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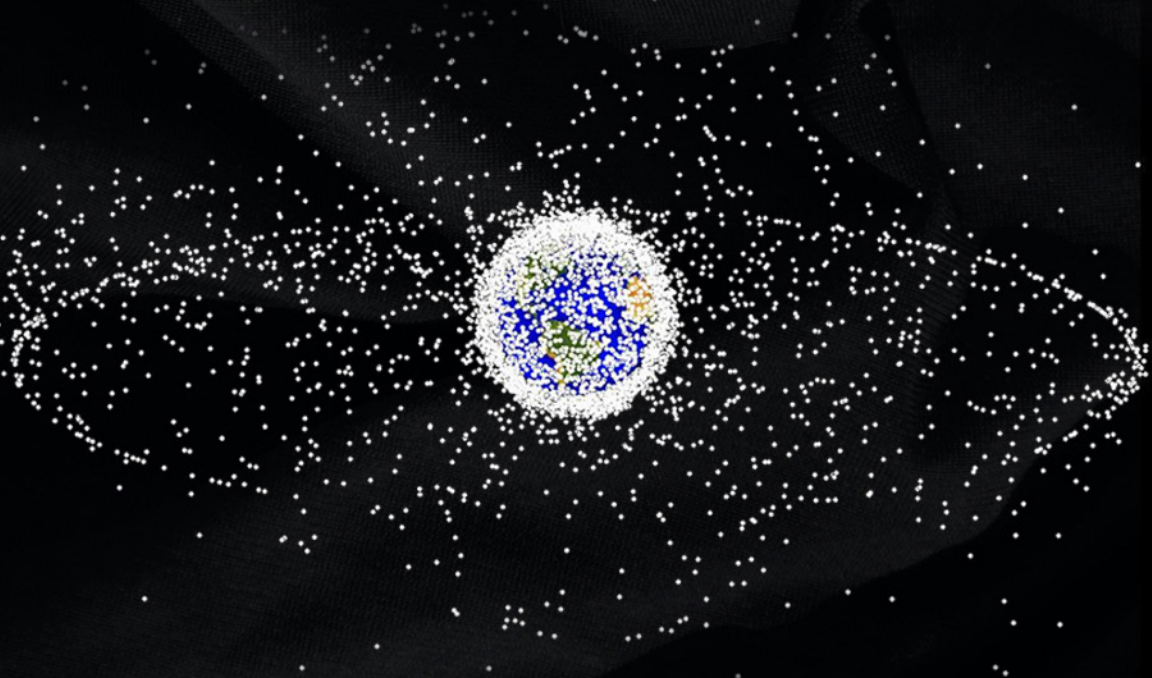
Winning the War Against Space Debris

An International Imperative



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Winning the War Against Space Debris: An International Imperative

Preamble

The scientific community across the world was elated to hear about the success of the satellite being launched in 1957. This provided them with a platform in space which could be used for multiple tasks that would benefit society and humanity. For almost two decades, this platform was exploited for a number of experiments and services like communications and earth observation were engineered. Demand for orbital slots also shot up resulting in congestion.

This was also the period when maximum trash was generated and thrown in space. Some of the low altitude objects entered the atmosphere and got burnt. Others at higher altitude are still orbiting the earth. They are called debris or space junk. Hazards of space junk became abundantly clear in 1978, when the nuclear-powered Soviet satellite Cosmos 954 plummeted to Earth, scattering potentially radioactive debris across the Northwest Territories. The first accidently in-orbit collision between two satellites happened on 10 February 2009 at 776 km altitude. A US privately owned communications satellite, Iridium 33, and a Russian Strela-2M military communications satellite, Cosmos 2251, collided.

Background

Since the dawn of the space age in 1957, 80 countries and intergovernmental organizations have launched more than 9,000 objects into space — with 800 in just the past year. While the benefits of this explosive rise in space-based ventures are many (better communications, scientific advancements and stronger national security, to name a few), there are drawbacks as well. The more congested space is, the more contested it becomes and therefore it throws up more challenges for both national and global security.

Over the sixty years of space activities, some 6,600 satellites have been placed in orbit of which about 1,100 are still operating. Most of these are still orbiting, though they either have completed their mission or have become defective. There is an exceedingly high probability that these defunct objects have collided or will collide and split into thousands of smaller objects called 'Debris'. Some of those would have burnt on entering the earth's atmosphere. This is a cumulative process resulting in crowding of the space in no time.

