Science and Technology Class 06

Previous Class Topic

- **Coronal holes:** Regions in the Sun's corona with open magnetic fields, source of solar wind, and appear dark in extreme UV/X-ray images.

Space Technology: Organization of Notes

- Maintaining up-to-date notes on space technology is essential for tracking new developments.
- Dedicated sections for space technology, ICT, biotechnology, etc., help in organized updates.
- Employ physical or digital folders to update and integrate information from various reliable sources.
- Avoid haphazard note-making; allocate space in notes for future updates and systematic revision.

Gaganyaan Mission

Overview and Key Facts

- **Gaganyaan** is India's first manned space mission, undertaken by ISRO.
- Three astronauts are planned to spend 3–4 days in low Earth orbit (400–450 km) before returning safely.
- If successful, India will become the fourth nation after Russia/USSR, the US, and China to send its astronauts to space.
- Four astronauts have been shortlisted; the mission is likely to send two or three initially.

Unique Challenges of Manned Missions

Technical and Physiological Challenges

- Microgravity can cause bone density loss and muscle atrophy; with short duration, impacts are minimized but still present.
- Re-entry into the Earth's atmosphere presents risks from atmospheric friction and heating (temperatures up to 800–900°C).
- The crew module requires advanced thermal insulation to safeguard the astronauts during re-entry.
- Safe splashdown and quick astronaut recovery in the Indian Ocean require precise predictions and coordination.

Life Support Requirements

- Maintaining optimum temperature, oxygen supply, food, water, and waste management within the crew module is essential.
- Space suits are necessary to protect astronauts from cosmic radiation, given the absence of Earth's atmosphere.
- Habitable conditions must be continuously managed for crew safety and well-being.

Training and Adaptation

- Astronauts undergo rigorous training for weightlessness and physical changes encountered in microgravity.
- On returning, astronauts face difficulty in adjusting to gravity, needing therapy and rehabilitation for basic movements.

The Concept of Weightlessness and Free Fall

- Weightlessness is experienced due to **free fall** condition in orbit, not due to absence of gravity.
- Even at 400–450 km above Earth, gravity is significant; free fall results because astronauts, their capsule, and any objects inside it all accelerate at the same rate.
- It is analogous to being inside a falling elevator, where no normal force is experienced, so weight cannot be felt.
- The satellite's speed provides adequate kinetic energy to maintain orbit instead of falling directly to Earth.

Launch and Crew Escape Systems

- The mission employs the LVM 3 launch vehicle(formerly known as GSLV Mk III), specially modified to carry humans.
- LVM 3 has three stages: boosters, liquid stage, and cryogenic stage, all of which must separate seamlessly for successful orbit insertion.
- A Crew Escape System is incorporated—a safety feature enabling complete separation and return of the crew module in the event of a malfunction during launch.

Launch Challenges Table

Booster Separation
Liquid Stage Separation
Cryogenic Stage Separation
Crew Escape Safety

Phases of Mission Challenges

- **Launch Phase:** Requires flawless rocket stage separations and emergency readiness.
- **On-Orbit Phase:** Survival in harsh space environment; reliable functioning of life-support systems; microgravity adaptation.
- **Re-Entry Phase:** Managing atmospheric friction and heating; effective thermal protection inside the module.
- **Recovery Phase:** Accuracy in splashdown location and rapid retrieval of astronauts for medical evaluation.

Significance and Rationale for the Gaganyaan Mission

Tangible and Quantifiable Benefits

- **Stepping Stone to Indian Space Station:** The Gaganyaan mission is foundational for subsequent projects, including the Bharatiya Antariksh Station.
- **Future Lunar Manned Missions:** It prepares India for planned manned missions to the Moon by 2040.
- **Space Tourism:** Enables India to participate in a burgeoning space tourism sector, which has both sub-orbital and orbital branches.
- *Sub-orbital:*Short trips just above the atmosphere, experiencing weightlessness briefly.
- *Orbital*:Longer duration trips, involving one or more orbits around Earth.
- Private sector examples include SpaceX, Blue Origin, and Virgin Galactic.
- **Spillover Technological Benefits:** Developments for space missions foster advancements in unrelated sectors.
- Food processing for prolonged shelf life, initially for astronauts, now benefits the general food industry.
- Water purification and recycling technologies adapted for terrestrial use.
- Memory foam—first developed for space, now used in mattresses and cushions.
- High temperature-resistant materials transferred to civilian sectors like infrastructure and transportation.
- **Private Sector Involvement:** Collaboration with startups and private companies leads to broader innovation and economic growth.

Intangible Benefits

- **Soft Power Enhancement:** Space achievements boost national image, influencing global diplomacy, particularly among developing countries.
- **Strategic Importance:** Active participation in a renegotiation of space-related treaties; recognition as a major space-faring nation.
- **International Cooperation:** Collaborative activities with agencies from Russia, the US, France, and others enhance mutual understanding.
- **National Pride and Inspiration:** Catalyzes inspiration in all generations, fostering scientific aspiration and unity across society.

