Science and Technology Class 03

Previous Class Topic

- Applications of remote sensing and navigational satellites
- Introduction to **Kepler's laws** and **Newton's laws of motion**

Newton’s Laws of Motion and the Concept of Frames of Reference

Newton’s Laws of Motion

- **First Law:** An object remains at rest or in uniform motion unless acted upon by an external force.
- **Second Law:** Force is needed for any acceleration, including changing direction at a constant speed.
- **Third Law:** Every action has an equal and opposite reaction.

Universal Law of Gravitation

- All objects with mass attract each other via gravitational force.
- The force is extremely weak in daily life but very significant on astronomical scales (planets, stars, galaxies).

Relative Nature of Motion and Rest

- Motion and rest are *relative* concepts, meaning there is no absolute rest or absolute motion.
- The same object can be at rest or in motion depending on the observer’s frame of reference.
- *Example:* Two people in a moving car are at rest relative to each other; however, from the road observer’s frame, they are moving.
- For all observers on Earth, stars and the Sun seem to move, but from another frame (outside the solar system), both Earth and Sun are in motion.
- The *frame of reference* must be specified to apply Newton’s laws correctly.

Importance of Frame of Reference

- Calculations involving Newton's laws require a defined frame of reference.
- Without a specific frame, mathematical and conceptual errors arise.
- Forces such as Coriolis and centrifugal forces are only meaningful in non-inertial (accelerating) frames.

Orbital Motion: Centripetal and Centrifugal Forces

Orbital and Circular Motion

- Objects in orbital or circular motion need a continuous force that changes their direction by acting towards the center (**centripetal force**).
- For planetary orbits, this force is provided by gravity.
- For a bicycle turning on a flat road, friction provides the centripetal force.
- Even at constant speed, changing direction means the object is accelerating, and therefore a force is required.

Centripetal and Centrifugal Force: Reference Frames

- **Centripetal force:** Directed towards the center of the circular path; keeps the object in orbit.
- **Centrifugal force:** An apparent force perceived in a rotating (non-inertial) reference frame, directed outward from the center.
- In an inertial frame, only centripetal force acts; in a rotating (non-inertial) frame, centrifugal force must be considered for calculations.

Table: Comparison of Centripetal and Centrifugal Forces

Force Type	Direction	Acts In	Origin
Centripetal Force	Towards the center	Inertial frames	Real force
Centrifugal Force	Away from the center	Non-inertial frames	Pseudo-force

Concept of Pseudo-Force

- Pseudo-force appears when observing from a non-inertial (accelerating) frame.
- It is essential to introduce pseudo-forces in accelerating frames to correctly apply Newton's second law.
- Pseudo-forces are not generated by mass or charge but are a result of being in an accelerating reference frame.

Inertial and Non-Inertial Frames

Inertial Frames

- An inertial frame is either at rest or moves with uniform velocity (constant speed and direction).
- Newton's second law ($F = ma$) can be directly applied.
- *Example:* A truck moving at constant velocity—throwing a ball upward makes the ball land back into the thrower's hand, as observed from inside the truck.

Non-Inertial Frames

- A non-inertial frame is accelerating (changing speed or direction).
- Newton's laws cannot be directly applied; pseudo-forces must be introduced to maintain correct calculations.
- *Example:* A truck accelerating forward—objects inside appear to move backward due to a pseudo-force.

Planetary Motions and Solar System Dynamics

Motion of Earth, Sun, and Galaxy

- The Earth spins on its axis and revolves around the Sun; the Sun itself orbits the center of the Milky Way galaxy.
- The Milky Way and other galaxies move relative to each other; the universe itself is expanding.
- Traditional solar system diagrams are simplified because, in reality, everything is in motion.

