Space Exploration

Aerodynamics,SSTOs,History

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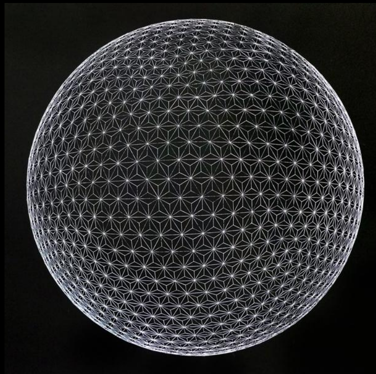
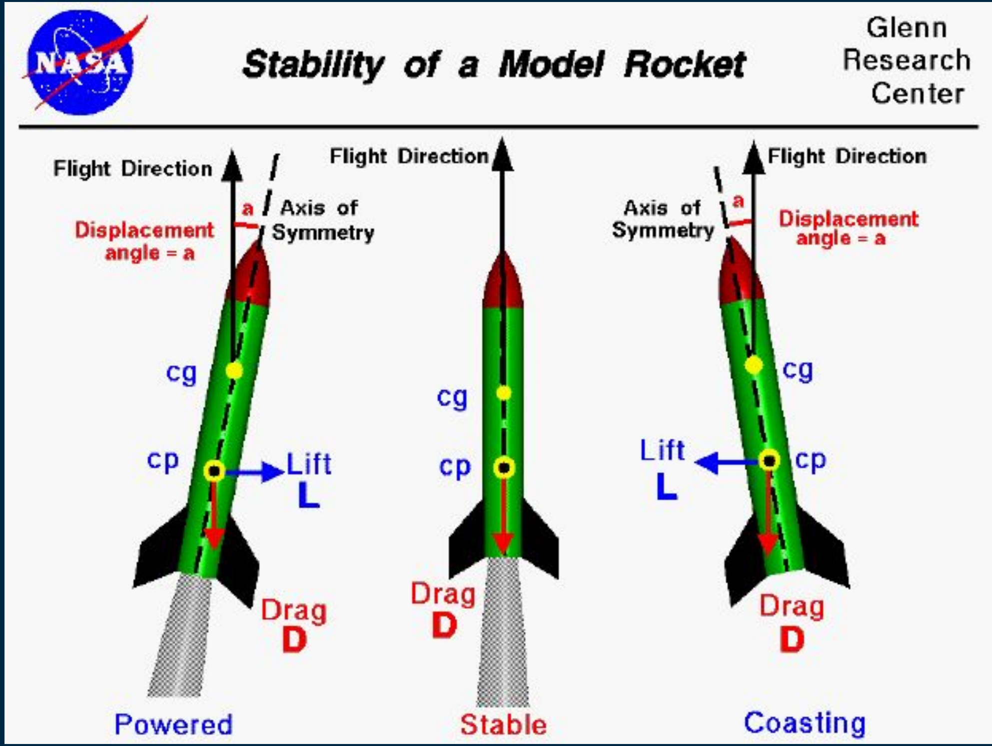


Aerodynamic stability in Rockets

- Center of Pressure
- Center of gravity
- Center of Thrust

"Center of Thrust should always be below center of gravity"

Center of Pressure is not Constant throughout the flight



Center of Pressure as the Mach number increases

- The center of pressure C_p Gradually moves upward as the speed of the rocket increases.
- The center of gravity also changes as the rocket loses the fuel mass
- It should be kept in mind that the center of pressure never overtakes the Center of gravity in mid flight

