**Science and Technology Class 04**

## Previous Class Topic

- Types of satellites, their classification, and various types of orbits.

## Geotransfer Orbit (GTO) and Orbital Transfers

### Basics of Geotransfer Orbit (GTO)

- Geotransfer orbit functions as a temporary, highly elliptical path for payloads unable to reach final orbits in a single launch.
- Commonly used for transitioning satellites from low Earth orbit to higher orbits like geosynchronous orbit.
- Typically involves a perigee (closest point to Earth) of about 300-400 km and an apogee (farthest point) near 36,000 km.

### Satellite Maneuvering and Fuel Usage

- Satellites carry their own fuel and propulsion systems to perform orbit-raising maneuvers after separation from the launch vehicle.
- Multiple burns and gradual increases in altitude are performed using onboard engines to eventually achieve the desired geostationary or geosynchronous orbit.

## Orbital Mechanics: Torques, Precession, and Sun-Synchronous Orbits

### Torque Due to Orbital Asymmetry

- Asymmetric satellite mass or shape can cause torque, leading to changes in orbital orientation over time.
- This torque causes precessional motion of the orbital plane, which is generally undesirable.

### Sun-Synchronous Orbits

- Exploit natural precession for benefit; orbit is designed to precess roughly 1 degree per day, matching Earth's orbit around the Sun.
- Enables satellites to consistently pass over specific locations at the same solar time, improving comparability of longitudinal images and data.
- Sun-synchronous orbits are particularly suitable for remote sensing, environmental monitoring, and consistent surface imaging.

## Geosynchronous and Geostationary Orbits

### Key Features and Differences

- Both orbits complete one revolution around Earth every 24 hours.
- **Geostationary:** Special case of geosynchronous, with zero-degree inclination and circular path over the equator—remains fixed above one longitude.
- **Geosynchronous:** May have inclination and eccentricity, leading to a figure-eight ground path; not stationary over a single point.

### Application Decisions

- Geostationary and geosynchronous orbits are highly valued for continuous regional coverage, requiring fewer satellites for targeted geography.
- India’s NAVIC system utilizes GEO/GSO to optimize satellite number and region focus, compared to global constellations like GPS or GLONASS in medium Earth orbit.

## Orbital Forces and Launch Corrections

### Coriolis and Centrifugal Effects

- The Coriolis effect is crucial during the launch phase, influencing vehicle trajectory planning.
- Centrifugal forces are accounted for in satellite design and onboard operations during orbit; Coriolis is negligible once stabilized in orbit.

## Rockets: Structure, Stages, and Propulsion

### Fundamentals of Rocket Propulsion

- Based on Newton's third law: expulsion of high-speed gases generates an equal and opposite reaction (**thrust**).
- Rockets comprise fuel, oxidizer, engine, strong structural frame, guidance electronics, and payload.

### Automation and Electronics

- Rocket systems are pre-programmed for key events such as stage separation and payload deployment.
- Automation has greatly increased launch success rates, as rockets require minimal human intervention post-launch.

### Mass Considerations

- Majority of rocket mass (80-85%) is dedicated to fuel and oxidizer to overcome Earth's gravity.
- The actual payload (e.g., satellite, scientific device, or crew capsule) constitutes a tiny portion—about 0.01% of initial rocket mass.
- The objective is to impart sufficient kinetic energy for presence in, or escape from, Earth orbit.

Major Components of a Rocket -

a) Payload: Primary mission
b) Rocket Fuel (Propellent):
c) Engine: Fuel and Oxidizer get mixed and combustion allows to gain K.E.
d) Mainframe: Structural part of rocket.
e) Electronics:

## Staging in Rockets

### Purpose and Implementation

- Staging involves sequential discarding of spent fuel tanks and engines, reducing dead weight and increasing kinetic efficiency for remaining assembly.
- With each stage, the subsequent sections are lighter and thus accelerate more with the available energy.
- Boosters and multiple stages enable orbital insertion and high-altitude missions without excessively large single rockets.

