Parallel Staging Strategy

Series Staging Features

Staging concept and formulation **presented** previously is **typically** termed '**series**' or 'simple' **staging.**

A basic **drawback** of series **staging** is the possible **interference** between the **two** stages at the **hand-shake** point**.** (i.e. burnout of one, **ignition** of next).

Series Staging Drawbacks

In particular, if **hand** shaking is to take place at a **lower** velocity in denser **atmosphere,** it can lead to **loss** of control of the vehicle due to **disturbances.**

Another issue with **series** staging is the **increase** in vehicle **length** with the increase in **number** of stages.

Series Staging Drawbacks

First impact of **increased** length is to **lower** the buckling **strength**, leading to extra structural **mass.**

Second impact is on the design of **control** systems due to very **low** structural vibration **frequencies.**

Parallel Staging Concept

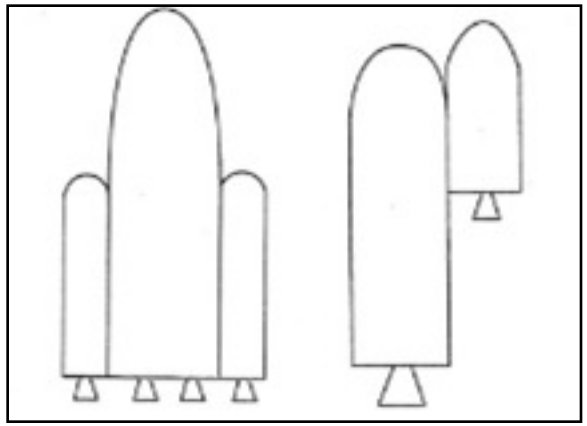
Lastly, **longer** vehicles require a taller **launch** tower, resulting in significant **cost** escalation.

All these have given **rise** to the concept of '**strap-on** boosters' bringing in the philosophy of **parallel** staging.

Parallel Staging Philosophy

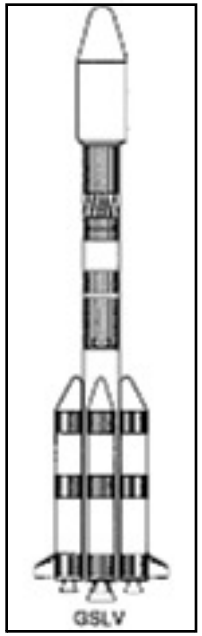
Parallel staging aims to significantly **improve** the rocket **performance**, while maintaining its overall **length** and simplifying the **separation** manoeuvre.

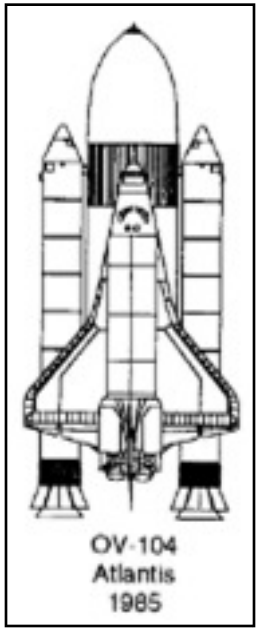
Given below are a few **typical** parallel staging **schemes.**

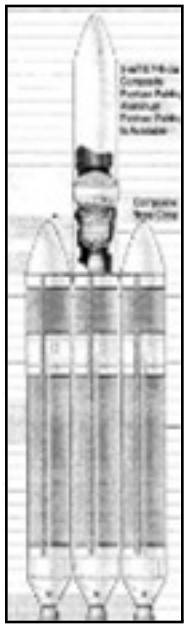


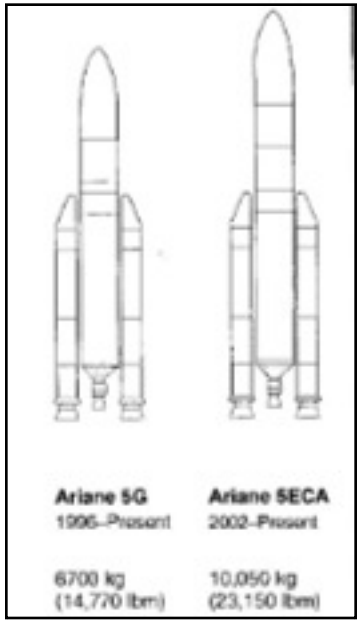
Parallel Staging Examples

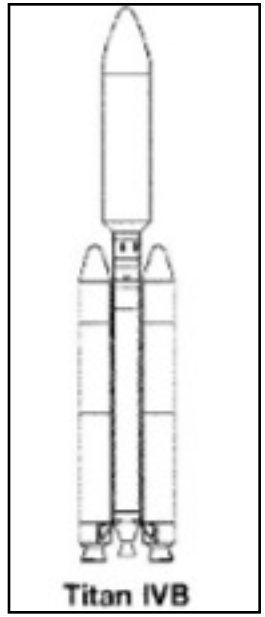
Most **current** day launch **vehicles** employ parallel **staging**, as shown below.











PSLV Strap-on Configuration

PSLV has m_0 of **295T** & m_* of **3.5T**, for a mission in **space** station orbit at 407 km **altitude.**

0-Stage: $I_{sp0} = 262s,$	$\varepsilon_0 = 0.182,$	$\pi_0 = 0.776$
1-Stage: $I_{sp1} = 264s,$	$\varepsilon_1 = 0.178,$	$\pi_1 = 0.267$
2-Stage: $I_{sp2} = 293s,$	$\varepsilon_2 = 0.116,$	$\pi_2 = 0.250$
3-Stage: $I_{sp3} = 291s,$	$\varepsilon_3 = 0.106,$	$\pi_3 = 0.444$
4-Stage: $I_{sp4} = 307s,$	$\varepsilon_4 = 0.251,$	$\pi_4 = 0.515$

PSLV Strap-on Configuration

Individual **stage-masses** are as follows.

0-Stage: $m = 66T$;	1-Stage: $m = 168T$;	2-Stage: $m = 45.8T$
3-Stage: $m = 8.5T$;	4-Stage: $m = 3.3T$;	$\pi_* = 0.0119$

We see that the strap-on **stage**, while not the heaviest, is **quite** bulky, which is trend common to **most** rockets.

Summary

To **summarize**, parallel staging is a **useful** concept that aims to **improve** the launch vehicle **performance**, while limiting the associated **drawbacks**.

We also note that booster or **strap-on** stage is quite bulky and **sometimes** can also be the heaviest **stage** in a rocket.