Space Debris and its Impact on Space Exploration

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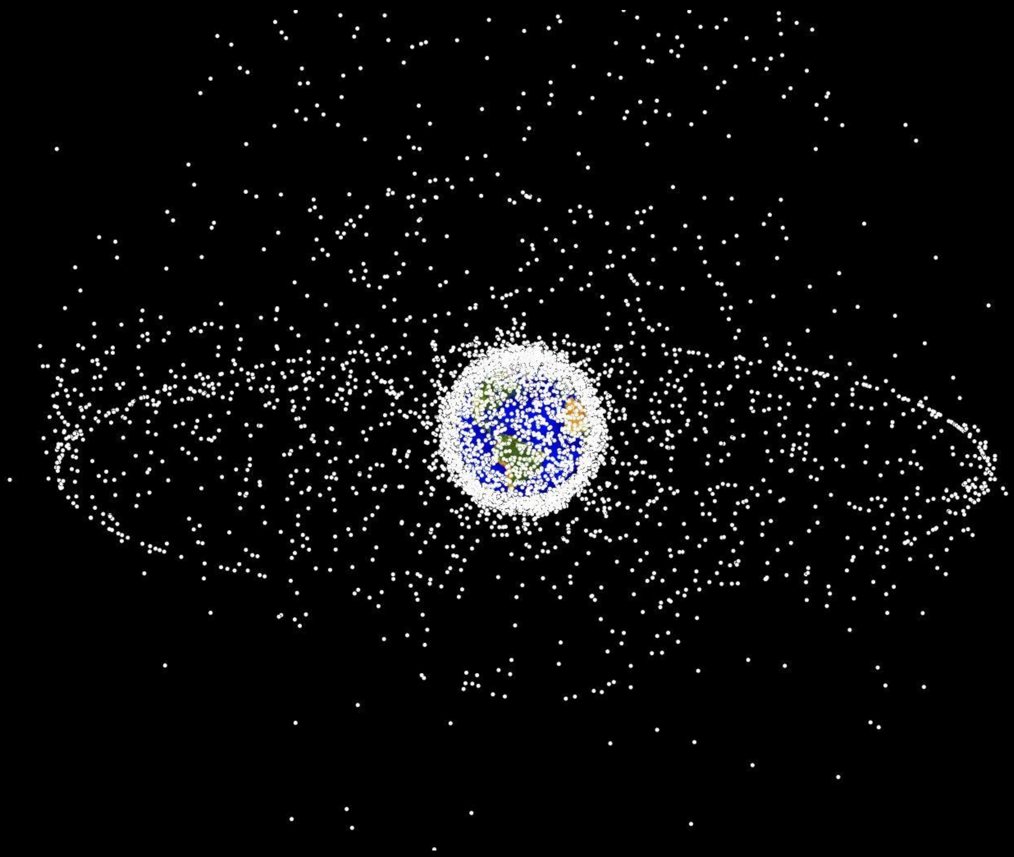

Space Debris and its growing risk

Humanity has advanced into space, yet our forays beyond Earth's atmosphere have resulted in a growing concern: space junk.

These fragments, often known as orbital debris or space junk, pose considerable hurdles to current and future space exploration efforts.

This article delves into the world of space debris, looking at its origins, impact on space exploration, and solutions to this celestial problem.

Space debris, also known as orbital debris and space garbage, are made up of man-made objects that circle the Earth which may include: defunct satellites, spent rocket stages, remnants from prior collisions, and other man-made objects that linger in orbit after their operational life has finished, paint chips for decommissioned weather satellites and rocket stages.
Routine space activity involves the unintentional destruction of satellites and stages in orbit, contributing to the growing problem of space debris. ASAT (anti-satellite) weapons further exacerbate this issue, as these weapons can collide with satellites at high speeds, adding more fragments to the already cluttered space environment.