How long an object will take to fall back to Earth depends on its altitude. Objects below 600 km (375 miles) orbit several years before re-entering the Earth's atmosphere. Objects above 1,000 km (600 miles) orbit for centuries.

Debris' Definition

"Space debris are all man-made objects, including their fragments and parts, whether their owners can be identified or not, in Earth orbit or re-entering the dense layers of the atmosphere that are non-functional with no reasonable expectation of their being able to assume or resume their intended-functions or any other functions for which they are or can be authorized" (Technical Report on Space Debris in 1999 by UN/COPUOS/STSC).

The definition emphasises two things to remember, "all manmade objects" and "non-functional". This means that space debris can be anything, from a little screw to an entire derelict satellite. Most of the satellites are used until they are non-functional. From that moment, the satellite becomes a space junk orbiting around the Earth, and no more action can be performed by it. Not even to avoid another debris! Generated by on-orbit satellite collisions, these debris (space junk) present man-made threats. This threat is unlike those coming from the counterspace weapons which press belligerence in a progressive manner. Much of the debris is in low Earth orbit, within 2,000 km (1,200 miles) of Earth's surface; however, some debris can also be found in geostationary orbit 35,786 km (22,236 miles) above the equator.

The European Space Agency (ESA) estimates there are currently 128 million pieces of debris smaller than 1cm, about 900,000 pieces of debris 1–10 cm in length, and around 34,000 pieces larger than 10 cm in Earth orbit. More than 20,000 such objects are tracked by the US Space Surveillance Network. Damage assessment due to collisions is estimated as follows:-

- Less than 5 mm, the impact may be absorbed by the cladding.
- 5 to 15 mm, debris would damage the satellite.
- Greater than 15mm, debris would destroy the satellite.

As Earth's orbit gets more and more congested, the space trash become more likely to crash, and collisions can send new clouds of metal chunks careening around the planet. Referred to as the Kessler Effect/ Syndrome, such collisions over time could create a thick belt of debris that, in a worst-case scenario, may cut off access to outer space.

The Situation

The crash of Cosmos 954 (Russia) in 1978 and collision of Iridium 33 (US) and Strela-2M (Russia) has been mentioned above. In recent times, we have seen several near collisions in space. In late January 2020, we all watched helplessly as two much larger "dead" satellites – IRAS and GGSE-4 – passed within metres of each other and exploded. Later, a defunct Soviet satellite and an old Chinese rocket body passed alarmingly close together. Since nobody could control either spacecraft, there was no way to prevent a collision. Luckily, the objects did not crash. But if they had, astronomer Jonathan McDowell calculated it would have produced an explosion equivalent to detonating 14 metric tons of TNT and sent chunks of spacecraft rocketing all over.

The intentional destruction of the Fengyun-1C weather satellite by China in 2007 and the accidental collision in 2009 between two communications satellites, (the operational American Iridium-33 and the decommissioned Russian Cosmos 2251) greatly increased the number of large debris in lower earth orbit. Cosmos-2251 was a 950-kilogram military communications satellite launched in 1993. Iridium 33 was a 560-kilogram commercial communications satellite, part of the Iridium constellation. The collision happened at a speed of 42,120 km/h at an altitude of 789 km above Siberia. The U.S. Space Surveillance Network catalogued over 2000 large debris. These now represent, according to NASA, one-third of all catalogued orbital debris.

Fragmentation

Fragmentation events describe moments in which debris is created due to collisions, explosions, electrical problems and even just the detachment of objects due to the harsh conditions in space. The first recorded fragmentation is dated back to 1961 when the US Ablestar upper stage exploded in an orbit 800 by 1000 kms releasing nearly 300 large fragments and increasing the total orbital debris by 400 percent. In 2021, sixty years after the event, 60 percent of the debris is still in the earth orbit due to the height of the event. On average over the last two decades, 12 accidentals 'fragmentations' have occurred in space every year – and this trend is unfortunately increasing.

Emerging Scenario

Space is recognised as a separate domain which is very congested and contested. Till recently, the main users were the Governments and the

Defence Services. But now the Private Sector has come in very strongly. This has given a new perspective to both, exploitation of space and its security.

This decade is likely to see exponential rise in the exploitation of space for provision of numerous services, security, and capabilities, thanks to the developments in technology, entry of the private sector, defence projects and social pressure for better life on earth. It is estimated that more than ten thousand satellites would be placed in low earth orbits in the current decade. This figure is likely to be around 25 to 30 thousand in the following decade. Satellite systems would undergo complete transformation. They would be more resilient and be cheaper, smaller, and lighter. Developed nations are likely to compete and look for 'first person' advantage in resource generation, technology, and security. The pressure will be to reduce cost and share technologies for mitigation of orbital debris. Security of space assets and infrastructure would be top priority. World class training establishment and R&D laboratories would come up. Emphasis will be on producing highly skilled human resource.

