ORBITAL MECHANICS

Orbital mechanics is the study of how satellites and other spacecraft move in space. It's also known as flight mechanics.

The path followed by any moving object through space is called **Trajectory**.

- Object repeats its path: Called **Orbit,** Eg:- satellites revolving around earth.
- Object does not repeat its path: Eg:- interplanetary spacecraft.

There are infinite numbers of closed orbits around a celestial body, so we need some properties/parameters to determine an orbit uniquely.

The parameters determine the **shape and size**, **orientation** of the orbit and **location** of the spacecraft.

Based on shape and size there are 2 parameters :- **Eccentricity** and **Semi major axis**

Based on orientation there are 3 parameters :- **Inclination**, **Right Ascension of Ascending Node** (**RAAN**) and **Argument of periapsis**

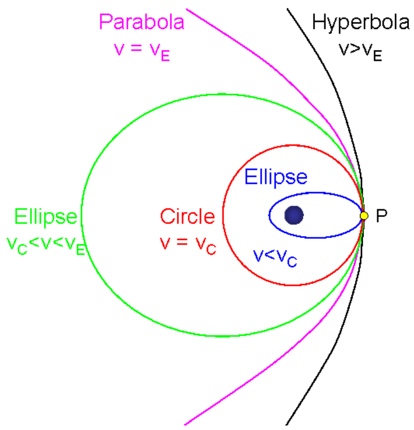
Based on location there is 1 parameter :- **True anomaly**

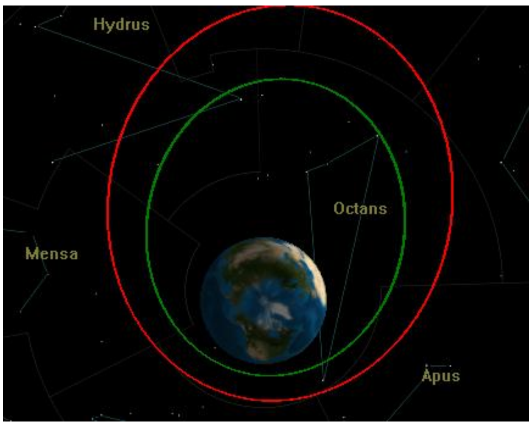
These 6 parameters are called orbital parameters or Keplerian elements.

Eccentricity (e)

Describes the roundness of an orbit

- Circular orbit: e = 0
- Elliptic orbit: 0 < e < 1
- Parabolic trajectory: e = 1
- Hyperbolic trajectory: e > 1





Now we can have same eccentricity of 0.5 but different orbits are possible as shown here.

So to constrain the size we will define Semi major axis.

Semi major axis (a)

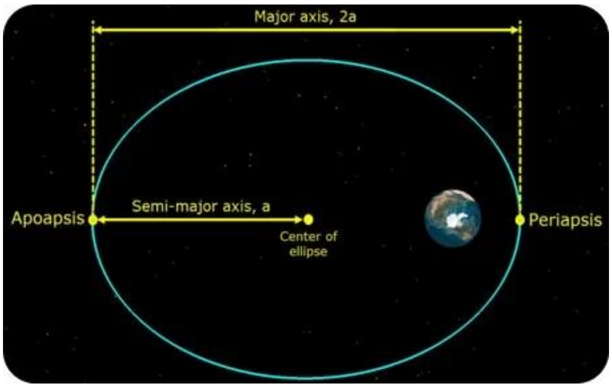
Distance from centre of the body (earth) to the periapsis = r_p

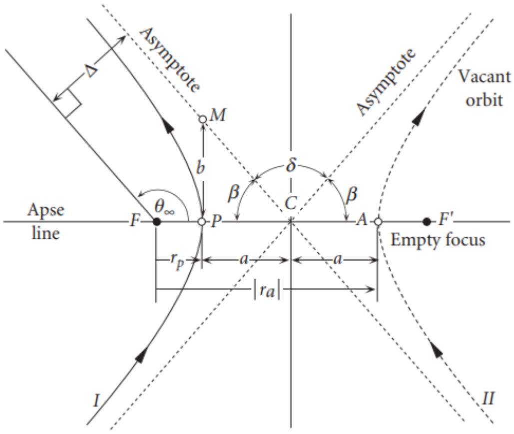
Distance from centre of the body (earth) to the apoapsis = r_a

For circle, a $=$ radius

For ellipse, $a = \frac{r_a+r_p}{2}$

For hyperbola, $a = \frac{-r_a-r_p}{2}$, r_a is negative in case of hyperbola.