### PSLV Staging Example

- PSLV utilizes four stages: first (solid), second (liquid), third (solid), and fourth (liquid).
- Fairing (payload cover) separates after atmospheric exit, protecting payload from friction during ascent.

### Multiple Payloads and Orbits

- Rockets can launch numerous payloads in a single mission, deploying them into different orbits through precise sequencing and velocity trimming.

### Propellant Types

i) **Solid Propellant**

- Remains solid at room temperature; examples include*HTPB (hydroxyl-terminated polybutadiene).*
- Easier and safer to store and transport.
- Cannot regulate thrust post-ignition; burns until complete exhaustion.
- Economical and simple engine structure suitable for boosters and initial lift-off.

ii) **Liquid Propellant**

- Flow can be controlled ~~throttled~~, shut off, or restarted as needed, providing control and flexibility.
- Examples include *UDMH* + $N_2O_4$ and *MMH* + *MON*; Vikas engine operates on liquid propellants.
- Require complex storage and logistics due to high reactivity and sometimes cryogenic needs.
- More expensive than solid propellants.

**Comparison Table: Solid vs Liquid Propellants**

| Feature | Solid Propellant | Liquid Propellant |
|---|---|---|
| **State:** | Solid at room temperature | Liquid at room temperature (or cryogenic) |
| **Ignition:** | Irreversible, burns fully | Thrust regulation and shutdown are possible |
| **Control:** | Minimal post-ignition control | High control, restart possible |
| **Engine Simplicity:** | Simple | Complex |
| **Storage/Logistics:** | Easy, low-cost | Complex, expensive |
| **Use:** | Booster/initial stages | Upper, velocity-trimming stages |

-> Rockets are launched in stages to shed the dead weights so that the remaining part can get more K.E.

## Cryogenic and Semi-Cryogenic Stages

### Cryogenic Stage

- Utilizes fuels (like hydrogen) and oxidizers (like oxygen) in a liquid state at extremely low temperatures.
- Liquid hydrogen condenses at approximately -253°C, while liquid oxygen at around -190°C.
- Offers highest energy density ~~among propellants~~, allowing greater payload capacity per kilogram.
  than solid or liquid fuel
- Only by-product is water vapor, leading to minimal pollution.
- Demands sophisticated engineering to maintain cryogenic temperatures and prevent boiling through thermal insulation.
- ISRO's CE-20 engine exemplifies indigenous cryogenic technology.

### Semi-Cryogenic Stage

- Fuel remains liquid at ambient conditions, while the oxidizer is cryogenic.
- Reduces storage challenges associated with full cryogenic stages.
- Under development in India to enhance rocket performance for upcoming missions.

## Rocket Stages: End-of-Life Disposal

- Once exhausted, higher rocket stages re-enter Earth's atmosphere.
- Lighter materials typically burn up; robust components (e.g., titanium) may survive re-entry, sometimes falling to Earth after prolonged orbital decay.

Types of ISRO Rockets

Past
-> SLV
-> ASLV

Present
-> PSLV
-> GSLV Mk-II
-> LVM-3 (earlier GSLV Mk-III)
-> SSLV

Future
-> NGLV (soorya)

## Major Types of ISRO Rockets

1. **PSLV (Polar Satellite Launch Vehicle)**

- Four-stage launcher, alternating solid and liquid fuel.
- Developed primarily for remote sensing and polar orbit missions, with capability for GTO and multiple payloads.
- Payload capacity: approximately 1,750 kg in a 600 km polar orbit; around 1,425 kg in GTO.
- Over 60 launches with a success rate above 95%; used for Chandrayaan-1, MOM, and Aditya L1.
- Cannot directly impart escape velocity; relies on onboard satellite propulsion for further maneuvers.

2. **GSLV Mk-II (Geosynchronous Satellite Launch Vehicle)**

- Three-stage rocket: 1st (solid with boosters), 2nd (liquid), 3rd (cryogenic).
- Payload capacity: approximately 5,000 kg to LEO; around 2,250 kg to GTO.
- Used for heavier communications and high-orbit satellites compared to PSLV.