Threat landscape will change drastically in consonance with the emerging geo-political scenario. China and USA may get involved in space race. The satellite design process will change to address man-made and counterspace threats in a broader context of securing spacecraft survivability in space. Guidelines for mitigation of debris would be enhanced and an appropriate legal framework put in place to ensure their compliance.

UN may have dedicated organisation for monitoring and policy formulation for matters related to space sustainability. To ensure security and availability, satellites will be deployed as constellations. Launch of multiple pay loads in a single rocket will become a preferred choice. Inter-planetary movement will increase with emphasis on Moon and Mars missions. Space tourism will become more affordable and would increase manifold. Intense competition amongst developed space faring nations is likely both in establishing space system infrastructure and providing services.

Counter-space activities, development of anti-satellite (ASAT) weapons and Ballistic Missile Defence (BMD) are likely to take priority. Cyber capability has emerged as an extremely potent weapon that presents exceedingly high threat to the space assets and infrastructure with high probability of collisions.

The Challenge

The future of humanity is inextricably tied to our ability to ensure a viable long-term future for space activities. The requirement is to develop technologies, processes, organisation, and legal framework for removal of debris and to find ways to co-exist with our planet and promote the ongoing safety, security and sustainability. The challenge is to make them internationally acceptable and enforceable.

It appears that we are at the threshold of a new epoch in which environmental preservation of outer space has taken on a new meaning and sense of urgency not only for purposes of protecting valuable space assets in the short term, but also to ensure the continued sustainability of space activities in the long term. In view of the constant increase in space-traffic, we need to develop and provide technologies to make debris prevention measures fail-safe.

Technologies

Recent events and the absolute necessity of satellites for development and provision of daily needs have caused increased awareness amongst people on the threat posed by the orbital debris and have heightened the concerns of the space technology threshold being crossed by the advanced space-faring nations. Further militarisation of outer space will certainly lead to a new race for space weapon technology and space control strategies. Space faring nations are carrying out extensive research to develop technologies for mitigation of debris. Various technical concepts, means and capabilities have been developed (currently being developed or being considered) to support active debris removal and on-orbit satellite servicing activities.

Efforts to address the risks posed by orbital debris fall into two categories: mitigation and remediation. Mitigation refers to attempts to prevent future debris generation through the design, operation, and post-mission disposal of spacecraft to ensure they do not explode or collide with other objects. Remediation refers to active removal of debris, including defunct spacecraft, before it explodes, collides, or fragments in orbit. Current strategies emphasize debris mitigation, as there is no practical method for debris removal.

Raytheon BBN Technologies (BBN) and the University of Michigan are studying 'Space Debris Elimination (SpaDE) System' to remove debris from orbit by firing focused pulses of atmospheric gases into the path of micro and nano satellites both for restoration of facilities and as weapons to destroy satellites. These capabilities must be developed concurrently to ensure greater survivability of our space assets. ESA and NASA recommended that Active Debris Removal should be adopted as a strategy for debris mitigation, and technologies should be developed accordingly. All space faring nations have given their consent. Active Debris Removal (ADR) is necessary to stabilize the growth of space debris, but even more important is that any newly launched objects comply with post-mission disposal guidelines – especially orbital decay in less than 25 years. Passive capabilities like physical and electronic hardening; anti-jam technologies, satellite maneuverability, redundancy at system and sub-system levels; quick launch facilities, mini, micro and nano satellites both for restoration of facilities and as weapons to destroy the satellites are being developed concurrently to ensure greater survivability of space assets.

As of date there is no confirmed technology for mitigation of space debris, though a large number of ideas and concepts are being tested. The principle seems easy; capture the object, slow down and give it a push downwards to enter earth's atmosphere, and burn out. Alternatively, the object can be given a push upwards and stay in the graveyard orbit. The technologies under study fall in two main categories corresponding to whether a pushing or a pulling manoeuvre is required for the de-orbitation. The ESA is studying the option of using a tethered capture system for controlled de-orbitation through pulling where the capture is performed using throw-nets or alternatively a harpoon. The Agency is also studying rigid capture systems with a particular emphasis on tentacles (potentially combined with a robotic arm). Here the de-orbitation is achieved through a push-manoeuvre.

