A Study On Space Debris

Source and Mitigation process

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***Abstract*— With very first launch of artificial satellite in earth's orbit on 4th October 1957, each successive space exploration program has added debris in earth's orbit. Although the earlier space agencies understood about the need to avoid addition of debris in earth's orbit and started making guidelines regarding it but the amount of debris still rose as the earth's orbit was started to be used for commercial and research purposes. This paper gives a short study on some of the sources of space debris and some of their mitigation measures and removal methods as mentioned by some international space agencies also giving a brief stat on number of debris present in the earth's orbit as of January 2017.**

Keywords—Space Debris; Low Earth Orbit (LEO); Geostationary Earth Orbit (GEO); deorbit; Robotic arm; Electrified Thether; Sail suicide;

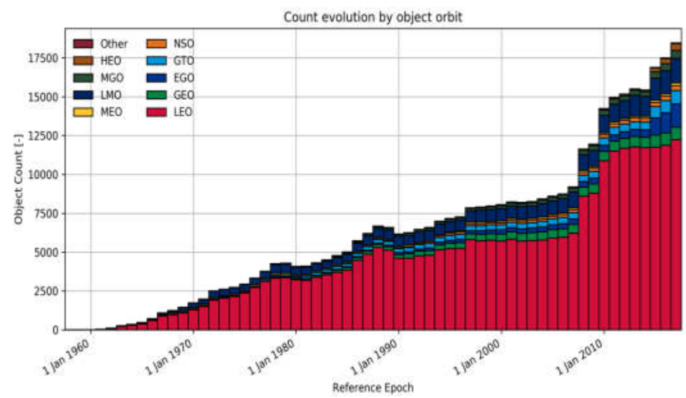
I. INTRODUCTION

Space Debris (Also referred as Orbital Debris) is an expression referred to unwanted and non-functional earth-orbiting objects originated from non-functional satellite, collisions, left upper stages of rocket, corrosion of surface of satellite etc and possess threats to current and future space programs.

II. CURRENT DEBRIS STATS

As to January 2017, there had been about 5250 rocket launches having placed about 7500 satellites in orbits of which there are 4300 satellites still up there orbiting the earth and only about 1200 of it is active and functioning [1]. Using statistical models, its estimated that there are nearly 29000 objects in space having size greater than 10 cm, 750 000 objects of size between 1 cm to 10 cm and nearly 166 million objects of size between 1 mm to 1 cm.

Currently, the JSpOC (Joint Space Operations Centre) tracks more than 16,000 objects orbiting Earth. Of all the earth orbiting object 95 percentage are debris and only 5 percent is active and functional payloads [2]. US Space Surveillance agency can track objects as small as 5 cm to 10cm in LEO and 0.3m to 1m in GEO.



Trackable Space Debris Distribution over time.[Courtesy : ESA]

III. SOURCES OF SPACE DEBRIS

The satellites which are either offline or dead or have completed their operational life are space debris now. The satellites which are positioned at altitude less than 600 km plunge into atmosphere in several years while those at 800 km takes decades and those beyond 1000 km have lifetime of centuries. Vanguard 1, the fourth artificial satellite launched in 1958 which was placed in orbit of 658 km by 3969 km has a lifetime of 240 years in earth's orbit. While the satellite in Geostationary Earth Orbit (GEO) are moved to Graveyard orbit at the end of its operational life. The satellites in graveyard orbit has orbital lifetime of thousands of years and beyond and don't changes its orbit much.

The exhaust from the engines remains in the orbit for weeks. They can be in form aluminum oxide from solid rocket engines whose size ranges from 1 to 10 microns. Centimeter sized aluminum slag also released from engines acts as debris. The small portion of propellant mass ejected during the end of engine burn. These particles remain in space for longer time.

The rocket stages are at times left in LEO or boosted towards parking orbit. They stay there in the orbit for quite long time. During normal payload deployment, various hardware like protective shields, fasteners, yaw and yo-yo weights, nozzle covers, lens caps, multiple payload mechanisms and others are discarded into orbits. As the stage separation and heat shield fairings use explosive bolts which disintegrate into particles and spreads in the orbits.

Various in orbit explosions adds up very large amount of debris. Its estimated that nearly 750000 fragments of size greater than 1 cm has been formed due to in orbit explosions. Its caused either due to meteoroids colliding with orbiting objects or explosion of leftover fuel in tanks and fuel lines of upper stages or satellites or spacecraft. The harsh condition of space weakens the mechanical integrity which results in leakages of this fuel and resulting in explosion or solar exposure increases the pressure in fuel tanks resulting in explosion. Also, overcharged batteries explode over time.