Figure 1_Space junk _© https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.airforce-technology.com%2Ffeatures%2Fspace-debris-tackling-threats-to-navigation-in-low-earth-orbit%2F&psig=AOvVaw2feb5PZlA52s1l0M33-il_&ust=1703920721102000&source=images&cd=vfe&ved=0CBIQjRxqFwoTCOjV5PaQtIMDFQAAAAAdAAAAABAE

Kessler Syndrome

With the launch of the first artificial satellite, Sputnik 1, in October 1957, space debris began to gather in Earth orbit.
In 1978, NASA scientist Donald Kessler postulated the Kessler Syndrome. This is a hypothetical situation according to which Earth's orbit becomes so clogged with objects and garbage that satellites cannot be used in specific areas.
The Kessler Syndrome is a growing threat to the vast expanse of Earth's orbit, which was once thought limitless. This theoretical cascade effect of space debris collisions, proposed by NASA scientist Donald J. Kessler, presents a time bomb that could put our dependence on satellites, space exploration, and the long-term sustainability of space activities at risk.
Each day, the prospect of the Kessler Syndrome becomes more apparent as the amount of space debris in Earth's orbit continues to increase.

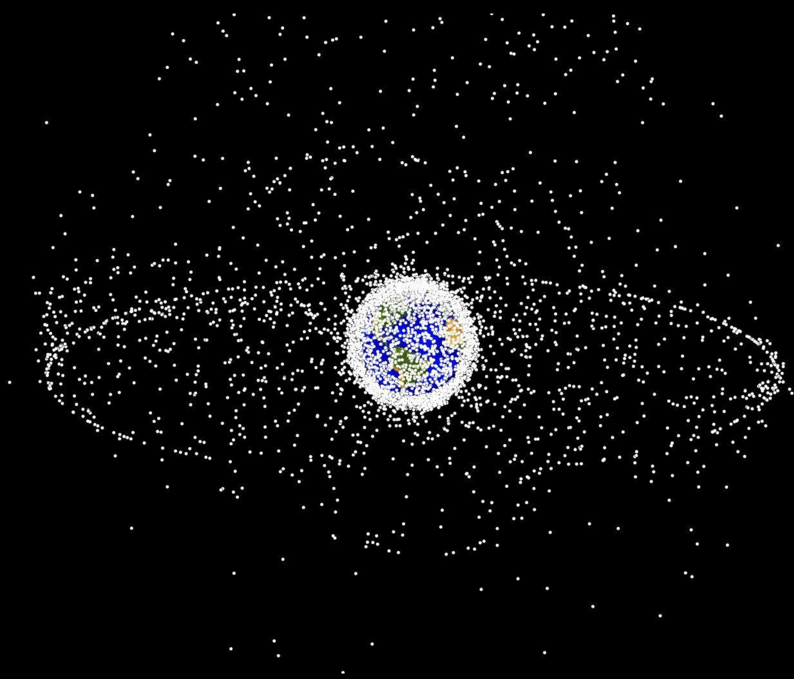

Figure 2_ Kessler Syndrome _© https://upload.wikimedia.org/wikipedia/commons/a/a1/Debris-GEO1280.jpg

Global Collaborative Efforts to Mitigate Space Debris

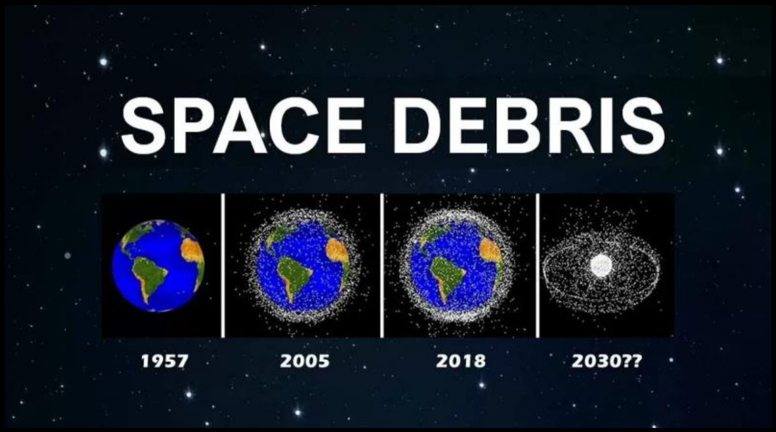

Figure 3_Space debris _© https://img.jagranjosh.com/images/2023/July/672023/what-is-space-debris-explainer.webp

Only around 6% of the over 8700 objects larger than 10 cm in Earth orbit are active satellites, with the rest being space trash. To prevent the potential catastrophe that space junk represent, the global space community needs an urgent and collaborative effort. Nations can work toward defusing the ticking time bomb in order to preserve the accessibility and sustainability of space for future generations by fostering international collaboration, investing in innovative technologies, and adopting responsible space practices.