Technology Development Projects

We will now look at the technologies being developed under various projects. These are listed in the succeeding paragraphs:-

RemoveDEBRIS. The British satellite RemoveDebris was launched in 2018 from the International Space Station (ISS) successfully demonstrated four novel orbital debris removal technologies since its launch. The four technologies the project demonstrated were: (1) deploying a net in space to capture a specified target, (2) tracking a specified target in orbit, (3) harpooning (firing a spear-like projectile) at a specified target in space, and (4) deploying a large drag sail that will shorten the time it takes for an object to deorbit before burning up in the Earth's atmosphere. More recently, commercial, and foreign entities have made progress in developing technologies needed to perform active debris removal. For example, the DARPA study identified advanced rendezvous operations as a necessary technology for performing active debris removal, and in February 2020, Northrop Grumman's Mission Extension Vehicle-1 performed advanced rendezvous operations when it successfully docked with a commercial communication satellite that was running low on fuel. Without such intervention, operators would have lost the ability to control the satellite. Mission Extension Vehicle-1 took over maneuvering and navigation for the communication satellite, which will now be able to function for an additional 5 years, before the extension vehicle manoeuvers the satellite to an orbit clear of other active satellites.

ClearSpace-1. ESA's 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. The need is clear for a 'tow truck' to remove failed satellites from this highly trafficked region. The ClearSpace-1 'chaser' will be launched into a lower 500-km orbit for commissioning and critical tests before being raised to the target orbit for rendezvous and capture of target "vespa" using a quartet of robotic arms under ESA supervision. The combined Chaser plus Vespa will then be deorbited to burn up in the atmosphere.

Active Debris Removal / In-Orbit Servicing. The need is to develop technologies to avoid creating new debris and removing the debris already present. NASA and ESA studies show that the only way to stabilise the orbital environment is to actively remove large debris items. Consequently, ESA has commissioned a separate Project called Active Debris Removal / In-Orbit Servicing (ADRIOS) with the mission of developing technologies for guidance, navigation, control, rendezvous and capture methods. The results will be applied to ClearSpace-1. This new mission, implemented by an ESA project team, will allow them to demonstrate these technologies, achieving a world first in the process.

Space Fence. The Space Fence is a second-generation surveillance system operated by the United States Space Force in order to track artificial satellites and space debris (https://en.wikipedia.org/wiki/Earth_orbit). Space Fence, now the world's most advanced radar provides uncued detection, tracking and accurate measurement of space objects, including satellites and orbital debris, primarily in low-earth orbit (LEO). The new radar permits the detection of much smaller microsatellites and debris than current systems. It also significantly improves the timeliness with which operators can detect space events. The flexibility and sensitivity of the system also provides coverage of objects in geosynchronous orbit while maintaining the surveillance fence. Space Fence is a key contributor to USSF's Space Domain Awareness (SDA), which provides information that Space Force needs to make informed decisions and take actions to protect key assets in orbit. Space Fence reinforces the Space Surveillance Network (SSN) which tracked more than 20,000 objects. Now, the catalogue size is expected to increase significantly over time. Space Fence also detects closely spaced objects, breakups, manoeuvres and launches. According to the Space Force, the system is the most sensitive search radar in the SSN, capable of detecting objects in orbit as small as a marble in low Earth orbit (LEO).

Space Fence began proving its unmatched capabilities in 2019. During testing, the system tracked a significant number of debris from an anti-satellite test conducted by India, proving the radar's ability to automatically predict and correlate their next orbital crossing times. In March of 2020 the United States Space Force (USSF) declared operational acceptance and initial operational capability of the Space Fence radar on the Kwajalein Atoll in the Republic of the Marshall Islands.

Magnetic Satellites. A magnetic spacecraft that can attract dead satellites has entered orbit - a test in a new effort to clean up space junk. Astroscale, a Japanese company has designed a spacecraft with a magnetic plate that can attach to dead satellites – if they have the other side of the magnet. That enables it to pull the satellites into a freefall, burning up both the spacecraft and its satellite passenger in Earth's atmosphere. The first version of this technology is called the End-of-Life Services by Astroscale demonstration mission, or ELSA-d, and it was launched from Kazakhstan. The spacecraft carries a fake piece of space debris with the necessary magnetic plate built in. The plan calls for ELSA-d to release this fake debris then practice grabbing it. "This is an incredible moment, not only for our team, but for the entire satellite servicing industry, as we work towards maturing the debris-removal market and ensuring the responsible use of our orbits," said Nobu Okada, Astroscale Founder, "Let the era of space sustainability begin."

