



# *Rocket Configuration Design Problem*



## *Problem No. 01*

A **rocket** is to be designed to **inject** a spacecraft of 1.5 Tons **mass** in a sun-synchronous circular **polar** orbit at 650 km altitude above **earth's** surface. ( $R_E = 6371$  km).

Further, it is **known** that spacecraft will need **7535** m/s of speed parallel to **local** horizon at the injection **point**.

**Assuming** that all the losses are restricted to **20%** of ideal mechanical energy, **determine** the lower bound on  $m_0$  if  $I_{sp}$  is 350s.

Lastly, if **14.5** Tons of inert mass is **unavoidable**, what would be  $m_0$ ?



## **Solution No. 01**

The **applicable** solution is as **follows**.

$$\frac{1}{2}V^2 + g_0 h = \frac{1}{2} \times 7535^2 + 9.81 \times 7.021 \times 10^6 = 9.7264 \times 10^7$$

$$\frac{1}{2}V_0^2 = \frac{9.7264 \times 10^7}{0.8} = 12.158 \times 10^7 \rightarrow V_0 = 15593$$

$$m_b = m_0 e^{-\frac{1589.6}{350}} = 0.01066 m_0 \rightarrow m_0 > 140.7 \text{Tons}$$

$$m_b = 1.5 + 14.5 = 16 \rightarrow m_0 > 1509.4 T$$



## *Multi-stage Performance Problem*



## *Problem No. 02*

**Consider a rocket of following configuration.**

$$m_0 = 80T, m_p = 60T, I_{sp} = 240 \text{ s}, g_0 = 9.81 \text{ m/s}^2.$$

**Assume equal stages and generate ideal velocity solutions for, 1, 2 and 3-stage operation.** (Hint:  $m_{inert} = 18T, m_* = 2T$ ).



## ~~Solution No. 02~~

The applicable solution is as follows.

$$V_{b-ideal-1st\ stage} = g_0 I_{sp} \ln \frac{80}{20} = 3264 \text{ m/s}$$

$$V_{b-ideal-2stage} = g_0 I_{sp} \left[ \ln \frac{80}{50} + \ln \frac{41}{11} \right] = 4204 \text{ m/s}$$

$$V_{b-ideal-3stage} = g_0 I_{sp} \left[ \ln \frac{80}{60} + \ln \frac{54}{34} + \ln \frac{28}{8} \right] = 4716 \text{ m/s}$$



## *Multi-stage Methodology Problem*



## Problem No. 03

**Angara 1.2**, a 2-stage rocket, has a **payload** of 4T, with the following stage-wise **parameters**.

$$\text{1-Stage: } I_{sp1} = 310s; \quad \varepsilon_1 = 0.072, \quad \pi_1 = 0.188$$

$$\text{2-Stage: } I_{sp2} = 342.5s; \quad \varepsilon_2 = 0.089, \quad \pi_2 = 0.124$$

**Determine** stage-wise mass **distribution**, the total lift-off **mass** and the ideal burnout velocity.



## Solution No. 03

The **solution** is as follows.

$$\checkmark m_{s2} = 0.089 \times 4 \times 7.064 = 2.515T$$

$$\checkmark m_{p2} = 0.911 \times 4 \times 7.064 = 25.74T; \quad \checkmark m_{o2} = 32.26T$$

$$\checkmark m_{s1} = 0.072 \times 32.26 \times 4.319 = 10.03T$$

$$\checkmark m_{p1} = 0.928 \times 32.26 \times 4.319 = 129.3T; \quad \checkmark m_0 = m_{o1} = 171.6T$$

$$\checkmark V_x = -9.81 \times \left[ \frac{310 \times \ln(0.072 + 0.928 \times 0.188)}{342.5 \times \ln(0.089 + 0.911 \times 0.124)} \right] = 9633.9 \text{ m/s}$$