Satellites and Orbits

- Artificial satellites, like planets and moons, are kept in orbit by gravity (the universal law of gravitation).
- Once placed in orbit, satellites do not require fuel for their motion; gravity provides the necessary centripetal force.
- The period of revolution (time to complete one orbit) depends only on the satellite's distance from Earth's center, not on its mass or inclination.

a) Low Earth Orbit (LEO):- 200 - 2000km

b) Medium Earth Orbit (MEO):- 2000 - 35,785km

c) High Earth Orbit (HEO):- greater than equal to 35,786km
h = 35786km (Geosynchronous orbit)

Classification of Satellite Orbits

~~By~~ Based Altitude

Table: Satellite Orbit Classifications by Altitude

Orbit Type	Approximate Altitude	Use Cases	Example Features
Low Earth Orbit (LEO)	~180–2,000 km	Remote sensing, Earth observation	Period: ~90 min at 500 km
Medium Earth Orbit (MEO)	~2,000–35,786 km	Navigation, some communications	
Geostationary Orbit (GEO)	35,786 km (above equator)	Communication, weather satellites	Fixed over equator, 24-hour period

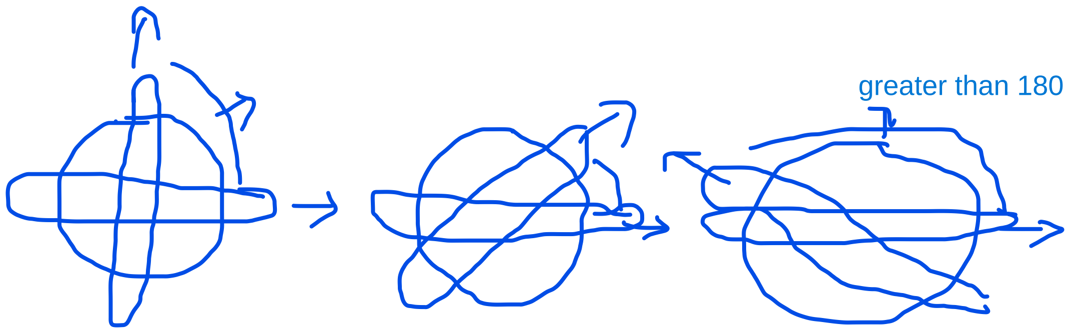
In low orbits like 500 km, satellites orbit quickly (~90 minutes) and can only observe a specific location for a few seconds as they pass overhead. Satellites in higher orbits (like geosynchronous) have longer periods and can provide continuous coverage over specific regions.

~~By~~ Based Inclination

Table: Satellite Orbit Classifications by Inclination

Orbit Type	Inclination Angle	Description
Equatorial Orbit	~0°	Above the equator
Polar Orbit	~90°	Passes over poles
Inclined Orbit	Any angle between 0°-180°	Between equator and pole

Inclination refers to the angle between the satellite's orbital plane and the equatorial plane. Polar orbits (near 90° inclination) allow satellites to pass over nearly every part of the globe as Earth rotates beneath them, while inclined orbits are used for various applications.



-> Rocket payload capacity will be less for polar orbits as it will not get any assist from Earth's rotation.

Based on shape -
a) Circular -> Geostationary, Sun synchoronus polar orbit
b) Elliptical -> Most of the orbit

Earth’s Shape and Effects on Orbits

Earth's Non-Spherical Shape

- Earth is not a perfect sphere; it has an equatorial bulge and is flattened at the poles.
- The equatorial radius is slightly greater than the polar radius, but this difference is negligible for most orbital calculations.
- The bulge affects certain orbital mechanics, especially in sun-synchronous orbits.

Launching Satellites: Constraints and Earth’s Rotation

Influence of Earth’s Rotation

- Launching satellites into equatorial orbits is easier from locations close to the equator due to assistance from Earth's rotation (*maximum linear speed*).
- Payload capacity is higher for equatorial launches due to this rotational boost.
- Launching into polar orbits is more challenging because Earth’s rotation does not assist directly, resulting in reduced payload capacities.

Practical Launch Site Considerations

- Most spaceports are located on eastern coasts to capitalize on Earth’s rotation (west to east launches).
- Geopolitical factors and proximity to the equator influence the site selection; maneuvers or alternate locations may be used to avoid populated or restricted regions.

Based on Earth's motion :-
a) Rotation on its axis -
-> Geosynchronous orbit.

b) Revolution around sun -
-> Sun-Synchronous orbit.

Unique Types of Orbits: Geosynchronous/Geostationary and Sun-Synchronous

Geosynchronous and Geostationary Orbits

Geosynchronous Orbits

- A geosynchronous orbit has a revolution period equal to Earth's rotation period: about 24 hours (more precisely, 23 hours and 56 minutes or one sidereal day).
- Any orbit with this period is geosynchronous, regardless of inclination; the path traced over Earth is not stationary except for a specific case.