Japan Aerospace Exploration Agency (JAXA). JAXA has planned a debris removal mission for both small and large debris. In the beginning, the aim is to collect a discarded large upper stage of a Japanese rocket to prove the technology. The mission is designed to be executed in two phases, "an approach and observe" phase from 2022 to 2024 and a follow up phase, "observe, approach, capture and retrieve" from 2024 to 2026.

China: Shijian-21 Satellite Project. This is the most advanced test, success of which has placed China in a different league all together. Following tests and activities were conducted. It involved the capture of satellite Tianzhou II cargo spacecraft by a mechanical arm, docking, unlocking and separation of Tianzhu II and the core module and reverse operation. The test initially assessed the feasibility and effectiveness of using the robotic arm to operate the space station module rotation, verified the space station module rotation technology and robotic arm large load manipulation technology, and accumulated experience for the subsequent assembly and construction of the space station in orbit. Salient inputs stated that:-

- China's Shijian-21 space debris mitigation satellite docked with a defunct Chinese satellite to drastically alter its geostationary orbit, demonstrating capabilities only previously exhibited by the United States.
- According to Chinese media reports, the mechanical arm successfully captured the Tianzhou II.
- It conducted sophisticated rendezvous and proximity operations (RPO) with other objects in and around the geostationary orbit belt since its launch.
- Data and tracking from space monitoring firms show that Shijian-21 has been conducting sophisticated RPO with other objects in and around the geostationary orbit belt since its launch in October last year.
- Ultimate action culminated in Shijian-21 docking with the defunct Beidou-2 G2 navigation satellite and towing it above the crowded belt of geostationary orbit some 36,000 kilometres above the equator.

Earlier China has also conducted successful field trials with LASER robot arm docking/undocking with their space station. Declared purpose was mitigation of space debris.

Project COMPASS: Making Satellites that 'Surf' in Space. Current space activities are enabled by space transfers that allow reaching and controlling operational orbits. Moreover, they are safeguarded by space-situation awareness. Orbit perturbations – natural forces due to the gravity of the moon and the sun, atmospheric drag and solar radiation pressure – affect the long-term evolution of the orbit of celestial bodies, satellites and space debris and need to be counter-balanced by satellite orbit manoeuvres, which increases their fuel requirements. However, the COMPASS project funded by the European Research Council aims to radically alter the current space mission design by exploiting natural and artificial orbit perturbations rather than counteracting them. A dedicated team is working on this Project in Milan. They would make satellites to 'surf', exploiting the forces of nature to reach their desired orbit while avoiding collisions. This would mean significantly reducing fuel consumption. The long-term outcome would be to reduce the high cost of space missions and to create new opportunities for space exploration and exploitation.

International Co-ordination

The future of space as a resource, depends not so much on technology as on the slow and difficult struggle to create sound international institutions to manage this resource. The United Nations Committee on the Peaceful Uses of Outer Space has paid particular attention to the issue of preventing and minimizing the creation of space debris. Every year, States and organizations exchange information on their space debris research at the Committee's Scientific and Technical Subcommittee. One important result of those discussions has been a set of Space Debris Mitigation Guidelines, which were endorsed by the General Assembly in 2007. In addition to scientific research, the Legal Subcommittee are discussing the national and international legal aspects of space debris mitigation measures. To aid their discussions, a compendium of space debris mitigation standards has been compiled by United Nations Office for Outer Space Affairs (UNOOSA) and, at the request of States, is made publicly available through UNOOSA's website IADC.

The Inter-Agency Space Debris Coordination Committee (IADC) is the international forum for the coordination of activities related to the issues of man-made and natural debris in space. The primary purpose of the IADC is to exchange information on space debris research activities between member space agencies, to facilitate opportunities for cooperation in space debris research and to identify debris mitigation options. The IADC Space Debris Mitigation Guidelines is the most prominent IADC document that includes proposals on debris mitigation and is based on consensus among the IADC members.

The IADC Space Debris Mitigation Guidelines describe best existing practices that have been identified and evaluated for limiting the generation of space debris in the environment The IADC Space Debris Mitigation Guidelines is a document of a technical nature that covers the principles of space debris mitigation and is applicable to Earth orbiting vehicles addressing: Mission Planning; Design and Operation (launch, mission, disposal). The IADC Mitigation Guidelines is itself a live document and work in progress. These guidelines may be updated as new information becomes available regarding space activities and their influence on the space environment. The first update to the IADC Mitigation Guidelines was officially adopted by the IADC Steering Group on 25 September 2007 while meeting at Hyderabad.