Antisatellite test from 1960 to 1990 by US and Soviet Union added a lot of debris. By 1990, 12 such tests were conducted. Even later China fired ballistic missile to destroy its weather satellite, FengYun 1C, in 2007. This event alone increased trackable objects by 25 %. Deliberate destruction of satellites has added lot of debris and over large space.

Even space debris have lost items from International Space Station (ISS) like a glove lost by Ed White, a camera lost by Michael Collins and by Sunita Williams, a thermal blanket lost from STS 88. Even toothpaste and wrench had been lost into space.

Another major incident took place in 1980 when 16 Russian RORSATs (Radar Ocean Reconnaissance Satellites) has lost their Sodium Potassium coolant Na-K during ejection for re-orbiting. Total of 50 kg coolant with population of 60,000 of size 6 mm to 4.5 cm got spread over 700 km to 950 km orbit.

A major side effect of debris was visible in February 2009 when an inactive Russian satellite Cosmos 2251 collided with Iridium. They collided at altitude of 776 km at the relative velocity of 11.6 km/s and added more than 1600 catalogued fragments. As per report of 2010, nearly 20 percent of the debris will remain in that orbit for 30 years and 70 percent would drop down to the level of ISS by 2030.

IV. DANGERS AND HAZARDS POSED BY SPACE DEBRIS

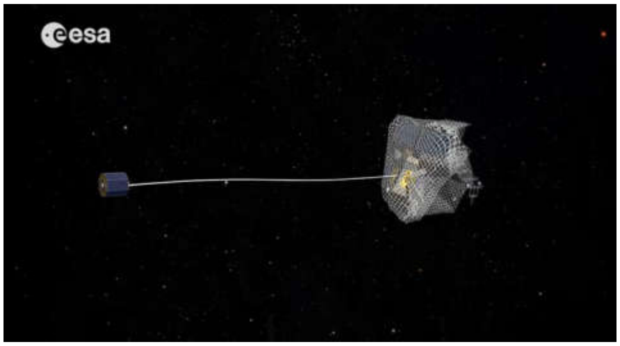
Space debris just float around in the earth's orbit without purpose and possess threats to operational satellites and other space exploration mission. US Space Surveillance tracks large debris and performs necessary maneuvers in its satellites, ISS, Hubble Space Telescope, and other functional spacecraft to avoid collision. Even a paint fleck of size 1 cm can cause devastating effect upon collision. The average relative velocity of objects in LEO is 8 to 10 km/s. the density of space debris in LEO is very high, being highest between 800 km to 1000 km. There is certain concentration at 1400 km. Spatial densities in GEO and some near navigation satellite. The problem is when a piece of debris of size 1 cm strikes a satellite, it has a collision impact equivalent to that of a hand grenade. A 10 cm projectile can produce impact energy equivalent to 7 kg of TNTs. ISS which is a space hub and astronaut life would be in danger if any collision occurs. A single collision adds up more and more debris which increases the chance of another collision. This is very well known as Kessler Syndrome named after Donald Kessler. It states that collisions add more debris and creates a runaway chain reaction of collisions and adding more debris. He stated demonstrated that when the amount of debris increases a critical mass, a single collision can start such cascading effect even though no more satellites are sent. If the number of debris in the earth's orbit increases, space exploration will suffer a lot and space around earth will become useless. Debris in LEO below 800 km will plunge into atmosphere in few decades but debris in GEO will remain there for centuries. Even after thousands and millions of years these debris will remain in orbit and will form a ring like structure around earth like those around Saturn.

V. REMOVAL OF SPACE DEBRIS

Various ideas have been proposed regarding removal of space debris and some are being prepared to be tested. Currently the only feasible and best way of debris removal is de-orbiting the debris which would burn in the earth's atmosphere upon reentry due friction from the atmosphere. But its only possible for debris in LEO. It can be obtained by following methods:

1. Large bodies such as boosters or dead satellite can be caught by a satellite using giant nets or robotic arms. The active satellite will follow its target and capture it with a robotic arm or giant net, and then slow down its speed or decay its orbit so that the debris burn up in the atmosphere upon reentry. This idea is upon development phase by European Space Agency (ESA) and will be tested in 2023.