Inclination (i)

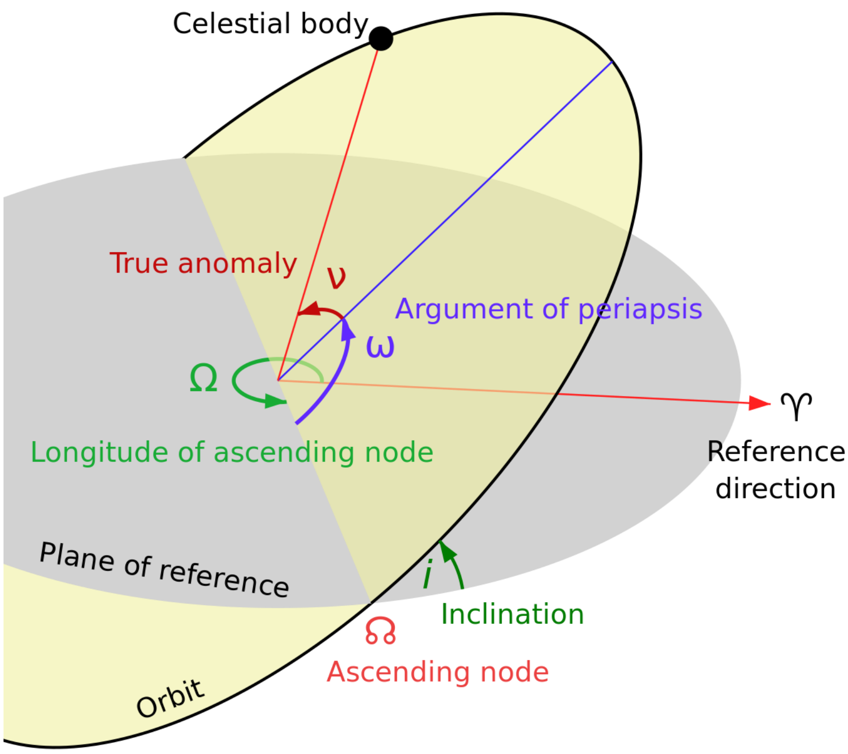
Angle made by orbital plane with equatorial plane.

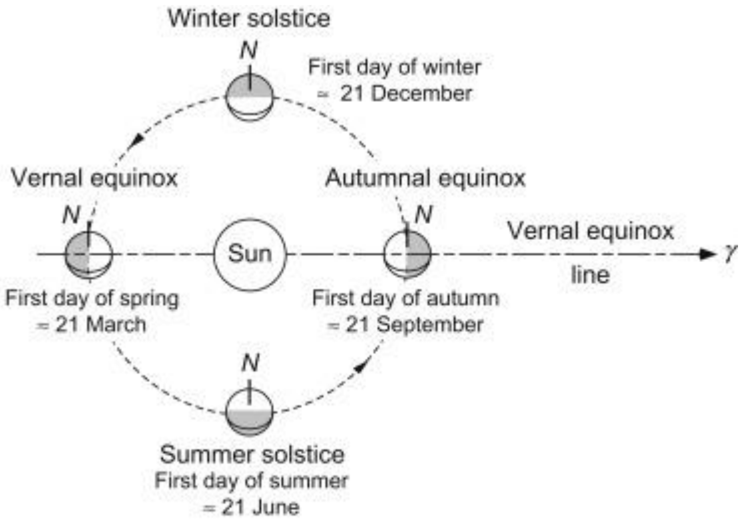
i=0°, is called equatorial orbit

i=90°, is called polar orbit

➔ Before proceeding further, let's define a Reference direction that does not rotate with earth. It also helps us to establish an inertial coordinate system called **Geocentric equatorial coordinates.**

➔ The reference direction, **vernal equinox** is the line from the Earth to the sun on the first day of spring, March 21.