The most effective short-term means of reducing the space debris growth rate is through the prevention of in orbit explosions (via passivation of space objects at the end of their operational life) or collisions (via collision avoidance manoeuvres while the objects are still active).

Passivation

'Passivation' is an important part of the end-of-life disposal of a space system to avert the risk of spacecraft break-up that could result in debris scattering. With passivation, all the stored energy of a spacecraft or orbital stage that is left in the propulsive and in the power systems is used up to prevent accidental post-mission explosions.

Plans to increase our space population with more CubeSats and other small satellites, as well as new, large constellations of satellites, were not envisioned when the above-mentioned guidelines and standards were established. These new planned spacecraft and constellations, coupled with improvements in space situational awareness, space operations, and spacecraft design, all provide an opportunity to expand upon established space operations and orbital debris mitigation guidelines following best practices. In 2019, for example, the Space Safety Coalition (SSC) laid out a set of proposed voluntary guidelines designed to keep the Kessler Syndrome, and space junk in general, at bay over the coming years. One recommendation is that all satellites operating above 250 miles (400 km) be equipped with propulsion systems allowing them to manoeuvre away from possible collisions. The SSC also recommends that satellite designers consider building encryption systems into the command systems of their craft, so they'll be harder for chaos-seeking hackers to hijack. And operators who control satellites in low Earth orbit should include in their launch contracts a requirement that rocket upper stages be disposed of in the atmosphere shortly after lift-off.

The United Nations Committee on the Peaceful Uses of Outer Space has paid particular attention to the issue of preventing and minimizing the creation of space debris. Every year, States and organizations exchange information on their space research, national and international legal aspects, information sharing on traffic management and implementation on ground. In addition, strong compliance with post-mission disposal guidelines is the most effective long-term means of stabilising the space debris environment at a safe level. Furthermore, the removal of mass (5–10 large objects per year) from regions with high object densities and long orbital lifetimes may be also necessary to stabilise the growth of the space debris population.

Both types of mitigation measures need to be applied broadly and in a timely manner to avoid uncontrolled growth of the debris environment. If mitigation concepts are applied insufficiently, or too late, some orbit regions, particularly the valuable 800–1400 km altitude, may experience a collisional cascading process that could render these regions too dangerous for space activities within a few decades.

Space Sustainability Rating (SSR)

The orbital environment is a globally shared resource where existing international guidelines steer space actors in their activities, however, these are not enforceable and derived standards are not always followed. The guidelines are not expected to sufficiently curtail the creation of new debris caused by fundamental shifts in traffic.

Space Sustainability Rating (SSR) will provide a new, innovative way of addressing the orbital challenge by encouraging responsible behaviour in space through increasing the transparency of organizations' debris mitigation efforts. The SSR will provide a score representing a mission's sustainability as it relates to debris mitigation and alignment with international guidelines. Organizations will provide mission data through a questionnaire, which will be evaluated and graded.

Space Debris and India Scene

India's space programme has been very impressive despite sanctions and a comparatively low budget. From building and launching commercial satellites to sending lunar probes and Mars Orbiter Mission, the Indian space programme spans the full spectrum of activities in various fronts of national development - commercial, strategic, societal, defence and economic. Any interruption in the availability of satellite services would have a direct impact on almost all facets of society and security.

India has indigenously developed full spectrum capabilities in space, and ground systems and is recognized as an emerging space power. Currently, India has 15 operational communication satellites in geostationary orbit (36,000 km). 13 remote sensing satellites in low earth orbit (LEO) of up to up to 2,000 km, and eight navigation satellites in medium earth orbit (MEO).

The space system operates in extremely harsh conditions, is vulnerable and is threatened by orbital crowding, space debris, traffic congestion and weaponization of space. Orbital debris poses a significant, constant, and indiscriminate threat to all space assets. The greatest risk to space missions comes from non-trackable debris. The Indian Space Research Organization (ISRO) is aware of the present space debris scenario and is aimed towards achieving the goal of preserving outer-space for humanity. ISRO works on different aspects to effectively manage the threats. India is fully committed to the sustainability of space and has contributed a lot in the formulation of various policies and guidelines. India is an active member of Inter- Agency Space Debris Coordination Committee (IADC) since 1996. It follows the guidelines recommended by the UN and IADC for space debris mitigation, limiting creation of space debris, on-orbit collision, and post mission disposal.