Additional Points

- **Sectoral Impact:** Investments in Gaganyaan lead to improvements in research sectors such as medicine (e.g., MRI derived from Nuclear magnetic Resonance (NMR) in astrophysics).
- **Balanced National Goals:** Space investments are long-term and do not preclude spending in other critical sectors such as health and education.

Challenges and Logistics in Manned Spaceflight

Life Support and Space Environment

- Habitable conditions must be controlled within a limited module volume.
- All life-sustaining resources must be carried in, including mechanisms for waste management.
- A continuous supply of oxygen, control of carbon dioxide levels, and maintaining pressure and temperature is crucial.

Psychological and Physical Demands

- Astronauts are trained to adapt to sensory changes and the absence of gravity cues.
- Extended spaceflight impacts circadian rhythms and can affect muscle memory and reflexes.
- Upon return to Earth, astronauts need therapy to regain musculoskeletal strength and correct old habits developed in microgravity.

Specific Design and Operational Aspects

- Capsules and space suits are designed to protect from both mechanical and radiation threats.
- Precise coordination is needed between ground stations and the crew for real-time communication and emergency management.
- Dedicated protocols exist for storing biological waste, ensuring hygiene and safety.

Knowledge Transfer and Applications from Space Technology

Examples of Technology Transfer	Origin in Space Research	Current Use on Earth
Food Processing Enhancements	Long shelf-life requirements for astronauts	Consumer food preservation
Water Purification	Recycling water in space stations	Urban & rural water treatment
Memory Foam	Vibration/impact reduction for astronauts	Mattresses, vehicle seating
Thermal-Resistant Materials	Re-entry shields, rocket bodies	Buildings, transport, logistics
MRI/NMR Technology	Astrophysical studies of radiowaves	Medical imaging (MRI scan)

Space Stations: International and Indian Perspectives

International Space Station (ISS)

- ISS has operated continuously since its inception, with occupants from multiple countries.
- Jointly managed by the USA, Russia, Canada, Europe, and Japan.
- Orbits at approximately 418 km, capable of hosting 10–12 astronauts.
- Supports a variety of experiments in microgravity, medical science, materials, biology, and physics.
- Promotes international cooperation; even adversarial countries work collaboratively (e.g., US and Russia).

Indian Plans for Space Stations

- India aims to assemble a permanent space station (Bharatiya Antariksh Station) by 2035, in modular launches akin to the ISS assembly.
- Early successes in manned flight (Gaganyaan) pave the way for more ambitious, complex, and collaborative projects.
- The proposed Indian station (~52 tons) is smaller than the ISS (~450 tons), reflecting capacity, experimental volume, and resource allotment.

Chinese Space Station (Tiangong)

- An example of a fully functional, independently operated station demonstrating advanced capabilities and long-term objectives.

Experiments and Activities in Space Stations

- Astronauts serve as subjects for microgravity and medical research; the effects of zero-gravity on human biology are observed.
- Experiments extend to the growth of plants under artificial light, nutrient management, and circadian rhythm regulation.
- Space conditions facilitate research in pathology, physiology, botany, and physical sciences, producing data relevant for terrestrial applications.

Astrobiology and the Search for Life

Europa Clipper Mission

- NASA's Europa Clipper mission investigates Jupiter's moon Europa, believed to have subsurface water and potential for life.
- The mission uses a complex orbit that avoids destructive exposure to Jupiter's radiation while allowing detailed study of Europa.
- Missions like this explore the possibility of extraterrestrial life and expand knowledge of solar system biology.

Space Debris

Types and Sources of Space Debris

- **Defunct Satellites:** Decommissioned objects, primarily from early space programs, are easier to track but still hazardous.
- **Large Fragments:** Rocket stages, separated satellite parts, and byproducts of stage explosions.
- **Small/Sand-like Particles:** Less than 1–2 cm; pose a corrosion threat to panels and windows; millions exist.
- **Dangerous, Medium-Sized Debris:** Pieces 5–15 inches in size, numbering in the hundreds of thousands in orbit, are very destructive and hard to track.

Table: Types of Space Debris and Risks

Defunct Satellites – large, trackable
Rocket/Stage Fragments – potentially explosive
Sand-sized Particles – numerous, cumulative damage
5–15 inch Medium Debris – high risk, hard to track

Consequences and Management

- High-velocity debris can cause major damage to satellites or space stations.
- Proactive orbital monitoring and avoidance maneuvers are required to protect valuable assets.
- Anti-satellite weapon tests, such as India’s Mission Shakti (2019), contribute to debris yet serve as demonstrations of national capability.

The Kessler Syndrome

- Proposed by Donald Kessler, it describes a scenario where cascading collisions exponentially increase debris, potentially rendering orbits unusable and threatening space access for generations.
- The risk increases as the number of satellites and space activities proliferate.