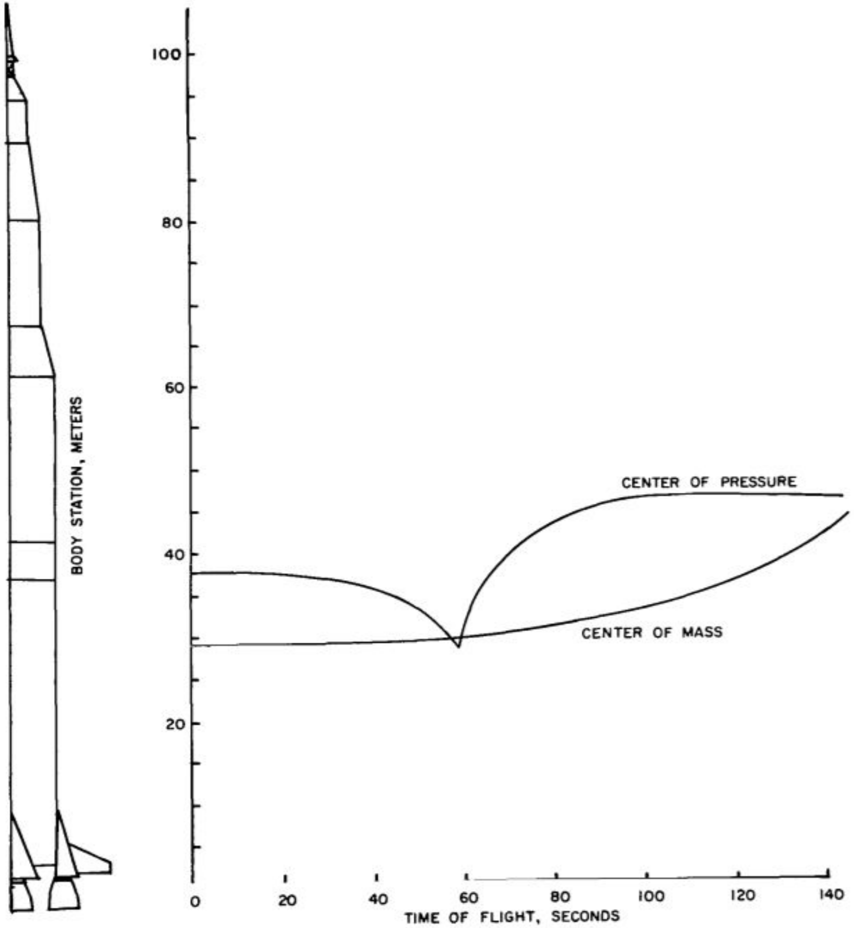


FIGURE 6. VARIATIONS OF CENTER OF PRESSURE AND CENTER OF MASS DURING FLIGHT.

- Center of Pressure and Center of gravity changes drastically when breaking the sound barrier
- CoP and CoG must be engineered perfectly for each and every stage separately

Shock Dynamics

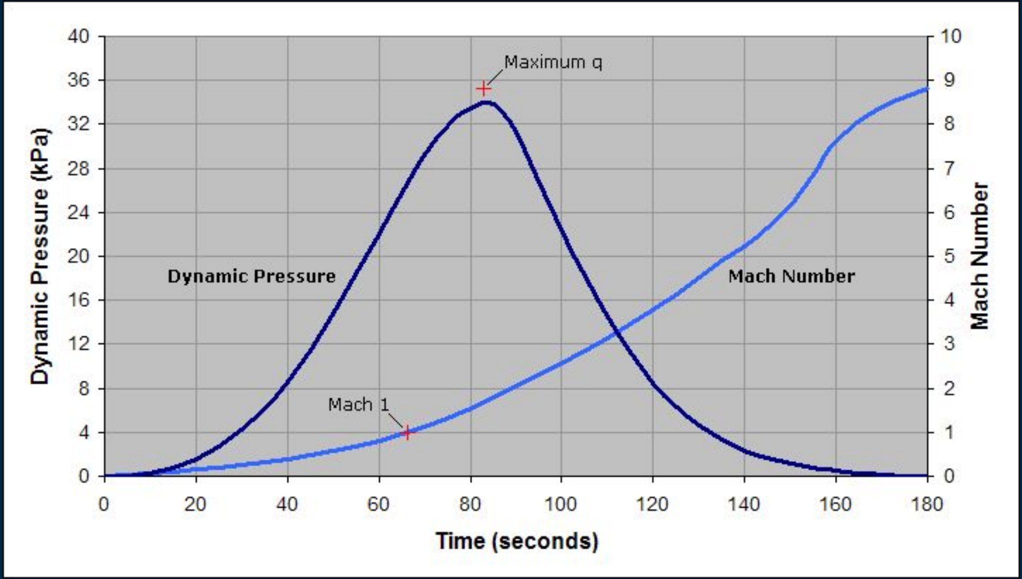
Rockets tend to break the sound barrier very fast and often when they haven't even left the lower atmosphere.