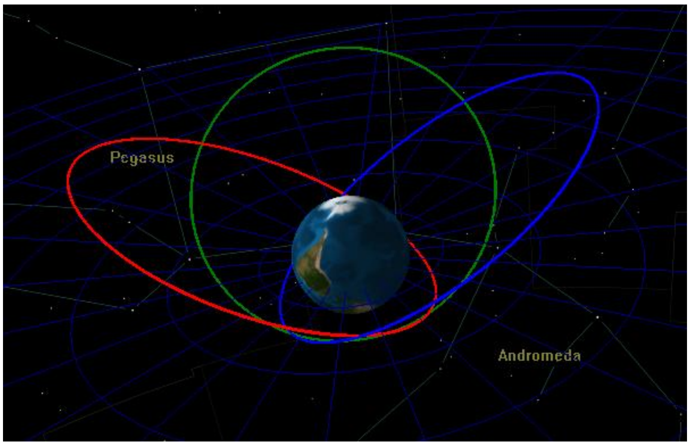


RAAN (Ω)

The Right Ascension of the Ascending Node (RAAN) is the angle between the Vernal Equinox direction and the ascending node.

The ascending node is the point where a satellite crosses the equator moving upward from south to north.

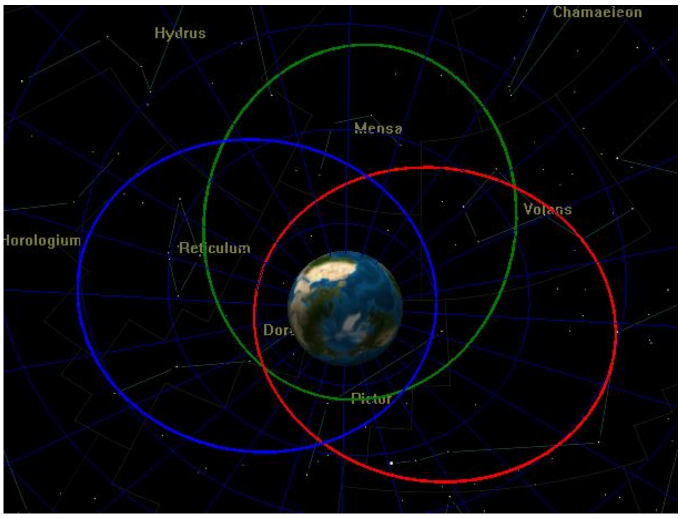
Here, these are 3 orbits with same “e”, “a”, “I” but different “Ω”.



Argument of periapsis (ω)

The argument of perigee (ω) is the angle between the ascending node and the perigee of an elliptical orbit measured in the direction of satellite’s motion.

Here, these are 3 orbits with same “e”, “a”, “I”, “Ω” but different “ω”.

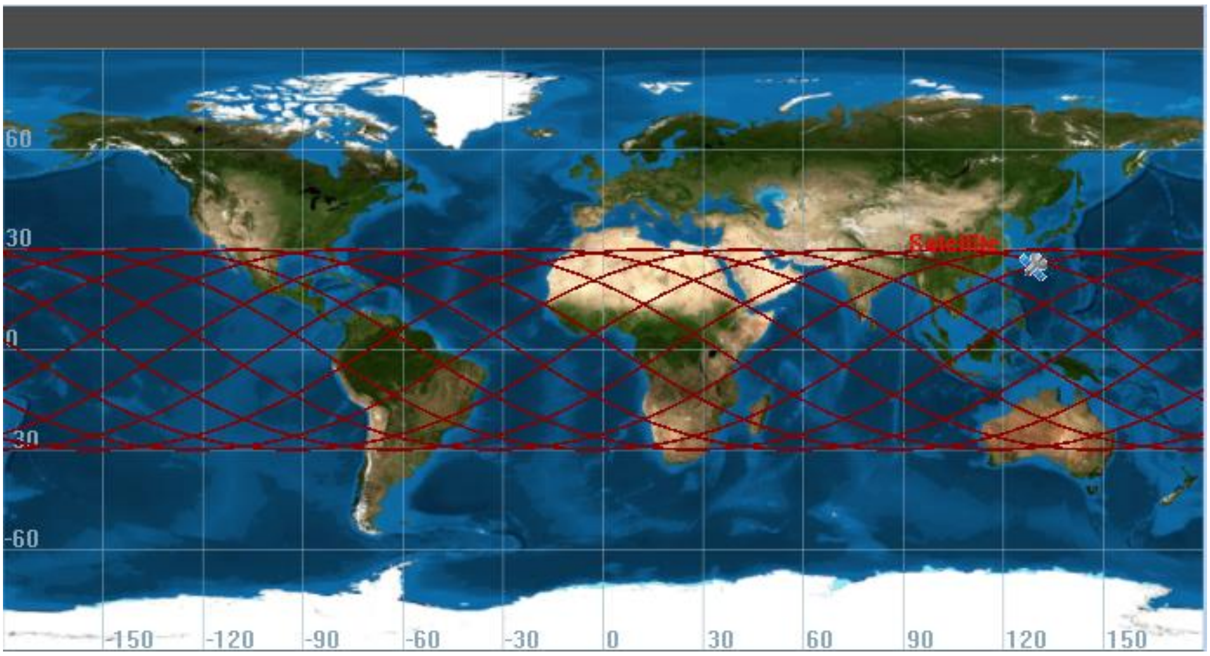


True Anomaly

It is the angle between the direction of periapsis and the current position of the body.