3. **LVM-III (Launch Vehicle Mark-3, previously GSLV Mark-3)**

- Heavy-lift rocket with three stages: massive solid boosters, a liquid stage, and an upper cryogenic stage.
- Payload capacity: approximately 8,000 kg to LEO; around 4,000 kg to GTO, with planned upgrades to enhance capacity.
- Launched Chandrayaan-2, Chandrayaan-3, and is planned for the Gaganyaan manned mission.

4. **SSLV (Small Satellite Launch Vehicle)**

- Designed for rapid, on-demand launches of light payloads.
- Payload capacity: up to 500 kg in a 500 km orbit; comprises three solid stages plus a liquid velocity-trimming module.
- First flight failed due to stage separation timing; subsequent launches succeeded, validating quick assembly and cost-efficient design.

**Table: Key ISRO Launch Vehicles**

| Rocket | Stages | Payload (LEO) | Payload (GTO) | Main Use | Propulsion Type |
|---|---|---|---|---|---|
| PSLV | 4 | 1,750 kg | 1,425 kg | Polar, remote sensing, multiple satellites, interplanetary | Solid-Liquid alternates |
| GSLV Mk-II | 3 | 5,000 kg | 2,250 kg | Communication, high-orbit launches | Solid-Liquid-Cryogenic |
| LVM-III | 3 | 8,000 kg | 4,000 kg | Heavier satellites, human spaceflight | Solid-Liquid-Cryogenic |
| SSLV | 3 (+ VTM) | 500 kg | - | Small, rapid, and on-demand launches | Solid (+ liquid VTM) |

## Launch Strategies and Selection Basis

### Orbit and Payload Considerations

- Higher orbital destinations require greater energy, which limits the available payload mass due to finite fuel and oxidizer.
- Launch strategies balance fuel availability, required orbital velocity, and dead weight minimization via staging.

## End-of-Life Management: Satellites and Debris

### Protocols for Satellite Disposal

- Satellites in low Earth orbit (LEO) are programmed to perform re-entry burns, causing controlled atmospheric re-entry and ocean impact.
- Satellites in geostationary or higher orbits are boosted to graveyard orbits (approximately 45,000 km), reducing collision dangers.

### Space Debris Risks

- Incomplete burn-up of rocket stages or satellite components can form debris, stressing the need for end-of-life planning.
- Space debris has been an increasing concern, prompting stricter international protocols and innovation in satellite design for disposal.

## Reusability in Rocket Technology

### International Developments

- SpaceX pioneered successful reusable rocket stages, dramatically reducing launch costs and promoting innovation via private sector participation.
- Private companies can take higher technological risks, leading to faster advances.

### Indian Initiatives

- ISRO's "Pushpak" technology demonstration and emerging plans for the NGLV (Next Generation Launch Vehicle) aim for part and full reusability.
- Reusable rockets are anticipated to cut costs, optimize resource use, and support ambitious human and interplanetary goals.

**Private Sector Innovation**

**Startups in Indian Space Sector**

- **Skyroot Aerospace:** First private Indian company to launch a rocket (Vikram S), targeting future payloads up to 815 kg for low Earth orbit.
- **Agnikul Cosmos:** Developed the Agniban rocket, with capacity for 100 kg payloads, and created a 3D-printed engine, marking a first in global rocket engine manufacturing.

## 3D Printing: Applications in Space Technology

### Additive Manufacturing in Aerospace

- 3D printing (additive manufacturing) constructs components by depositing material layer-by-layer based on digital models.
- Enables rapid prototyping, complex structures, and lightweight, strong components.
- Applied to rocket engines (for example, Agnikul Cosmos), satellite parts, housing, and even biotic organ fabrication.
- Promotes flexibility (*modifying digital models before printing*), reduces waste, and facilitates innovation in both government and private sector manufacturing pipelines.

## Satellite Life Cycle and Post-Mission Protocols

### Mission Types and End-of-Life

- **Orbiters:** Remain around target body for observation; do not land or move on the surface.
- **Landers:** Touch down on a surface but remain stationary.
- **Rovers:** Land, deploy, and move to survey terrain, collect data, and transmit images.
- Post-mission, satellites in LEO are de-orbited if possible; those in higher orbits are directed to graveyard orbits to reduce collision risk.