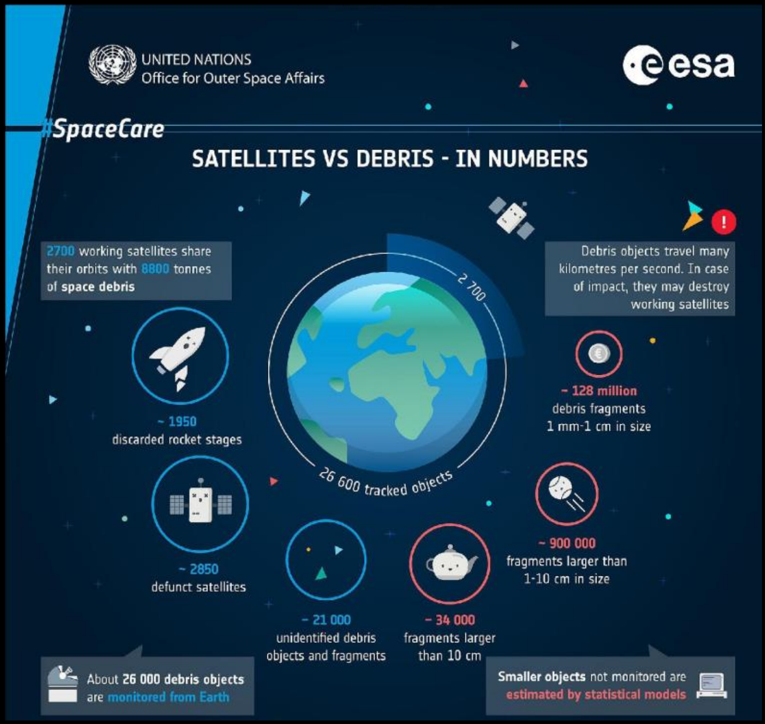

Figure 4_Subcommittee on Space Decay _© https://eoportal.org/ftp/satellite-missions/o/OrbitalDebris_220222/OrbitalDebris_Auto1C.jpeg

In 1995, during its thirty-second session, the Subcommittee on Space Decay decided to focus on various aspects of space debris research. This included methods for measuring space debris, mathematical modelling of the debris environment, characterizing the debris environment in space, and devising strategies to mitigate space debris risks, such as incorporating protective measures into spacecraft design. Consequently, the Subcommittee endorsed a long-term work plan outlining specific topics for the years 1996 to 1998. It was agreed that both potential future strategies and existing operational debris mitigation measures would be considered at each meeting.

Additionally, ISRO has established a Center for Space Debris Research aimed at monitoring and mitigating the risks associated with space debris. Furthermore, "Project NETRA" serves as an early warning system in space, tasked with identifying debris and other potential threats to Indian satellites. While Europe currently lacks an operational space surveillance system, the 34-meter dish radar at the Research Establishment for Applied Science (FGAN) in Wachtberg near Bonn, Germany, serves as a robust radar facility for detecting and tracking space debris, as well as imaging space objects.

Space Debris Tracking & Mitigating technology

FGAN Tracking and Imaging Radar (TIRA)

Figure 5_ FGAN Tracking and Imaging Radar (TIRA)_© https://i.stack.imgur.com/ViDdx.jpg

One successful collaborative effort in space debris research has been between FGAN and ESA's European Space Operations Centre (ESOC).

The FGAN Tracking and Imaging Radar (TIRA) comprise three main subsystems: a 34-meter parabolic antenna, narrow-band mono-pulse L-band tracking radar, and a high-resolution Ku-band imaging radar. The state-of-the-art 34-meter parabolic Cassegrain-feed antenna is fully computer-controlled and positioned on an elevation-over-azimuth pedestal, shielded by a robust 49-meter-diameter Radom against atmospheric disturbances. The L-band radar primarily serves for detecting and tracking space objects, generating high-frequency pulses of 1 to 2 MW peak power and 1 ms pulse length through a double-Klystron power stage.