Ground Track

A ground trace, or ground track, is the path on the surface of a planet directly below an satellite.



(ground trace of a satellite with a=8000km, e=0, i=30, Ω=0, ω=0)

Can you find the inclination of an orbit by seeing its ground trace?

Specific Orbits

Low Earth Orbit(LEO): Close to earth, normally less than 1000km altitude. Cubesats are generally inserted in LEO.

Geosynchronous orbit: Low inclination orbit about Earth having a period of 23 hours 56 minutes 4 seconds. A spacecraft in geosynchronous orbit appears to remain above Earth at a constant longitude, although it may seem to wander north and south.

Geostationary orbit: The orbital period of a satellite in a geostationary orbit is equal to the Earth's rotation period of 23 hours and 56 minutes. This means that a spacecraft in a geostationary orbit appears to be motionless in the sky to an observer on Earth.

Geostationary orbits are also known as geosynchronous orbits with 0° inclination.

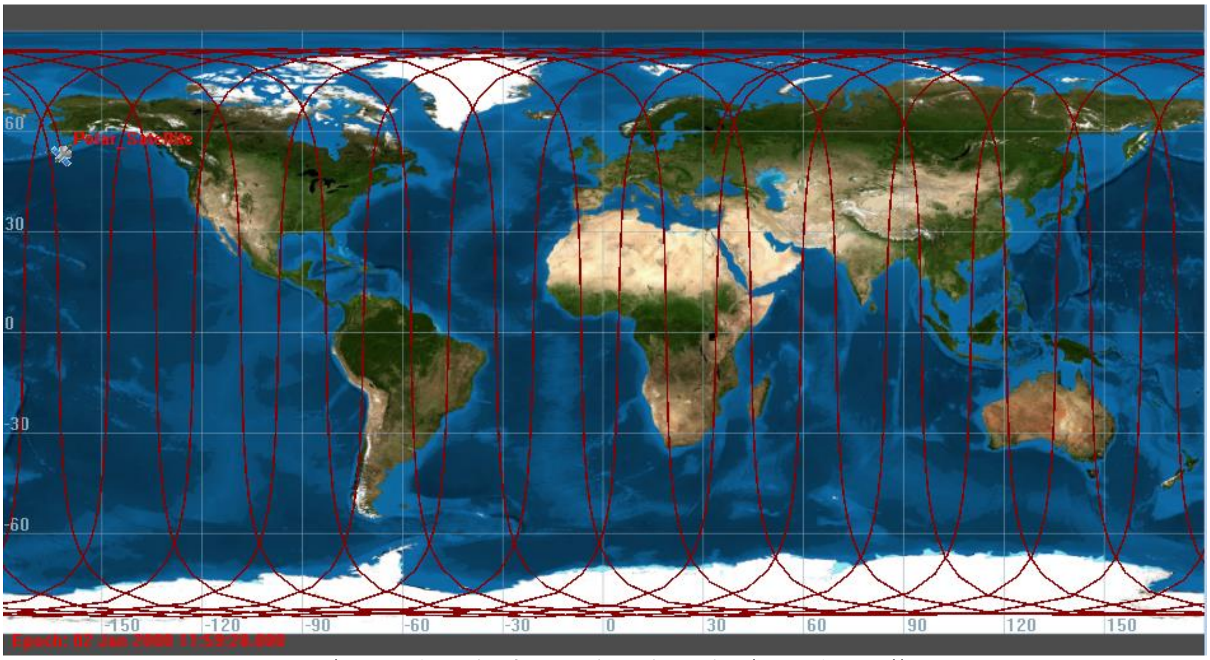
Geostationary satellites can see ~70°north and south of the equator.

Molniya orbit: Using Geostationary orbits for communication purposes was not possible for Russia because most of its area lies near 70°. So to overcome this problem they created a new type of orbit, Molniya orbit.