“Your the fins should be optimized for supersonic flight and ideally stay within your Mach Cone. There is always an optimum point and design style. In general, the larger the fin, the more drag but the more stable”

Dynamic Pressure and MAX Q

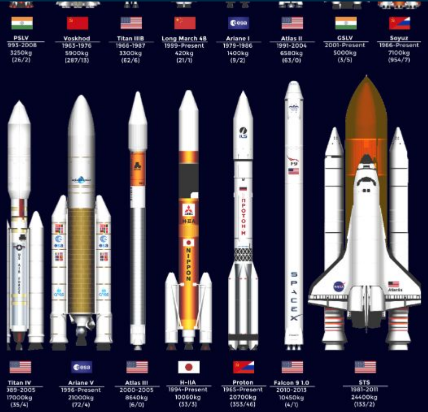
- The Dynamic Pressure in a rocket is given by

$$q = \frac{1}{2} \rho v^2$$

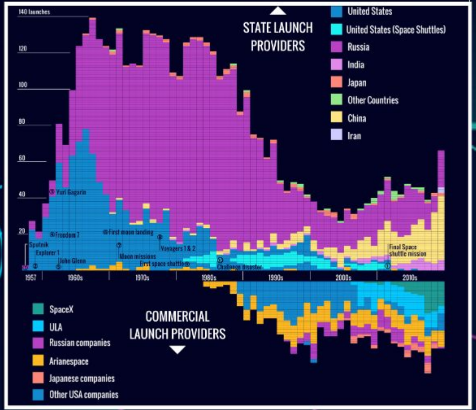


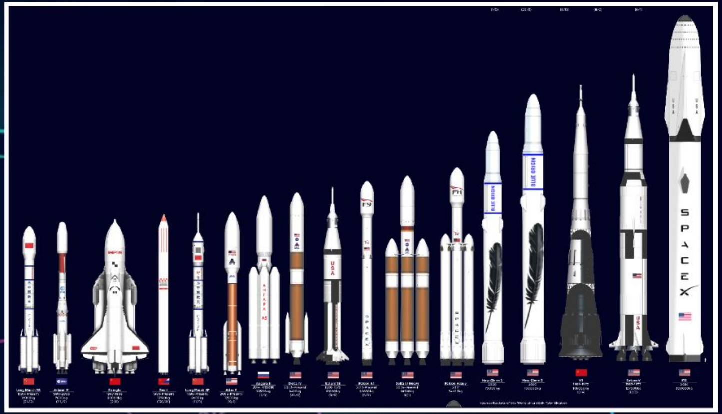
- The Density of Air decreases with altitude
- The velocity of rocket increases with altitude

HISTORY OF ROCKETS



Man has been studying rocketry for more than 2,000 years.



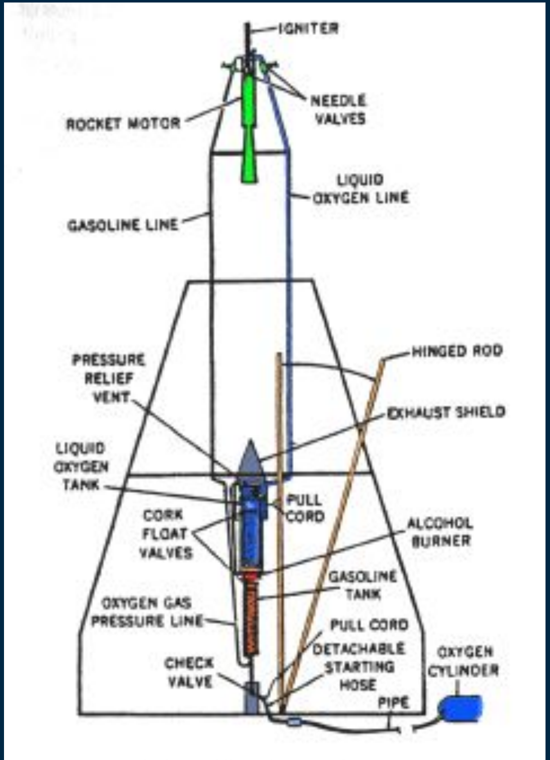


Current Standings in Rockets

"Every vision is a joke until the first man accomplishes it; once realized, it becomes a common place"

~Robert H. Goddard

- Early in the 20th century, an American, Robert H. Goddard, conducted practical experiments in rocketry.
- While working on solid-propellant rockets, Goddard became convinced that a rocket could be propelled better by liquid fuel.
- He achieved the first successful flight on March 1926, with oxygen and gasoline as fuel.