Usually, there exists preliminary information for tracking space objects, including orbital elements and the approximate size (radar cross-section) of the object. The radar beam is directed towards a predetermined spot in space, enabling the detection and subsequent tracking of the object. Observation vectors are then collected, facilitating the derivation of orbital parameters and radar signatures. The latter provides insights into the object's intrinsic motion, such as rotation or tumbling rate. This observation mode, termed 'target directed,' is employed when the uncertainty in an object's orbit is deemed unacceptable, necessitating more precise information. This is crucial for collision-avoidance manoeuvres involving operational spacecraft and re-entry predictions for potentially hazardous objects.

Another intriguing aspect of TIRA observations is the radar detection of meteoroids traveling at speeds exceeding 80 km/s. Such particles, traveling at such velocities, cannot originate within our Solar System, suggesting an interstellar origin. Given the ESA's Ulysses spacecraft's previous detection of interstellar particles in 1992, TIRA's detection of such rapid meteors is credible.

Consequently, high-power radars like TIRA not only offer valuable insights into space debris but also facilitate high-quality space-physics experiments. The radar tracking of re-entering hazardous objects is paramount, aiding in calculating the re-entry window in both temporal and geographical dimensions by discerning changes in orbit characteristics. Recent instances of re-entering objects, including Salyut-7/Kosmos-1686, Kosmos-398, China-40, and the Mir space station, have benefited from FGAN's assistance to ESA in this regard.

Net Technology of capturing Space Debris

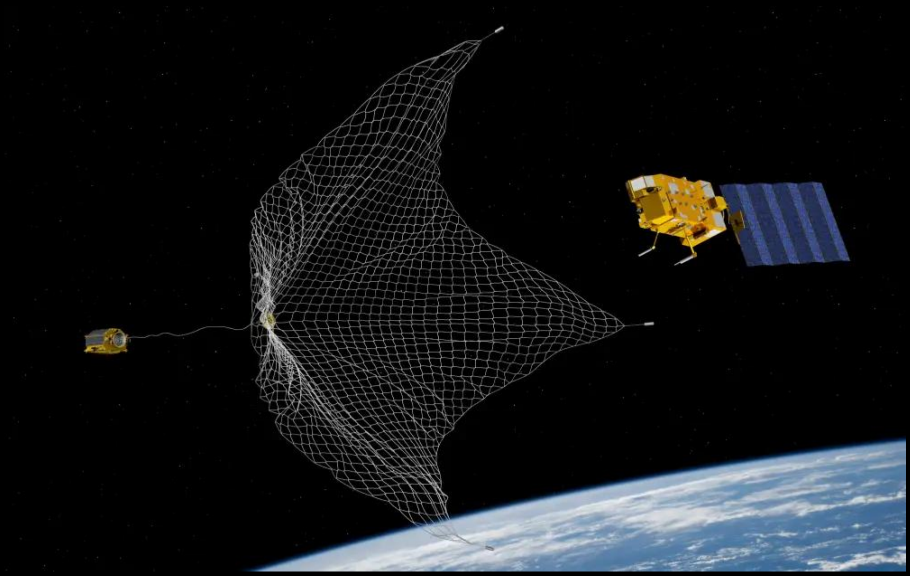

Figure 6_Space junk mitigation _© https://news.mit.edu/sites/default/files/styles/news_article__image_gallery/public/images/201706/MIT-Orbit-Debris_0.jpg?itok=is7Mk60S

To address the growing issue of orbital clutter, one proposed method is to use net technology to capture space debris. This net capture system relies on deployment masses that undergo acceleration during net deployment. This acceleration helps propel the net out of its container and inflates it as it travels toward its intended target. Upon capturing the debris, the net is wrapped around it and establishes a tether line connection to the servicing spacecraft.