In this orbit (highly elliptic and 63.4° inclination) most of the time the satellite remains over Russia and its argument of periapsis (ω) remains constant (which is not the case for any other orbits, ω changes with time because of earth's oblateness.)

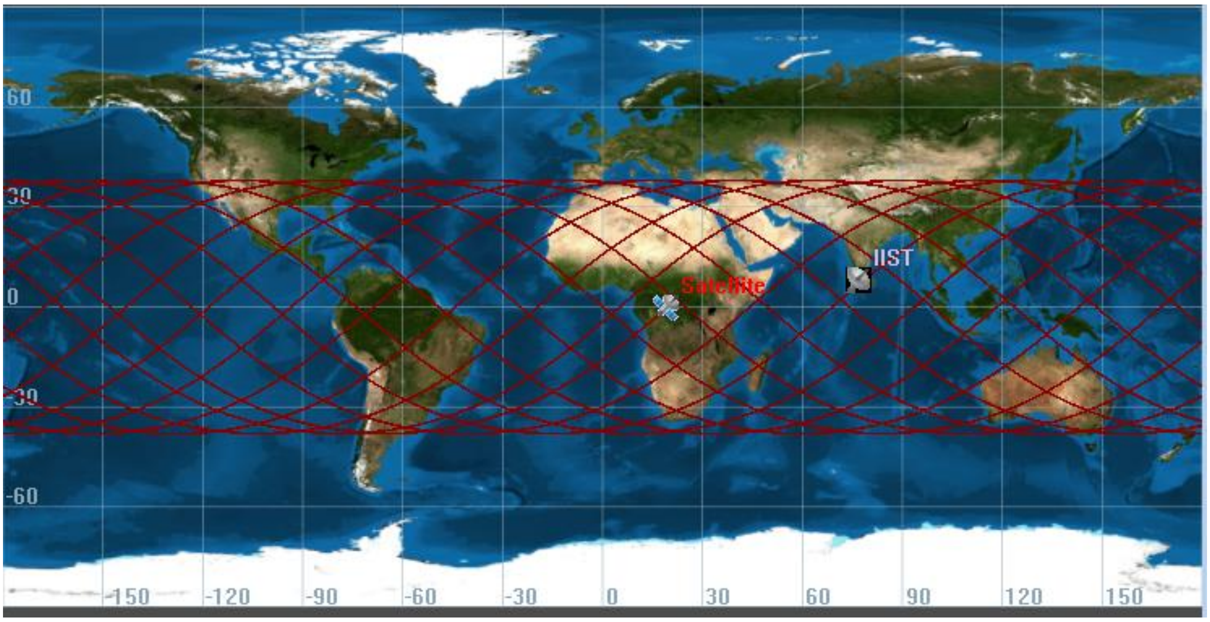
Orbit Design

- Designing any orbit requires you to choose the orbital parameters wisely to meet your mission requirements.
- Inclination is sometimes chosen based on ground station and global coverage.
    - A polar orbit (i=90) will cover the entire globe nearly 4 times daily.



(Ground track of a nearly polar orbit (i=85 degree))

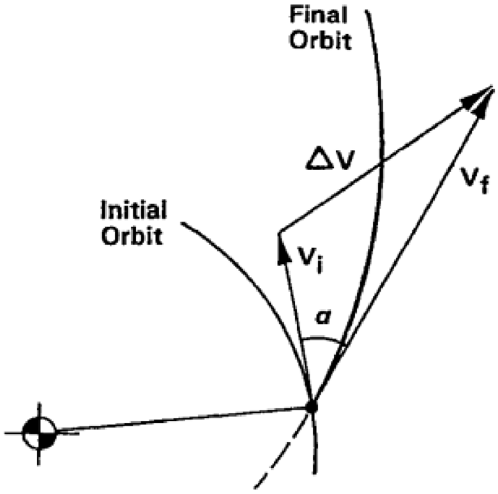
    - If we want the satellite to pass over a certain region or ground station many times in a day



(i=38 degree, Covers entire India and Ground station IIST)

(In this orbit the satellite can communicate 5 times with the ground station each day)

- ΔV budget
    - ΔV Is the change in velocity required to transfer the satellite from one orbit to another as shown here.



It is required for an interplanetary mission or any mission that requires orbital maneuver so that we can determine the amount of propellant required for the maneuver.

References

- Orbital Mechanics for Engineering Students, Howard Curtis
- Elements of Spacecraft Design, Charles D. Brown
- Software used: General Mission Analysis Tool (GMAT)