Dr. Goddard's 1926 Rocket

- Gasoline was used as a fuel and oxygen was used as an oxidiser.

But Hol’ Up!!

Pure Oxygen + Gasoline + ignition =

- He figured out a way to keep the combustion chamber from exploding by making a revolutionary modification, which is still used in modern rocketry!!
- He used extremely cold liquid oxygen via a network of pipes to keep the combustion chamber cool and making rocket more efficient since less energy is lost as heat.

- The rocket's combustion chamber is the small cylinder at the top, the nozzle is visible beneath it.
- The fuel tank is directly beneath the nozzle and is protected from the motor's exhaust by an asbestos cone.
- Asbestos-wrapped aluminum tubes connect the motor to the tanks, providing both support and fuel transport.
- Asbestos is a natural fiber which provided thermal insulation but is very dangerous.
- But this design was not stable and the combustion chamber and the nozzle was later put at the bottom

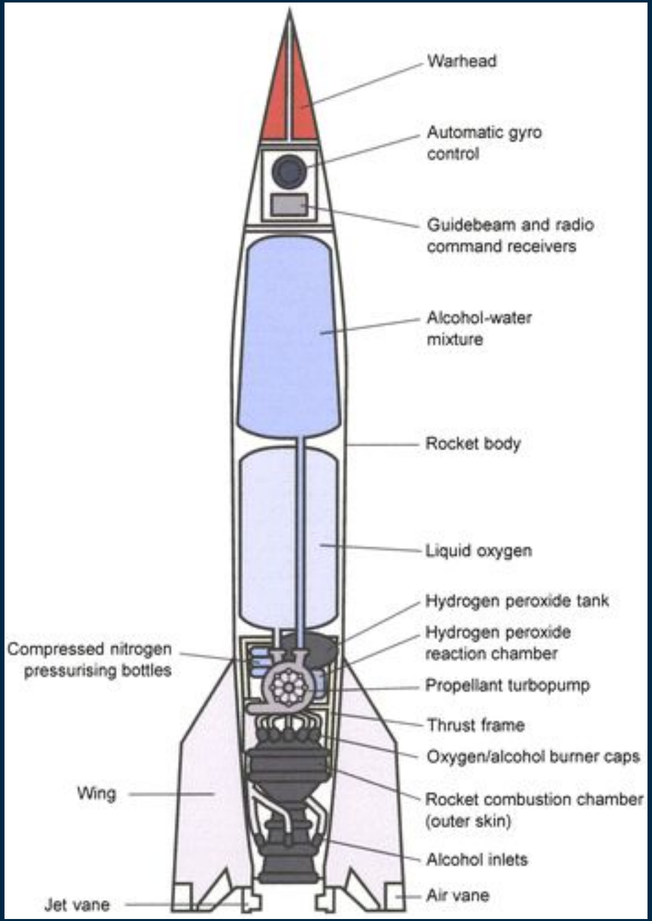
So the Big question. Why was the earlier design rejected?


Rocket Failures

“One good test is worth a thousand expert opinions”