Debris Solutions and Space Situational Awareness

- **Tracking Systems:** Usage of telescopes, radar, and supercomputers (e.g., ISRO's Project Netra) to predict debris orbits.
- **International Collaboration:** Agencies share debris data via the Interagency Debris Coordination Committee (IADC); global coordination is in demand though currently limited.
- **Active Removal:** Proposals for robotic retrieval missions or use of lasers exist, though they face financial and political hurdles. -> Ban on anti-satellite weapons.
- **End-of-Life Protocols:** Responsible agencies design satellite and rocket missions to de-orbit and burn up or shift assets to graveyard orbits (e.g., Cartosat-3).
- **Space Situational Awareness:** A comprehensive understanding of spatial dynamics, including potential hazards from debris, particles, and solar activity.

Space Weaponization

Anti-Satellite Weapons (ASAT)

- Countries such as the US, China, Russia, and India have demonstrated the ability to destroy satellites using ASAT missiles.
- ASAT missions can be kinetic (collision-based) or explosive; the kinetic method (e.g., Mission Shakti) causes physical destruction by direct impact.

Policy and Regulation

- Proposals for banning ASAT weapons are under discussion, but no international consensus or treaty currently exists.
- Management is further complicated by the ambiguities inherent in dual-use technologies.

NASA Missions and Frontier Exploration

Asteroid Threats and Defense

- Historical evidence links asteroid impacts to major extinction events (e.g., the extinction of the dinosaurs).
- The current likelihood of a large-scale impact is low, but long-term vigilance is necessary.
- **Planetary Defense Strategies:**
- Kinetic impactors (e.g., NASA's DART mission, which successfully redirected asteroid Dimorphos).
- Gravity tractors that use a spacecraft's mass to gradually alter an asteroid's trajectory.
- Nuclear deflection as a last resort if other methods fail.
- Ongoing astronomical surveys improve early detection capabilities.

Parker Solar Probe

- Travels within the solar corona to study its high temperatures and dynamics.
- It is the fastest human-made object (~700,000 km/h) and survives the high-temperature environment due to low particle density, which results in limited heat transfer.
- Designed to withstand surface temperatures of up to approximately 1,377°C.

Europa Clipper Mission (Further Details)

- Studies Europa's subsurface water beneath its icy crust, assessing its habitability and potential biosignatures.

Understanding Temperature and Energy Transfer

- Temperature is a measure of the average kinetic energy of particles but is not the same as energy transfer (heat).
- Heat flows from regions of higher to lower temperature.
- Absolute zero (0 Kelvin) is the state where atomic motion ceases.
- This understanding helps explain why spacecraft can survive in extreme environments with low particle density.

Q: What are Asteroids ? Can asteroids cause extinction of life on planet ? What can be done to avoid asteroid impact on Earth ?

Space Treaties and Governance

Outer Space Treaty (1967)

- The principal treaty governing the use of outer space.
- Mandates that outer space be used for peaceful purposes and prohibits the placement of nuclear weapons or Weapons of Mass Destruction (WMDs) in orbit.
- Does not clearly define the boundary of "outer space" (e.g., the 100 km Karman line is not legally established).
- Does not comprehensively address dual-use technologies and modern threats such as space debris and weaponization.
- There is a growing global demand for updating or renegotiating this treaty to address contemporary challenges.

Artemis Accords

- A set of non-binding, US-led principles for responsible behavior in lunar and outer space exploration.
- Key principles include peaceful exploration, transparency, interoperability, emergency assistance, registration, and scientific data sharing.
- Not universally signed; while India recently joined, countries like Russia and China prefer UN-led initiatives.

Space as a Global Commons

- Outer space is considered a global commons, similar to international waters, and is not under the national jurisdiction of any single country beyond recognized boundaries.
- Space activities are governed by international agreements and are managed as shared resources for all countries.

Biological Experiments and Circadian Rhythms in Space

- Plants can grow in space using artificial light, provided they receive sufficient water and nutrients.
- Managing light cycles is essential to respect plant circadian rhythms, thus preventing desiccation or stunted growth.
- Experimental successes demonstrate the adaptability of terrestrial organisms when environmental parameters are well-controlled.

Effects of Microgravity on the Human Body

- Microgravity induces physiological changes similar to accelerated aging, such as muscle and bone loss.
- Artificial gravity can be simulated using rotating systems, which helps in studying and managing these effects.

Additional Scientific Concepts

- Van Allen Radiation Belts and auroras are related but distinct phenomena; both result from solar particle interactions with Earth's magnetic field, but auroras are episodic events at the poles.
- Black holes do not emit X-rays themselves; rather, the regions around accretion disks emit X-rays due to high-energy particle collisions.
- Relativity predicts effects such as time dilation, although these effects are minimal at the speeds of space capsules used in these missions.

Topic to be Discussed in the Next Class

- Communication technology
- Computing technologies