontrolled burning re-entry into the orbit.

Total financing of ELSA-D has been $191 million to date. Astroscale's latest fundraising came from a group led by venture fund a START, joined by investors Hulic, I-NET, SHIMIZU Corp and SPARX Space Frontier Fund.

Mission operations for an Autonomous Capture demonstration began on January 25. After release of the client from the servicer's magnetic capture system, the servicer successfully maintained a distance of 30 meters from the client through the use of autonomous relative station-keeping algorithms.

On April 7, using limited thrusters, the servicer successfully maneuvered to a distance of 159 meters from the client, and the ability of the servicer to detect the client was validated. This has been the most challenging part of the ELSA-D mission so far .

As an appreciation of their ability and success, ELSA-D has received numerous awards for ensuring space sustainability and on-orbit servicing, including the Via Satellite 2021 Satellite Technology of the Year and the Minister of State for Space Policy Award, given by the Cabinet Office, Government of Japan.

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The biggest challenge of the autonomous demonstration was replanning the rendezvous approach with the use of only four of the eight thrusters on the servicer. This limited the ability of the servicer to maneuver as it was originally planned.

The company has been unable to fix some technical issues affecting four malfunctioning 1-newton High Performance Green Propulsion (1N HPGP) thrusters. However, Astroscale said the company detected an anomaly after the servicer began “autonomous relative navigation, maintaining a constant and safe distance from the client spacecraft over multiple orbits''. For safety of the satellite, they paused the mission till they fixed that anomaly.

Case Study: ESA ClearSpace-1

ClearSpace-1 will be the first space mission to remove an item of debris from orbit, planned for launch in 2025. The mission is obtained as a service contract with a startup-led commercial consortium, to initiate a new market for in-orbit servicing, as well as debris removal. The ClearSpace-1 mission will target the Vespa (Vega Secondary Payload Adapter) upper stage left at approximately 800 km orbit after the second flight of ESA’s Vega launcher back in 2013. With a mass of 112 kg, the Vespa is close in size to a small satellite. If everything works accordingly, the team can use the same technology to capture much larger pieces of space debris in future missions. The team plans to first test ClearSpace-1 in a lower orbit of about 310 miles (500 km), before launching the mission to capture Vespa in 2025.

ClearSpace-1 will use ESA-developed robotic arm technology to capture the VESPA, then perform a controlled reentry in the atmosphere. Some technologies used will be advanced guidance, navigation and control systems and vision-based AI, allowing the chaser satellite to fit on the target by itself. ESA is also working to design technologies that will ease the removal of space debris in the future. These ‘Design for Removal’ technologies will be added to future satellites and will include 2D and 3D graphic markers, handles to capturing and radio-frequency identifiers. ESA is also contributing key technologies for flight, developed as part of the agency’s Clean Space initiative through its Active Debris Removal/ In-Orbit Servicing project, ADRIOS.

ESA estimates that the total mission will cost 117 million euros ($129 million) to operate. ESA signed a $104 million (€86 million) contract with ClearSpace to accomplish this feat. In addition to the contract with ESA, ClearSpace will rely on commercial investors to cover other important mission costs.

Clearspace’s ‘tow truck’ design will be available to clear key orbits of debris that might otherwise make them unusable for future missions, eliminating the growing risks and liabilities for their owners, and benefitting the space industry as a whole. Unlike the removeDEBRIS or

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ELSA-D mission,the method involved in capturing debris from space in this mission, will be most effective to capture and remove the larger and more ambitious targets.

The ClearSpace-1 mission, built by Swiss startup ClearSpace, will fix on a piece of debris the size of a washing machine, seize or hold it with a four-armed claw, and escort it down to a lower orbit where both of them will enter the atmosphere and burn up upon reentry. ClearSpace opted for the claw because you can have multiple attempts.

Conclusion

Space debris is an issue which requires utmost priority from nations all around the globe. It can hinder space travel and even pose risks to the aircrafts flying at a considerable altitude and also result in Kessler Syndrome - when one piece of junk creates more space debris similar to a nuclear chain reaction, further flights into space will become impossible due to uncontrolled collisions.

The three most effective ways which have been employed have been discussed in this paper. Comparison can be done for these methods in some aspects. If we consider that mobility is associated with weight, then the removeDEBRIS satellite is the smallest as well as the lightest so, the maneuvering capability and the movement will be the best. In terms of technology, all the three are relatively more advanced and complex than other satellites which are launched in space but I personally believe that removeDebris has a variety of methods to engage with the debris but if we look at the durations of the missions, then ELSA-D will prove to be the fastest method employable in the current scenario to remove debris. ClearSpace1 is yet to commence, however, the developers of the mission aim to capture debris of a considerable size which has not been captured yet.

Effectiveness of the missions is something that can be ascertained only after the launch of ClearSpace1 and its success. The efficacy of all missions is something that future researchers can explore to identify the most potent way of solving the issue of space debris. It is imperative that the global scientific community collaborate over this issue to ensure that space debris does not cause long term environmental and other concerns.

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