Geostationary Orbit (Special Case)

- A geostationary orbit is a circular, equatorial geosynchronous orbit at 35,786 km altitude.
- The satellite appears fixed at a single point above the equator.
- It is ideal for continuous communication, broadcasting, and some navigation applications.

Comparison Table: Geosynchronous/Geostationary Orbits

Orbit	Revolution Period	Inclination	Altitude	Appearance from Earth	Applications
Geosynchronous	24 hours	Any	Varies	Moves in the sky	Navigation, comm.
Geostationary	24 hours	0°	35,786 km	Fixed over equator	TV, comm., weather

Most geostationary satellites are communication satellites, providing continuous coverage to large parts of the Earth (except the polar regions).

-> These orbits are very useful for communication, Earth observation and Navigational satellites.

Sun-Synchronous Polar Orbits (SSO)

Definition and Concept

- A sun-synchronous orbit is a near-polar orbit where the satellite crosses any point on Earth at the same local solar time.
- The orbital plane slowly rotates (precesses) around Earth, matching Earth's revolution around the Sun (about 1 degree per day).
- This ensures a consistent sun angle during repeated observations—critical for optical remote sensing and accurate year-over-year data comparison.

Why Sun-Synchronous Orbits Are Needed

- Consistent lighting conditions are essential for remote sensing, especially for optical imaging (e.g., forest cover mapping).
- They eliminate issues related to varying shadows and lighting across different days and seasons.

How Sun-Synchronous Orbit Is Achieved

- Earth's equatorial bulge exerts an asymmetric gravitational force on inclined satellites, causing a torque.
- This torque results in the precession (rotation) of the satellite's orbital plane.
- At specific altitudes (600–800 km) and inclinations (94°–96°), the rate of this precession matches Earth's movement around the Sun.
- As a result, the satellite's orbital plane maintains a fixed orientation relative to the Sun, ensuring the local solar time of overpasses remains constant.

-> Earth is not a perfect sphere it has bulge on the equator and flatness on the pole because of this for high inclined orbits the asymmetric gravitational force exerts a torque on the orbit this causes satellites orbit to precess i.e. orbits in itself starts rotating such precess is a challenge most of the time but in sun synchoronous it is used as an opportunity we need to achieve a precession of about 1 degree everyday so that satellite's orbit maintains the same angle w.r.t sun even though Earth is revolving around Sun.

Key Points on Sun-Synchronous Orbits

- Precession, although usually undesirable, is used beneficially in sun-synchronous orbits.
- The calculation for achieving exact precession is complex and depends on altitude and inclination.
- Sun-synchronous orbits are typically used for remote sensing and environmental monitoring satellites.

Comparison Table: Geostationary/Geosynchronous vs. Sun-Synchronous Orbits

Feature	Geostationary/GSO	Sun-Synchronous Orbit
Altitude	35,786 km	600–800 km
Inclination	0° (geo), any (GSO)	~98° (polar)
Coverage	Same region (global)	Different points, near-polar sweep
Time for one orbit	24 hours	~90–100 minutes
Sun angle for overpass	Varies/constant (geo)	Constant for any location
Applications	Communication, navigation	Remote sensing, Earth observation

Effects of Earth’s Motion on Air Travel and Satellite Launches

Air Travel and Non-Inertial Frames

- Passengers and the atmosphere move with Earth; simply elevating an aircraft does not allow travel via Earth's rotation.
- Earth's rotational momentum is shared by everything attached to its surface.
- To exploit Earth's rotation for travel, one must leave the atmospheric system, which is impractical for commercial aircraft.

Rocket Launches and Direction

- Launching from west to east leverages Earth's rotation for added velocity.
- Launches to polar orbits do not benefit from rotational assistance, requiring more energy and resulting in lighter payloads.

Orbit Shape: Circular vs. Elliptical

Types of Orbits by Shape

- **Circular orbits:** Maintain constant altitude and speed; geostationary orbits are always circular.
- **Elliptical orbits:** Feature varying altitude (perigee and apogee); many practical orbits are slightly elliptical for fuel efficiency or due to launch constraints.
- Satellites launched in elliptical "transfer orbits" (e.g., geosynchronous transfer orbit—GTO) later circularize at their operational altitude.