Over the years ISRO has developed the system for Collision Avoidance (COLA) analysis and Space Object Proximity Analysis (SOPA) for protecting our space assets. ISRO carries out COLA analysis for launch vehicles as a mandatory activity for lift-off clearance. In case the risk is high either in the ascent phase of launch vehicles or post-injection initial phase of the injected pay loads, the mitigation is done by changing the lift-off time within the launch window. SOPA is carried out for all operational satellites on a regular basis to predict any malfunction

ISRO Project 'NETRA'

Threat to Indian assets in space is growing primarily because of space trash. Last year, the space agency tracked 4,382 LEO (Low Earth Orbit) and 3,148 geostationary orbit instances where space debris came dangerously close to Indian assets. ISRO had to undertake 19 collision avoidance manoeuvres (CAM) in 2021 to preserve its space assets, 14 of which were in Low Earth Orbit (LEO) and five in geostationary orbit. From three in 2015 to 12 in 2020 and 19 in 2021, the number of CAMs has increased dramatically.

As a responsible space power, India must have SSA as part of its national capabilities. This is a force multiplier as well as a strategic imperative for securing our space assets

Project NETRA, a 400-crore Rupees project, was developed by ISRO to detect debris and provide Space Situational Awareness (SSA). With that India joined the elite group of nations having their captive capability in these areas. India, thus joins international efforts to track, warn against, and mitigate space debris. NETRA can detect, track and catalogue objects of 10 cms at a distance of 2000 kms. NETRA is a strategic military asset to provide SSA and forms part of combined intelligence surveillance and reconnaissance capability of the nation. NETRA would also provide an ideal foundation for enhancing the capabilities of India. Thanks to long-range radars, the SSA also provides early warning against ballistic missiles and other man-made threats.

India's Space Achievements

Some of the major achievements of India in space are given in the succeeding paragraphs.

International Collaboration and Activities. India is intimately involved in International efforts in the following spheres: -

- Space Debris Mitigation.
- Collision Avoidance studies for Launch Vehicle Lift-off clearance (COLA);
- Space Object Proximity Analysis (SOPA);
- Space debris modelling.
- Long term evolution of Space Debris scenario.
- Establishment of Multi-Object Tracking RADAR;

- Joint activities with Inter Agency Space Debris Co-ordination Committee (IADC);
- Outreach programmes.

International Collaboration.

These include:-

- Member of Inter Agency Space Debris Co-ordination Committee (IADC) since 1997;
- Hosted IADC annual meeting in 2003 and 2010;
- Significant contributions in framing IADC Space Debris Mitigation Guidelines;
- India has bi-lateral agreements on Space withUSA, Russia, France, Japan, Israel and UAE;
- Indian Space Research Organisation (ISRO) of Department of Space, Government of India has signed MoU/ Cooperative agreements for exploration and use of outer space with 37 countries. Ten nations are having discussions with India for a similar agreement.

Some Additional Observations

Space is undergoing a major transformation with drive towards miniaturisation, low power consumption, very rapid manufacturing, extra resilience and deployment as constellations, counter space capability, inter planetary travel, attempt at colonisation of space and so on. There is no organisation which can handle all these singlehandedly. Consequently, the development of space systems lacks an *integrated* approach with attendant inadequacy in schedule, supply chain inefficiency, delayed decisions and time taken for 'engineering to production'.

There is a definite requirement of an empowered organisation under the United Nations to formulate policies, seek consensus to ensure equitable distribution of the resources, economy of effort, integrated R&D and appropriate code of conduct. This organisation will have to find answer to a number of relevant issues like:-

- How do we ensure level playing field, essential for long term stability?
- How can guidelines evolve to ensure a more sustainable use of space?
- What is the most effective way to tackle short term aspects?
- How far can one go when asking transparency of operators?
- Beyond the issues enumerated above, debris removal raises complex policy, geopolitical, legal and social economic challenges like:-
- Who is responsible for debris removal?
- Who should pay?
- What rights do non-spacefaring nations have in discussions?

Besides space debris, space system is exposed to threats, natural and man-made making them very vulnerable. These threats will have to be met internationally both at specific individual and integrated levels.

Orbital debris is a global concern with stakeholders across public, civil, and private sectors who have adopted an array of guidelines, standards, and policies to limit the generation of future debris. However, global compliance with these guidelines, standards, and policies remains low, and global remediation activities designed to remove existing debris from space are limited and largely in the planning phases of development.

