Parallel Staging Benefits

Parallel Staging Design Benefits

The **bulky** booster stage provides the **following** benefits.

Firstly, it **limits** the velocity during the **dense** atmosphere, leading to lower **losses** due to drag and lesser **impact** of the atmospheric **disturbances**.

Secondly, it **marginally** improves the efficiency of the **first** stage, which needs to propel a **lower** mass and also can **use** the gravity turn manoeuvre **more** effectively.

Parallel Staging Operational Benefits

In **addition**, there are other aspects of **parallel** staging which provide mission **operational** flexibility, as **explained** below.

In **many** missions, in order to achieve a **specific** trajectory profile, we can **sequence** the firing of booster and first **stages** in a parallel mode, without the **risk** of interference.

Parallel Staging Operational Benefits

This **aspect** is evident from the **operation** of both PSLV and Space Shuttle, as **described** below.

In case of **PSLV**, which has **6** strap-on motors, **4,** along with the first stage, are **ignited** at lift-off, while the remaining **2** are ignited 25 s **later.**

Similarly, in Space shuttle, both the **boosters** operate along with the **first** stage, in order to provide a **heavy** lift capability (~ 29 T) at the **lift-off**.

Parallel Staging Formulation

Formulation for parallel staging is **similar** to the **series staging** in situations where **strap-on** stage is allowed to **complete** before the ignition of **first stage.**

However, in cases where **both** strap-on and first stage **operate** together, while the **basic** formulation **remains** same, actual **mass** solution depends on operational mode.

Parallel Staging Formulation

In **this** context, we consider the **general** case, when more than one rocket **engines** fire together.

In **such** a case, we know that **total** thrust is the algebraic **sum** of thrust of all the rocket **engines** firing together.

However, in **order** to use the already developed **relations**, we represent the multiple **rockets** as a single equivalent **rocket**, as shown next.

Parallel Staging Formulation

Following are the applicable **equations** for a equivalent single rocket **stage**.

$$T_0 = \sum_{i=1}^{n} T_{0-i} = -g_0 \sum_{i=1}^{n} \dot{m}_{0-i} I_{sp0-i}; \quad \dot{m}_0 = \sum_{i=1}^{n} \dot{m}_{0-i}$$

$$T_0 = -g_0 \dot{m}_0 I_{sp0}; \quad I_{sp-0} = \frac{T_0}{g_0 \dot{m}_0} = \frac{\sum_{i=1}^{n} \dot{m}_{0-i} I_{sp0-i}}{\sum_{i=1}^{n} \dot{m}_{0-i}}$$

We see that I_{sp0} is now an **effective** mean I_{sp} of 0^{th}-stage.

Parallel Staging Formulation

In **such** a case, the stage-wise **ratios** that have been defined **earlier**, can be re-written as **follows**.

$$\in_0 = \frac{\sum_{i=1}^{n} m_{s0-i}}{\sum_{i=1}^{n}\left(m_{s0-i} + m_{p0-i}\right)}; \quad \pi_0 = \frac{m_{01}}{m_0} = \frac{m_0 - \sum_{i=1}^{n}\left(m_{s0-i} + m_{p0-i}\right)}{m_0}$$

We see that with these **definitions** for the booster stage, **we** can make use of the **velocity** and mass fraction relations **derived** previously for the series staging **case**.

Summary

To **summarize**, parallel staging formulation is **similar** to serial staging **formulation** in an overall manner.

However, we **need** to take into account the **differences** in the various rockets that **fire** together and also for **different** durations, leading to extra **numerical** effort.