# *Spacecraft Motion Basics*

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**End** point of an **ascent** mission is the **start** point for the **orbital** mission.

**Similar** to ascent mission, **orbital mission** also can be divided into **segments.**

**First** segment is immediately after **separation**, when it is normally **put** into a temporary orbit called **LEO or GTO.**

# *Orbital Mission Phases*

Next, a **series** of orbital **manoeuvres** are carried out in order to **put** spacecraft into the **final** or parking **orbit.**

However, for **inter-planetary** missions, manoeuvres **aim** to put spacecraft on a **trajectory** for other planets.

# *Spacecraft Motion Scenarios*

Upon **injection,** spacecraft **moves** as per its **initial** conditions and **forces** experienced by it.

Thus, in order to **predict** motion of spacecraft from this point **onwards,** there a need to **create** mathematical **models**, that represent the above **motion** scenario.

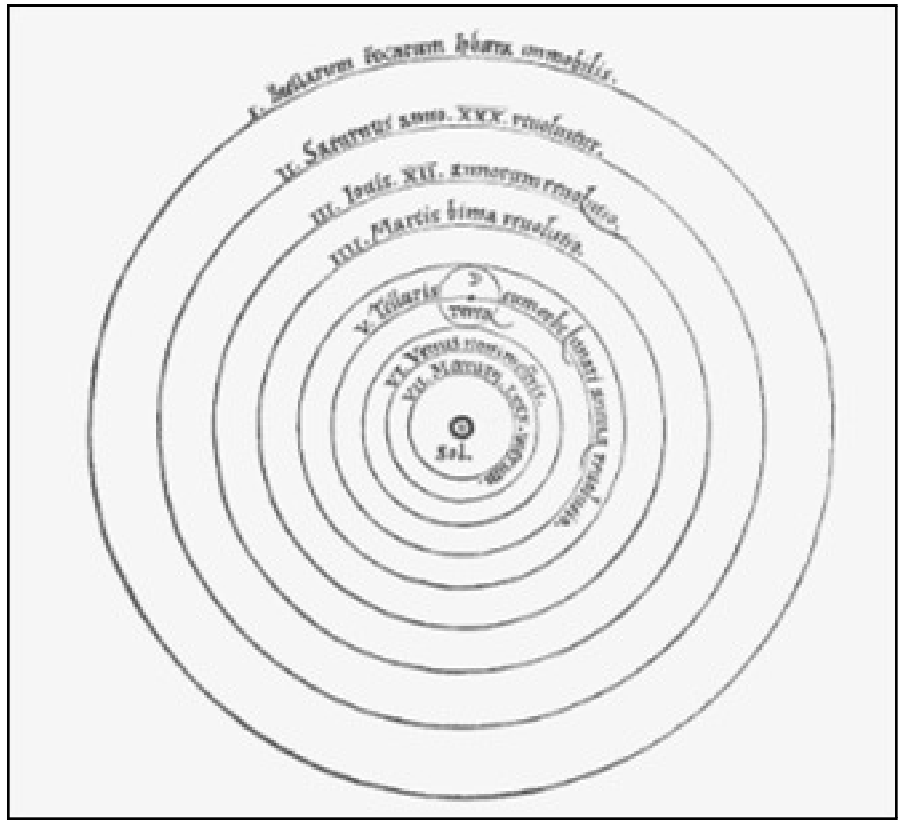
# *Context of Spacecraft Motion*

As **spacecrafts** operate mainly in our **solar system**, forces present in it **need** to be modelled **suitably.**

In this regard, it is **useful** to understand the **nature** of motion of **planets**, as these are also under **similar** forces**.**

# *Copernican Motion Model*

**Copernicus** in 1543, established **sun** as centre**,** with all the planets **orbiting** around it.



# *Kepler's Motion Hypothesis*

**Kepler** subsequently formulated the **laws** of planetary **motion,** which are given **alongside**.

**These** laws are **generic** and can be **applied** to any **orbit**, including **Earth-satellite** system.

1. All **planets** move around the **sun** in planar and **elliptic** orbits, with sun as one **focus**.

2. **Radius** vector from **sun** centre to **planet** centre sweeps **equal** areas in equal **time**.

3. (**Time period** of the orbit)$^2$ $\propto$ (**Semi-major** axis)$^3$

# *Planetary Motion Features*

**Orbital** solution, as proposed by **Kepler**, is based on the **premise** that all **objects** in space form an **orbit**, which can be **observed.**

However, there are no **explicit** guarantees in Kepler's laws that all **objects,** if left in space, will form **orbits.**

# *Planetary Motion Features*

This **issue** was settled by **Newton,** who formally derived the **Kepler's laws**, using his own three **laws** of motion.

This also led to the **evolution** of particle motion **theory**, which is central to the **orbital** mechanics.

# *Space Force System*

# *Force Field in Space*

In outer **space**, there is practically no **atmosphere** and therefore no **aerodynamic** forces are present.

Also, spacecraft has **limited** propulsion capability, which is used only for short-duration **manoeuvres**, resulting in no **propulsive** forces either.

# *Force Field in Space*

Further, forces due to **magnetic** field and solar **radiation** are very **small** and have **impact** only on the long term **drift** of the satellite from its **path**, and hence, ignored.

Thus, **gravity** is the only **important** force, which **primarily** determines the spacecraft **motion.**

# *Gravitational Model*

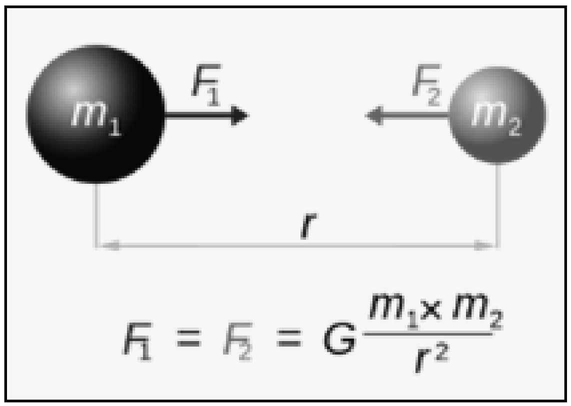
In **space**, general form of the **universal** law of gravitation is **applicable.**

Further, as **sizes** of planets are much **smaller** in relation to their **mutual** distances, (as indicated by fact sheet), we invoke **spherical** symmetry and **point mass** assumptions.

| | MERCURY | VENUS | EARTH | MOON | MARS | JUPITER | SATURN |
|---|---|---|---|---|---|---|---|
| **Dia (km)** | 4879 | 12,104 | 12,756 | 3475 | 6792 | 142,984 | 120,536 |
| **Sun Distance ($10^6$ km)** | 57.9 | 108.2 | 149.6 | 0.384* | 227.9 | 778.6 | 1433.5 |

# *Applicable Gravitational Model*

**Space** gravity model is also based on the **universal** law of gravitation, which is **defined** as follows.




$$\vec{F}_g = -\frac{Gm_1m_2}{r^3}\vec{r} = -\frac{\mu m_2}{r^3}\vec{r}$$

$$\mu = Gm_1; \quad \Phi_g = -\frac{\mu}{r}$$

$$g = \text{grad}(\Phi_g)$$

## ***Summary***

The **motion** of spacecraft upon **injection** is similar to the **planetary** motion features and is broadly **governed** by the Kepler's laws.

Further, the **force** system, for most **space** based objects, consists only of the **gravitational** force.