Robotic Arm [Courtesy: ESA]



Giant Net [Courtesy: ESA]

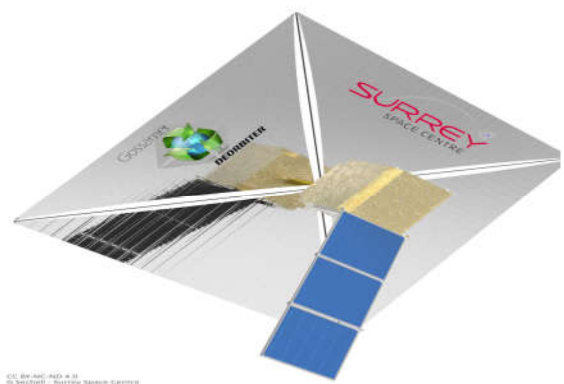
2. JAXA has proposed the idea of Electrified Tethered made of aluminum and stainless steel to slow the orbital velocity of the target debris. The active satellite will attach a long tether to its target which could be as long as 4 to 6 football fields. Since the tether is electrified, drag will be created because of earth's magnetic field and the orbital velocity will decay and debris could be burnt upon reentry.

Electrified Tethered [Courtesy: JAXA]

3. Sling shot is another proposed idea wherein a satellite with two capturing structure which will capture the debris and will hold it for some time and then throws the debris into a reentry orbit using its propulsion.

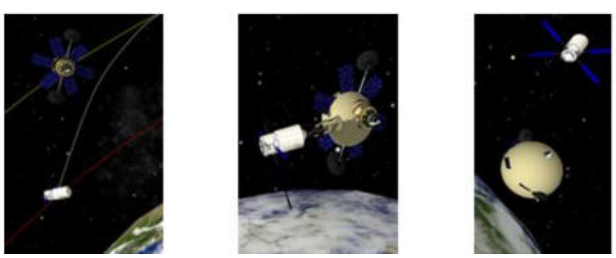
4. Lasers from earth can be used to slow down the target in space resulting in its orbital decay and finally plunging into the earth's atmosphere.

5. Sail suicide is a way to increase aerodynamic drag by deploying sheet of large dimension at the end of the operational satellite. This sheet will remain attached to the satellite and will decrease the time of orbital decay. Also, a satellite can be launched and it can place sail suicide on the debris floating in space and will in faster decay of the debris.



Sail Suicide [Courtesy : Survey Space Centre]

6. Expanding foam idea proposed deals with idea of drag augmentation method wherein target or a part of target will be covered with foam which will then increase in volume due to low pressure outside it. This will increase the surface area of the target and will finally plunge it in the atmosphere [6].



Representation of the foam augmentation method: target debris interception (left), foaming process (centre), debris deorbiting (right) [6]

7. Another idea which is proposed here is using a large cylindrical spacecraft which will be hollow from front having very large diameter with nets attached in it. As above methods cannot remove smaller debris, this method can be useful of capturing debris which are small. This spacecraft will be maneuvered to high density space debris area. The spacecraft will capture the debris in its mouth whilst it follows them. Thereafter debris can be segregated based on their sizes as they will pass through different layers of net having different hole sizes. The net at mouth of the spacecraft will have large holes and the one at the end will be thick elastic sheets or a very fine net to capture very small debris. Then the collected debris along with its nets can be directed to burn in the earth's atmosphere using small rocket engine or sail suicide or can be brought back to earth for recycling. Thereafter new layer of nets can be deployed to continue the cleaning process. To prevent the damage of ship, its vulnerable parts or exposed parts can be made of whipple shield to prevent any collision damage from small debris.

To keep the GEO clean, satellites can be moved to graveyard orbit which is 300 km above Geosynchronous Earth Orbit where they will stay for very long time.

VI. REDUCTION IN ADDITION OF DEBRIS

Certain methods must be implemented to avoid adding anymore debris. Satellites which will be sent now can be installed with sail suicides to drop its orbit and plunge into atmosphere after the end of operational life for those in LEO. Whilst satellite at higher orbit should be propelled to graveyard orbit just after the end of its operational orbit and leave the useful orbit free to be used again.

Steps must be taken to make the energy sources in the satellite such as fuel tanks, pipelines, batteries etc. passive. So, that no in orbit explosion takes place after the satellite is decommissioned.

Normal launch sequence also adds a lot of debris and steps must be taken so that launch be clean without any debris addition. This can be done by taking following steps in mind like:

- Any detachable parts of the rocket should be kept intact even after their purpose is competed. Like engine cover, lens cap etc. should not be left free even after their purpose is served instead
- Upper stage of rocket must not be left in orbit instead it should be ignited and placed into reentry orbit so that it burns upon reentry in earth's atmosphere.
- Also, the heat shield separation should use high pressure nitrogen gas to rupture the shied to separate heat shield instead of using explosives bolts.

VII. CONCLUSION

To continue the future space exploration, all the space agency on the globe should work together to reduce space debris. Strict measures and rules must be implemented on the normal launch sequence to avoid addition of debris. And the satellite must be discarded properly to avoid any interference with future space exploration or current active satellites.

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