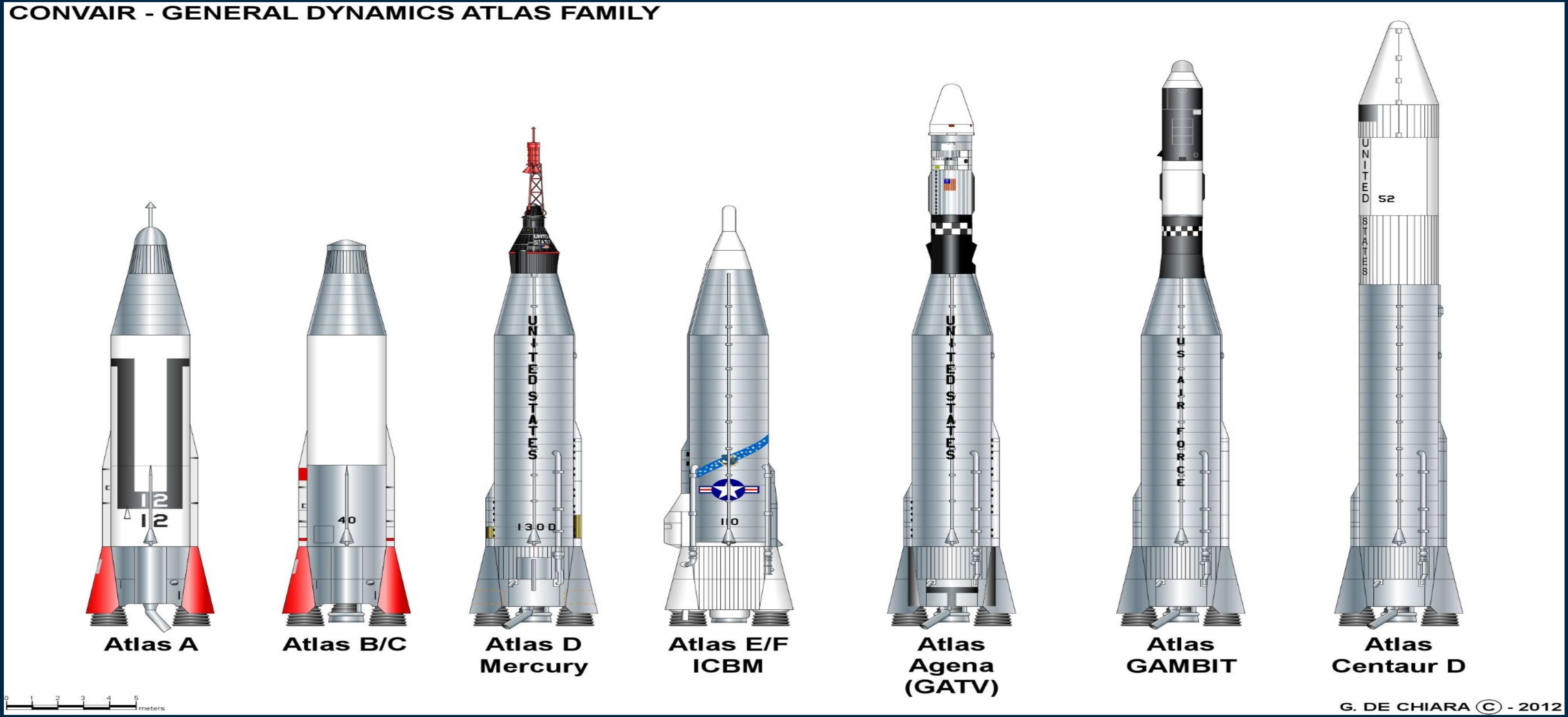
~Wernher von Braun

- He was the pioneer of the famous V-2 rocket, first long ranged guided ballistic missile.
- It used 75% Ethanol/ 25% water(as coolant) mixture for fuel and liquid oxygen as an oxidiser.
- The pump was driven by a steam engine which carried fuel and oxygen to the combustion chamber.
- Sodium permanganate was used as a catalyst to make steam from hydrogen peroxide.



ATLAS (ROCKET FAMILY)

- It is a family of US missiles and space launch vehicles that originated from SM-65 Atlas (first ICBM).
- It was a liquid propellant rocket burning RP-1 fuel with liquid oxygen configured in a parallel staging design.
- RP is shorthand for rocket propellant which is nothing but highly refined kerosene.
- The family consists of rockets (A-G)
- More powerful and better designs came in future, like Atlas I, II, etc.



2 engines	3 engines, so better	More powerful engines	Used as a war missile	Used hypergolic fuels	Used to carry observation satellite	More powerful. 1st use of H_2 engine in space

ROCKET EQUATIONS

[Continued.....]

