6. Re-Entry Corridor in Space Missions – Science & Technology

With India undertaking advanced missions such as Gaganyaan and reusable launch vehicle experiments by the Indian Space Research Organisation (ISRO), the concept of a re-entry corridor has gained prominence in space safety and mission design.

1. Meaning of Atmospheric Re-entry

1. Atmospheric re-entry refers to the process by which a spacecraft, satellite, or space capsule returns to Earth by entering the planet's atmosphere from outer space.
2. Objects in orbit travel at speeds of about 7.8 km/s (approximately 28,000 km/h).
3. At such velocities, a direct descent toward Earth is not possible without reducing speed.
4. Therefore, spacecraft must perform a de-orbit manoeuvre, which initiates a controlled descent toward Earth.

2. Mechanism of Re-entry

De-orbit Burn

1. The re-entry process begins with a de-orbit burn, where spacecraft engines fire in the direction opposite to the vehicle's motion.
2. This manoeuvre reduces orbital velocity and allows Earth's gravity to pull the spacecraft toward the atmosphere.

Atmospheric Entry

1. As the spacecraft enters the atmosphere, atmospheric density gradually increases.
2. This generates aerodynamic drag, which slows the spacecraft.
3. Extreme heating occurs because of compression of air molecules in front of the spacecraft.

Controlled Descent and Landing

1. Several systems ensure safe descent and landing-
    1. Thermal protection systems (heat shields)
    2. Attitude control thrusters
    3. Parachute or landing systems
2. Depending on mission design, landing can occur through-
    1. Ocean splashdown
    2. Land landing
    3. Runway landing in spaceplane vehicles.

3. Types of Atmospheric Re-entry

Controlled Re-entry

1. In controlled re-entry, the spacecraft follows a planned trajectory called the re-entry corridor.
2. Mission controllers carefully calculate the entry path to ensure safe deceleration and landing.
3. Features of controlled re-entry include-
    1. Accurate navigation systems
    2. Thermal protection shields
    3. A predetermined landing zone
4. Examples include-
    1. India's SRE-1 (Space Capsule Recovery Experiment)
    2. CARE (Crew Module Atmospheric Re-entry Experiment)

3. Future Gaganyaan crew module.

Uncontrolled Re-entry

1. In uncontrolled re-entry, spacecraft or debris returns to Earth due to natural orbital decay caused by atmospheric drag.
2. There is no active guidance system, so the path becomes unpredictable.
3. Some debris burns completely in the atmosphere, while some fragments may survive and fall to Earth.
4. Examples include-
    1. Old satellites
    2. Spent rocket stages
    3. Space debris fragments.

4. Importance of the Re-entry Corridor

1. The re-entry corridor is a narrow window of entry angles that ensures safe atmospheric descent.

Correct Entry Angle

1. If the spacecraft enters at the correct angle, atmospheric drag gradually slows it while heat shields protect it.

Too Steep Entry

1. A steep entry angle may cause-
    1. Extreme aerodynamic heating
    2. Excessive deceleration forces
    3. Structural damage or burn-up.

Too Shallow Entry

1. A shallow angle may cause the spacecraft to skip off the atmosphere, similar to a stone skipping across water.
2. This may send the spacecraft back into space instead of landing.

Human Safety

1. The correct trajectory ensures manageable gravitational forces (G-forces) on astronauts.

5. Major Challenges in Atmospheric Re-entry

Extreme Thermal Stress

1. At hypersonic speeds, air compression generates temperatures exceeding 1500–2000°C.
2. Spacecraft require advanced heat shields and ablative materials to withstand these temperatures.

Plasma Formation and Communication Blackout

1. Ionized gases form a plasma sheath around the spacecraft during re-entry.
2. This plasma blocks radio signals, causing a temporary communication blackout lasting several minutes.

Aerodynamic Instability

1. Incorrect spacecraft orientation may cause tumbling or deviation from the re-entry corridor.

Precision Navigation

1. Even small trajectory errors can lead to-
    1. Overshoot – spacecraft skipping back into space
    2. Undershoot – excessive heating and destruction.

6. Importance of Atmospheric Re-entry Technology for India

Human Spaceflight Capability

1. Mastery of atmospheric re-entry is essential for India's Gaganyaan Mission, which aims to send Indian astronauts into space.
2. Experiments such as CARE (Crew Module Atmospheric Re-entry Experiment) have demonstrated India's capabilities in-
    1. Heat shield technology
    2. Parachute recovery systems
    3. Capsule retrieval mechanisms.

Strategic Defence Applications

1. Re-entry technology is also critical for ballistic missile systems.
2. Missile warheads must withstand extremely high temperatures during atmospheric re-entry.
3. For example, the **Agni-V intercontinental ballistic missile uses advanced re-entry vehicle technology.

Technological Sovereignty

1. Developing indigenous re-entry technology places India among a select group of advanced spacefaring nations including-
    1. United States
    2. Russia
    3. China.

Global Collaboration

1. Countries possessing re-entry expertise are valuable partners in international space missions and satellite recovery operations.

7. International Legal Framework Governing Re-entry

Outer Space Treaty (1967)

1. States remain responsible for space objects launched under their jurisdiction.
2. They retain jurisdiction and control over those objects even after re-entry.

Liability Convention (1972)

1. Launching states are absolutely liable for damage caused on Earth by their space objects.
2. For damage occurring in space, liability depends on fault.

Registration Convention (1976)

1. Countries must register space objects with the United Nations.
2. Registration includes information about-
    1. Orbital parameters
    2. Function
    3. Ownership.

UN Space Debris Mitigation Guidelines

1. Encourage safe practices such as-
    1. Controlled re-entry of satellites
    2. Disposal in graveyard orbits
    3. Minimizing risks from space debris.

8. Way Forward

Advanced Controlled Re-entry Systems

1. Development of high-precision guidance and navigation systems will improve re-entry safety.

Indigenous Technology Development

1. India must strengthen capabilities in-
    1. Thermal protection materials
    2. Automated re-entry systems
    3. Parachute recovery technologies.

International Cooperation

1. Global cooperation is needed to manage space debris and enhance re-entry safety standards.

Conclusion

Atmospheric re-entry is one of the most complex and critical phases of any space mission. It involves precise navigation, advanced thermal protection, and sophisticated landing systems. For India, mastering re-entry technology is vital for human spaceflight missions, strategic defence capabilities, and strengthening its position as a leading space power.

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