US Space Surveillance Network (SSN)

Another method of monitoring space debris involves the use of the US SSN. However, while the US Space Surveillance Network (SSN) is adept at monitoring larger debris, its current capabilities do not extend to detecting and monitoring smaller items.
Consequently, there is an urgent need to develop a more robust system to address the issue of tiny space debris.

The increasing volume of space debris traffic heightens the risk of collisions between launch vehicles and satellites in orbit. If the SSN anticipates a collision between a known object and an operational satellite, the owner/operator is typically alerted.
While stationary debris presents a challenge, movable satellites may execute avoidance maneuvers to evade collisions, a process that can take hours or days to plan and execute. Other countries utilize data from the Combined Space Operations Center (CSpOC) in conjunction with their own tracking data to protect their satellites. Therefore, accurate assessment and prediction techniques are crucial for mitigating the risks associated with both current and future space missions.

Market for space debris

Figure 7_Space junk _© https://news.mit.edu/sites/default/files/styles/news_article__image_gallery/public/images/201706/MIT-Orbit-Debris_0.jpg?itok=is7Mk60S

Regarding the market for space debris monitoring and cleanup, it is segmented based on factors such as activity, debris size, orbit, and region. The activities are divided into space debris cleanup and monitoring, while debris size is further categorized into three groups: 1mm to 1 centimeter, 1 cm to 10 cm, and larger than 10 cm. Orbit-wise, the market is classified into two categories: LEO and GEO, with research conducted across regions including North America, Europe, Asia-Pacific, and Latin America.

Conclusion

Figure 8_Space junk in LEO_© https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.esa.int%2FESA_Multimedia%2FImages%2F2008%2F03%2FDebris_objects_in_low-Earth_orbit_LEO2&psig=AOvVaw1bme15A8Kpeb_r1-Vj750l&ust=1705253691002000&source=images&cd=vfe&opi=89978449&ved=0CBMQjRxqFwoTCPCqnJrz2oMDFQAAAAAdAAAAABAI

In conclusion, the impact of space debris reverberates across all sectors of society, owing to the pervasive reliance on satellite technology in modern life. This poses substantial risks to current and future space endeavors due to their swift trajectories. Even the smallest debris items wield the potential to inflict severe harm on essential spacecraft components, underscoring the gravity of the challenge at hand. The looming threat of collisions, even with objects as diminutive as one millimeter, underscores the urgency of addressing this issue. Moreover, the mounting debris population exacerbates the complexities and expenses associated with orbit operations and space travel, particularly as maneuvers become increasingly necessary to navigate through the cluttered space environment.

Efforts and technologies geared towards the detection, tracking, and mitigation of space debris, collectively known as space debris monitoring and removal, are pivotal for upholding the safety and sustainability of space activities.
The overarching objective remains steadfast: to mitigate the risks posed by space debris to operational satellites, spacecraft, and the broader realm of space endeavors.
Through concerted action and innovation in this domain, we can chart a course towards a safer and more sustainable future in space exploration.

Reference:

- What is space junk (debris) and why is it a global threat? (2023) Jagranjosh.com. https://www.jagranjosh.com/general-knowledge/what-is-space-junk-1688640690-1(Accessed: 23 December 2023).
- Space debris and space traffic management: The Aerospace Corporation (2018) Aerospace Corporation.https://aerospace.org/space-debris (Accessed: 29 December 2023).
- Detecting, tracking and imaging space debris - european space agency. Detecting, Tracking and Imaging Space Debris (Accessed: 29 December 2023).
- What is space junk (debris) and why is it a global threat? (2023a) Jagranjosh.com. https://www.jagranjosh.com/general-knowledge/what-is-space-junk-1688640690-1 (Accessed: 29 December 2023).

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Siddhi is a B.Tech student and a dedicated aerospace enthusiast aspiring to specialize in aerodynamics, propulsion, space science, satellites, and launch vehicles. Having recently completed an internship at the National Aerospace Laboratory, she has co-authored two international conference papers [IAC 2023, Baku]. Siddhi has also served as an ambassador for the International Astronomy and Astrophysics Competition 2023 and the National Students' Space Challenge 2023, in addition to holding the position of joint secretary at the Alatus Space Club in her college.
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