Q: Discuss the achievements of ISRO in space science and technology, how does space technology contribute to socio economic development of the nation?

Hint: In second part we will talk about benefits to common people so think w.r.t healthcare, education, infrastructure development such as road and rail, communication, disaster management, agriculture.

## Socio-Economic Applications of Space Technology

### Major Use Cases Across Sectors

- *Meteorology and Weather Forecasting:*Enhanced accuracy for forecasts, tracking storms, and monitoring climate events like heatwaves.
- *Disaster Management:*Early warning systems support better planning, response, and recovery from events such as cyclones, floods, and earthquakes.
- *Agriculture:*Improved crop monitoring, soil analysis, and productivity through precision agriculture and meteorological data.
- *Healthcare and Education:*Satellite-based telemedicine and distance education foster better access in remote and rural areas.
- *Resource Monitoring and Urban Planning:*High-resolution satellite imagery underpins infrastructure planning and management in both urban and rural environments.
- *Communication and Navigation:*Widespread telecommunication, GPS, and terrestrial navigation systems improve logistical efficiency and safety.
- *Defense and Security:*Space-based assets support surveillance, navigation, and national security.
- *Maritime Navigation (Gemini) and Civil Aviation (GAGAN):*Specialized satellite services provide enhanced navigation for shipping and aviation sectors.

## Major ISRO Space Missions: Past, Ongoing, and Future

### Past Missions

**Chandrayaan-1 (2008)**

- India’s first mission to the Moon; orbiter design.
- Confirmed the presence of water on the lunar surface and atmosphere; identified various trace minerals with spectroscopy instruments.

**AstroSat**

- India’s first astronomical observatory, dedicated to studying extragalactic phenomena such as supernovas, neutron stars, and black holes.

**Mars Orbiter Mission (MOM/Mangalyaan)**

- India’s first interplanetary mission, which placed an orbiter around Mars on the first attempt—an unprecedented feat.
- Successful on the first try, with an extremely low mission cost (notably, less than the budget for the Hollywood film “Gravity”).

**Chandrayaan-2**

- Included an orbiter, lander, and rover; the orbiter remains operational, but the lander and rover failed to operate as planned due to a crash landing.

**Chandrayaan-3**

- Successfully landed a rover near the Moon’s south pole, making India only the fourth nation to achieve this.
- Focused on locations with potential water ice, crucial for potential lunar habitation.

### Ongoing Missions

#### Aditya L1

- India’s dedicated solar mission in operation, focusing on solar observations.

#### Exposat and Spadex

- **Exposat:** Observatory mission.
- **Spadex:** Technology demonstration for space docking experiments.

### Future and Planned Missions

- **Gaganyaan:** Human spaceflight mission targeting launch in 2027.
- **Chandrayaan-4:** Planned lunar mission for the late 2020s.
- **Shukrayaan:** Venus mission in the pipeline (2028-2030).
- **~~Bharti Antarik~~** Bhartiya Antariksha **Station:** Indian space station, with initial construction expected by 2028 and possible completion by 2035.
- **NGLV/Surya:** Next-generation, high-capacity, reusable launch vehicle under development.

## Additional Technical Concepts

### Escape Velocity and Mission Profiles

- Escape velocity from Earth’s surface is 11.2 km/s; rockets like PSLV cannot impart this in one launch, necessitating orbital maneuvers using satellite propulsion.

### Fuel Types: Chemical Details

- *MMH (Monomethylhydrazine)*and*MON (Mixed Oxides of Nitrogen)*are common liquid propellant combinations for upper rocket stages.
- Cryogenic propellants (liquid hydrogen/oxygen) are increasingly preferred for their efficiency.

### Atmospheric Re-entry and Payload Fairing

- The payload fairing separates once atmospheric friction is no longer a concern, typically after initial stage separation.

## Topic to be Discussed in the Next Class

- Detailed discussion on the Aditya L1 solar mission.
- Exposat, Spadex, Gaganyaan, and other current and future ISRO missions.