Launch Vehicles and Indian Space Program Examples

PSLV (Polar Satellite Launch Vehicle)

- Designed primarily for launching satellites into polar orbits, but can also be used for equatorial launches.
- Launches from Sriharikota and is subject to payload constraints particular to orbit type.

Geo-transfer Orbits (GTO)

- Intermediate elliptical orbits used to transfer a satellite to its final geosynchronous or geostationary position.
- Satellites use onboard fuel to reach and circularize at their intended altitude after separation from the launch vehicle.

Indian Satellite Navigation & Remote Sensing Systems

NAVIC

- Utilizes a constellation of seven satellites: three geostationary and four geosynchronous.
- Provides navigation and location information exclusively over India and surrounding regions.
- The satellites remain positioned above India, not covering the entire globe.

GAGAN

- An Indian Satellite-Based Augmentation System (SBAS) designed for improved accuracy in civil aviation.
- Uses three geostationary communication satellites as primary relays.
- Relies on both Indian satellites and GPS signals; includes ground-based antennas and computational infrastructure.
- Initially intended for aviation, it is now used in railways, mapping, surveying, and ocean sciences.
- Serves as both a precursor and a complement to NAVIC.

Satellite Resolving Power

Concept of Resolving Power

- The ability of an optical instrument (or the human eye) to distinguish between two closely spaced objects or wavelengths.
- *Example:*When viewing distant car headlights, they may appear as one light; as the car approaches, the two become distinguishable.
- All optical devices have a finite resolving power, which defines the level of detail visible in images or observations.

Current and Upcoming Satellite Missions

NISAR Mission

- A joint NASA-ISRO radar imaging mission targeting environmental monitoring and disaster management.
- The satellite will be launched into a sun-synchronous polar orbit.
- Utilizes L-band and S-band synthetic aperture radars for detecting changes on Earth’s surface, including minute alterations by natural or human causes.
- Aims for global mapping and continuous collection of environmental data.

Application and Limitations of Satellite Data

Revisiting and Coverage Constraints

- Low Earth Orbit (LEO) satellites revisit the same location only after several days; they do not provide continuous coverage.
- Geostationary satellites offer persistent coverage for their fixed region but at a lower spatial resolution.
- Polar/sun-synchronous satellites are crucial for global mapping and climate change monitoring, especially in remote or high-latitude regions (poles).
- Navigation satellites (like NAVIC) have restricted coverage, focusing on their targeted area, such as the Indian subcontinent.

Phenomena Related to Rotating Reference Frames

Coriolis Force

- An apparent force in rotating reference frames that causes moving objects to deviate from a straight path.
- It is responsible for the direction of cyclones and prevailing winds.

Centrifugal Force (as Pseudo-Force)

- An apparent outward force on a body moving in a circle, which is felt only in the rotating frame.
- This force is physically real in the non-inertial frame, yet it vanishes when analyzed from an inertial frame.

Key Physics Concepts in Orbit Determination

Escape Velocity and Period Independence

- Both the orbital period and escape velocity are **independent** of the satellite's mass.
- The orbital period depends solely on the satellite's altitude (distance from Earth's center).
- The height required for a 24-hour revolution (geosynchronous orbit) is approximately 35,786 km.

Torque, Precession, and Orbit Adjustment

- **Torque**: The rotational equivalent of force, defined as the product of an applied force and its distance from the axis of rotation.
- **Precession**: The gradual change in the orientation of the orbital plane, driven by asymmetric gravitational forces due to Earth's shape.
- Precession can be undesirable for certain missions, yet it enables sun-synchronous satellites to maintain a constant solar alignment.

Satellite Collisions and Crowding

Probability and Risks

- Due to the vastness of space, actual satellite collisions are extremely rare.
- Most orbital regimes, including popular ones like geostationary and polar, have ample separation between satellites.

Practical Examples and Analogies

Everyday Analogies for Reference Frames

- Motion in a moving bus or car illustrates relative motion and the importance of defining a frame of reference.
- Exiting a moving vehicle without adjusting your speed can lead to a fall due to retained momentum.
- Earth's rotational frame is shared by land, air, and water, affecting perceptions of motion.

Topic to be Discussed in the Next Class

- Rockets: Detailed discussion on principles, operation, and launch mechanisms.
- Overview of Indian space science missions and astronomical observatories (Chandrayaan, Mangalyaan, current, and upcoming missions).