Plane Change Manoeuvres

Orbit Plane Change Requirements

There are times when it is **necessary** to change **plane** of an orbit, after the **satellite** establishes an **initial** orbit**.** It may also be needed for **inter-planetary** missions.

Plane change also is required if a **satellite**, launched into an **equatorial** orbit, is needed above a **different** latitude.

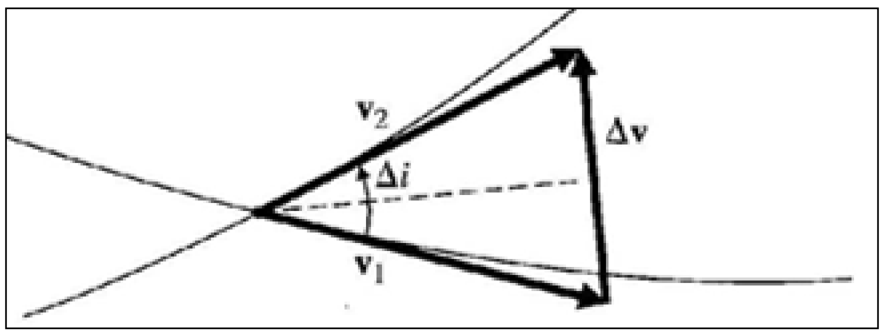
Orbit Plane Change Features

This is **particularly** true for sites in **higher** latitude (e.g. **Kiev** in Ukraine), for achieving **equatorial** orbits.

A change in **orbital** plane is an **expensive** manoeuvre and **every** effort is **made** to either avoid or **minimize** it.

Inclination Changing Concept

Plane change requires **non-coplanar** velocity impulse, as **shown** in the figure below.



Inclination Changing Formulation

In the **general** case when we want both the **orbit** and its **plane** to change, we can write the **following** relation.

$$\boxed{\Delta V^2 = V_1^2 + V_2^2 - 2V_1V_2\cos\Delta i}$$

If both **orbits** are same except **inclination**, $V_1 = V_2 = V$.

Orbit Plane Changing Solution

The expression for **'ΔV'** can be simplified as follows.

$$\Delta V^2 = 2V^2(1-\cos\Delta i) \rightarrow \Delta V = \sqrt{2}\cdot V\sqrt{1-\cos\Delta i} = 2V\sin\frac{\Delta i}{2}$$

This 'ΔV' **instantaneously** changes the orbit **inclination**.

Orbit Plane Change Solution Features

Small changes in ‘i’ are possible **anywhere** on the orbit.

However, for **large** inclination **changes**, impulse requirements are **large**, and hence large **changes** in ‘i’ are carried out where **local** velocity is **small.**

Large Inclination Changing Concept

In general, large **inclination** change is more **efficient** at apoge**e**, in comparison to **perigee**, as shown below.

$$\frac{\Delta v_a}{\Delta v_p} = \frac{v_a}{v_p} = \frac{r_p}{r_a} = \frac{1-e}{1+e}$$

Large Inclination Changing Strategy

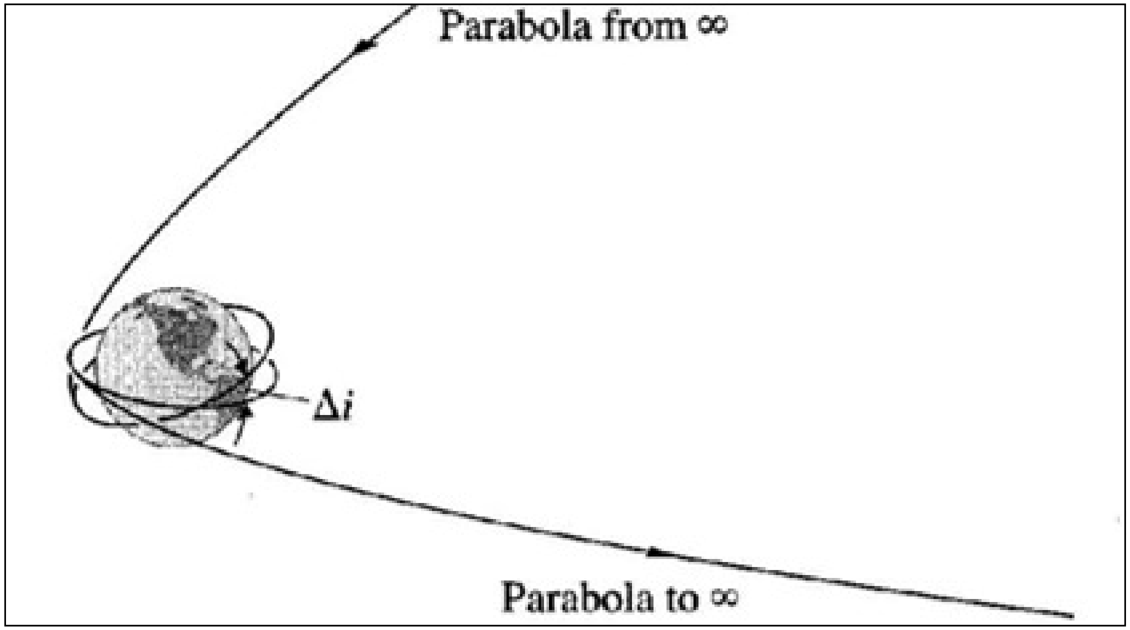
We see that 'Δ**V**' required **reduces** with increase in 'e' and becomes **zero** for **e = 1.**

This has resulted in a novel way of **changing 'i'**, which involves **increase** in e to **1,** change of 'i'& decrease in 'e' **back** to original.

This manoeuvre requires **two** velocity impulses **equal** in magnitude **but** opposite in **direction.**

Orbit Plane Changing with e ~ 1

Consider an **inclination** change for two **circular** orbits, as shown **below**, through a nearly **parabolic** trajectory.



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Orbit Plane Changing with Parabola

Initially, spacecraft is put on an **approximate** parabola and is allowed to **travel** until it reaches its **apogee**.

At this point, a **very** small normal **impulse** is sufficient to **rotate** the H vector through the **required** angle.

Orbit Plane Changing with Parabola

Once the **plane** is changed, spacecraft **returns** along the other **branch** to perigee, where next in-plane **impulse** brings it back to **circle** so that total ΔV for **e ~ 1** is,

$$\Delta V \approx 2\left[\sqrt{\frac{2\mu}{r}} - \sqrt{\frac{\mu}{r}}\right] = 2\left(\sqrt{2}-1\right)v_{cir} = 0.828 v_{cir}; \quad v_{cir} = \sqrt{\frac{\mu}{r}}$$

Above solution is **independent** of inclination **change**.

Combined Orbit & Plane Changing

In **situation**s, where there is a **need** to change both the **orbit** nature and its **plane**, there are many **possibilities**.

In **one** case, we can first **enter** the new orbit and then **later** give impulse for the **plane** change.

Combined Orbit & Plane Changing

In another case, we can **enter** the new orbit and **wait** for spacecraft to reach **apogee** and then make plane **change.**

Lastly, we can make both the **changes** simultaneously at **perigee**.

Summary

In **conclusion**, we see that plane change, though **feasible**, is an expensive manoeuvre and, **hence**, should be avoided, as far as **possible.**

In this **context** we also note that use of **parabola** for plane change is helpful when **large** plane changes are **needed**.