SPECIFIC IMPULSE [Efficiency]

→ Specific Impulse is actually termed in ROCKET SCIENCE to be “efficient use of propellants in rockets/spacecrafts and fuels in jet engines”.

→ Some Formulation :

$$I_{sp} = \lim_{(\Delta t \to 0)} \{(F_{thrust}.\Delta t)/(m_p.g_o)\} \rightarrow (13)$$

→ Check By Definition of Impulse.

→ $I_{sp} = F_{thrust}/[(dm/dt).g_o] \rightarrow (14)$

→ $\Delta v = I_{sp}.g_o.\ln(M_o / M_f) \rightarrow (15)$ [Change in velocity in terms of specific impulse]. Note :[$\int (F_{thrust})dt = I$ *and to make it specific just divide by* m_p]

SSTO Rockets

[Single-Stage-to-Orbit Rockets]

About

→ Rockets which reach to certain orbit from Body's surface with the **ONLY** use of Propellants and fuels w/o any expending tanks, engines or major hardwares.

→ It's somewhat, but not fully "REUSABLE VEHICLE"

→ CONTEXT of Reusability?

→ Advantage :

(*) Elimination of Hardwares which is inherent in expendable Launch Systems.

→ Disadvantage :

(*) Cost of DDR&E is significantly higher than expendable Launch Systems.

CHALLENGES Earth Launch

→ High Orbital Velocity of ~7400 m/sec

→ Overcome Earth's gravity

→ Limitation of speed in Earth's atmosphere, affecting Engines Efficiency.

→ Achieving High enough M-R for carrying sufficient propellants & Meaningful payload weight.

→ Weaker gravitational fields as well as Lower pressure than earth atmosphere is favoured for SSTO launch (Think of Moon) [Less fuel utility/ unit time]

→ Fuels?

DC-X Prototype

Few Rigorous Calculations :

Recall Eqn. (15) $\Delta v = I_{sp} . g_o . \ln (M_o / M_f)$

Focus on : M_o/M_f term

$M_o = M_{prop} + M_{pay} + M_{rocket} \rightarrow (16)$

$M_f = M_{pay} + M_{rocket} \rightarrow (17)$

Eqn. 16/ Eqn. 17

$$\Rightarrow \frac{Mprop + Mpay + Mrocket}{Mpay + Mrocket} \rightarrow (18)$$

$$Let\ \ \zeta = \frac{\text{Mprop}}{\text{Mprop} + \text{Mrocket} + \text{Mpay}} \ \ and\ \ \lambda = \frac{\text{Mrocket}}{\text{Mrocket} + \text{Mpay}}$$

where ζ is propellant mass fraction and λ is structural coefficient*.

We can also define Overall structural mass fraction given as :

$$\frac{\text{Mrocket}}{\text{Mrocket} + \text{Mpay} + \text{Mprop}} = \lambda\left(1 - \frac{\text{Mpay}}{\text{Mpay} + \text{Mrocket} + \text{Mprop}}\right)$$

$$Mi = Mpay + Mrocket + Mprop$$

$$Also;\ \frac{\text{Mpay}}{\text{Mi}} + \frac{\text{Mrocket}}{\text{Mi}} + \frac{\text{Mprop}}{\text{Mi}} = 1$$

$\Rightarrow$ *Mi (Total Initial Mass)* $= Mrocket + Mpay + Mprop$

$$\Rightarrow Mi = \frac{Mpay}{\left(1 - \frac{\zeta}{1-\lambda}\right)}$$

$\Rightarrow$ This Equation shows, How size of vehicle and Structural efficiency are correlated for SSTO's.

[H.W.] $\rightarrow$ *Given specific impulse, attainable velocity to reach certain orbit and fixed payload. How you can relate Vehicle's size with structural Constant (λ). Graphically as well as physical interpretations.*

$\rightarrow$ What can be the Maximum Structural Coeff. (λ) a mission should have?

$\rightarrow$ Compare it with Double stage to Orbit Rocket?

$\rightarrow$ Also with multiple staging rocket.

THANKS

LET's CONTINUE LATER WITH MORE INTERESTING STUFFS AND FEW MORE CALCULATIONS.