Space has been recognised as an independent domain. It is crowded with range of diverse activities from landing on the moon, asteroid mining, inter planetary movements and so on. On the other hand, scientists busy to find an answer for debris mitigation technology are trailing by about two years. During this time gap, certain actions must be taken for protection against debris. About 30 to 60 percent of the launches are using passivation and sharing of information and flexibility of time with in the launch window.

Space Sustainability. Measures for long-term sustainability have been on the agenda of United Nations Committee for Peaceful Use of Outer Space (UNCOPUS) for many years. It seeks the adoption of a comprehensive approach to the multifaceted challenges of preserving space for the generations to come and needs to be expedited.

Space Security. Of late, space security has become a very sensitive issue. Many nations have raised space forces and developed and tested counter space capabilities. There is an urgent need of an internationally accepted Code of Conduct which can assist in achieving enhanced safety and security in space, comprehensive Transparency and Confidence Building Measures (TCBMs) to strengthen adherence and an authority which can effectively enforce the agreed rules and procedures.

The future of the space as a resource, however, depends not so much on technology as on the slow and difficult struggle to create sound international institutions to manage this resource. It will depend most of all upon humanity's ability to prevent an arms race in space. The trend lines indicate that Space has the potential to become an over-contested domain particularly in the continuing absence of integrated policy and the promotion of best practices and behaviour. The greatest risk to space missions comes from non-trackable debris. Space debris pose significant, constant, and indiscriminate threat to all space assets. Despite debris mitigation guidelines, such as those of the Committee on the Peaceful Uses of Outer Space (COPUOS), the problem remains overwhelming and a great threat to space assets. With 57 countries operating in space currently and many more to follow including the private launch operators, the problem of orbital crowding and debris is going to grow exponentially necessitating international collaborations and partnerships to conceive and develop innovative solutions and strategies as part of worldwide space traffic management architecture.

The threat of weapons likely to be placed in space and weapons designed to attack space systems both in space and on ground like counter-space and anti-satellite weapons (ASATs) is very real. Avoidance of an arms race in outer space is the biggest challenge.

Environmental preservation of outer space has taken on a new meaning and sense of urgency not only for purposes of protecting valuable space assets in the short term, but also to ensure the continued sustainability of space activities in the long term. Space pollution is a product of negligence. The detrimental effects of space junk grow worse each year, putting the international space infrastructures increasingly at risk. With a very large number of satellites planned to be launched in the coming decade, the challenge is to limit space pollution through innovative strategies, international collaborations and partnership and legally bound stringent measures.

The future of humanity is inextricably tied to our ability to ensure a viable long-term future for space activities. Developing new debris removal methods, and the legal frameworks to make them usable, are important steps towards finding ways to co-exist with our planet and promote the ongoing safety, security and sustainability. TCBMs have also been introduced through the draft International Code of Conduct for Outer Space Activities proposed by the USA. However, there are issues of verification, compliance, and the authority to ensure their implementation. The future of the space as a resource, however, depends not so much on technology as on the slow and difficult struggle to create sound international institutions to manage this resource. With an enormous increase in the number of institutions/persons operating in space, the consequent problems of orbital crowding and increased debris would necessitate an efficient and responsive space traffic management system.

Conclusion

Number of Communication satellites planned for launch in this decade are: Space X < 1700, Star Link 42,000, One Web 648, Amazon 3200 and Astra 13000. Therefore, mitigation of space debris is a very complex international activity with many facets and challenges. Success of the effort is contingent on mutual trust, cooperation, information sharing, an appropriately empowered organization, legal framework and implementation and monitoring mechanism.

Threat of weapons likely to be placed in space and weapons designed to attack space systems both in space and on ground like counter space and anti-satellite weapons (ASATs) is very real. Avoidance of an arms race in outer space is the biggest challenge. Destruction of the satellite Cosmos 1408 by Russia on 21, November 2021 and raising of Space Forces by many nations are pointers towards that. While technology would be a major factor, a lot needs to be done before an operational system becomes available.

Taking into consideration that there is a massive amount of space debris already in orbit, estimates suggest that, even if no new space objects are launched, the amount of space debris will continue to grow. Space debris would have the initial advantage. At one point, technology and integrated capabilities will come into play and an offensive would put us in an advantage. The war has just begun and is likely to be of long haul. Development of new debris removal methods and their quick operationalisation will determine the winners who would have to find ways to co-exist and promote the ongoing safety, security, and sustainability of space.

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