4. Protecting Astronauts from Deadly Space Debris – S & T

The rapid expansion of satellite launches and commercial space activity has intensified the threat posed by Micrometeoroids and Orbital Debris (MMOD), raising serious concerns for astronaut safety and long-term sustainability of Earth's orbits

1. Micrometeoroids and Orbital Debris (MMOD)

MMOD is a collective term used in space engineering and space safety to describe high-velocity natural and artificial particles present in Earth's orbital environment that pose a serious collision hazard to spacecraft, satellites, and astronauts. Even millimetre-sized particles can cause catastrophic damage due to extremely high relative velocities. MMOD risk increases with the growing congestion of Low Earth Orbit (LEO) and Geostationary Orbit (GEO).

2. Components of MMOD

Micrometeoroids

Naturally occurring particles originating mainly from

1. Asteroid belt collisions
2. Comet debris trails

Size ranges from microns to a few millimetres. Travel at extremely high velocities

1. 11–72 km/s, far exceeding orbital debris speeds.
2. Cannot be tracked due to their tiny size and random trajectories.
3. Pose continuous, unavoidable background risk to spacecraft.

Orbital Debris (Space Junk)

Human-made objects resulting from space activities, including -

1. Defunct satellites
2. Spent rocket stages
3. Fragments from explosions and collisions

Typically orbit at speeds of around 7–10 km/s. Objects larger than 10 cm can be tracked; smaller ones cannot. Concentrated mainly in LEO, where most Earth-observation and communication satellites operate.

3. Dangers Posed by Space Debris

According to NASA, orbital debris can travel at speeds up to 18,000 mph, nearly 10 times faster than a bullet. Even paint flecks or metal fragments can -

1. Penetrate spacecraft shielding
2. Damage solar panels
3. Disable critical onboard systems

International Space Station (ISS) damage - In 2021, a two-inch debris fragment struck one of the ISS components, highlighting the real-world risk to astronauts and infrastructure.

4. Kessler Syndrome

Proposed by NASA scientist Donald J. Kessler. Refers to a runaway chain reaction where -

1. Collisions between satellites create debris
2. New debris triggers further collisions

Consequences

1. Exponential growth of debris in LEO
2. Certain orbits becoming unusable for decades or centuries
3. Severe constraints on future space missions, launches, and satellite services

This is considered one of the most critical long-term threats to sustainable space use.

5. MMOD Protection Measures

Debris Avoidance Manoeuvres (DAM) - Objects larger than 10 cm are continuously tracked by global space surveillance networks. When collision probability exceeds a defined threshold - Spacecraft perform orbital adjustments using onboard thrusters. Commonly used for -

1. Crew-carrying missions

2. High-value satellites
3. Space stations

Whipple Shields

Primary passive protection system against MMOD. Structure

1. Multiple thin layers of materials such as
    1. Aluminium
    2. Kevlar
    3. Carbon fibre
2. Separated by air or vacuum gaps.

Working principle

1. Incoming debris shatters on the outer layer
2. Energy is dispersed across a wider area
3. Prevents penetration of the main spacecraft wall

Widely used on

1. Space stations
2. Crew modules
3. Long-duration spacecraft

6. International Agreements and Norms on Space Debris

Space Liability Convention, 1972 - Part of the UN space law framework.

Key provisions - A launching state is absolutely liable for damage caused by its space objects on Earth or to aircraft. Fault-based liability applies for damage caused in outer space. Establishes responsibility but does not prevent debris creation.

Zero Debris Charter - Signed by 12 nations and the European Space Agency at the ESA–EU Space Council.

Objective - Achieve debris-neutral space operations by 2030.

Focus areas

1. Sustainable spacecraft design
2. End-of-life disposal
3. Active debris removal

Legal Gap - There is no binding international law that -

1. Penalises creation of space debris
2. Prevents uncontrolled debris re-entry

Current regime relies largely on voluntary guidelines and best practices.

7. Missions for Removing Space Debris

Remove Debris Mission - Led by the European Space Agency (ESA). Demonstration mission in Low Earth Orbit. Technologies tested -

1. Nets
2. Harpoons
3. Vision-based navigation

Aimed at validating active debris removal (ADR) techniques.

Space Debris Removal System (SDRS)- Proposed by Roscosmos.

Objective -Demonstrate feasibility of capturing and deorbiting debris in LEO. Still largely at conceptual and experimental stages.

Cleanup Mission - Initiated by China National Space Administration.

Focus - Combination of active (capture, deorbit) and passive (design changes) methods. Reflects China's growing role in space sustainability discussions.

8. Steps Taken by India

Project NETRA

NETRA - Network for Space Object Tracking and Analysis.

Initiated by Indian Space Research Organisation (ISRO).

Purpose -

1. Early warning system for space hazards
2. Detection and tracking of space debris and near-Earth objects

Enhances India's indigenous Space Situational Awareness (SSA) capability.

IS4OM

ISRO System for Safe and Sustainable Operations Management.

Established in **2022**.

Functions -

1. Continuous monitoring of objects posing collision threats
2. Risk assessment and mitigation strategies
3. Coordination of debris avoidance manoeuvres

These initiatives place India among responsible spacefaring nations focusing on long-term orbital sustainability.

9. Broader Significance

MMOD management is essential for -

1. Protection of astronauts and space stations
2. Safeguarding satellite-based services (navigation, communication, weather)
3. Ensuring sustainable and equitable access to outer space

Space debris governance is emerging as a critical global commons issue, similar to climate change and oceans governance.

Source - https -//www.thehindu.com/sci-tech/science/how-are-we-protecting-astronauts-from-deadly-space-debris/article70426332.ece