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QUICK REVISION *FORMULA SHEET*

for
GATE-AE ROCKET PROPULSION





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ROCKET PROPULSION

BASICS OF ROCKET

1. Thrust Equation

$$F = \dot{m}_p V_e + (p_e - p_a) A_e$$

$F \rightarrow$ Thrust

$\dot{m}_p \rightarrow$ Propellant mass flow

$V_e \rightarrow$ Nozzle exit plane velocity

$p_e \rightarrow$ Nozzle exit plane pressure

$p_a \rightarrow$ Ambient pressure

$A_e \rightarrow$ Nozzle exit plane area

Note: - For optimum expansion $p_e = p_a$

2. Specific Impulse

$$I_{sp} = \frac{F}{\dot{m}_p g_0}$$

3. Effective Exhaust Velocity

$$C_j = \frac{F}{\dot{m}_p} = I_{sp} \times g_0$$

4. Tsiolkovsky Rocket Equation:

$$\Delta V = V_b - V_i = C_j \ln \left[\frac{m_o}{m_f} \right] - g t_b$$

$\Delta V \rightarrow$ Change in velocity

$m_o \rightarrow$ Initial Mass

$m_f \rightarrow$ Final Mass

$g \Delta t \rightarrow$ Gravity loss

$V_b \rightarrow$ burnout velocity

$V_i \rightarrow$ initial velocity

$t_b \rightarrow$ burnout time

5. Mass Ratio:

$$\mu = \frac{m_f}{m_o} = 1 - \frac{m_p}{m_o}$$

6. Propellant Mass Ratio:

$$\xi = \frac{m_p}{m_o} = \frac{m_p}{m_p + m_f} = 1 - \frac{m_f}{m_o}$$

7. Propulsive Efficiency:

$$\eta_p = \frac{2\sigma}{1 + \sigma^2}$$

$$\sigma = \frac{U}{C_j}$$

$U \rightarrow$ Rocket's forward speed

8. Terminology

$$m_o = m_p + m_s + m_L$$

$$m_f = m_o - m_p = m_s + m_L$$

$m_o \rightarrow$ Initial Mass

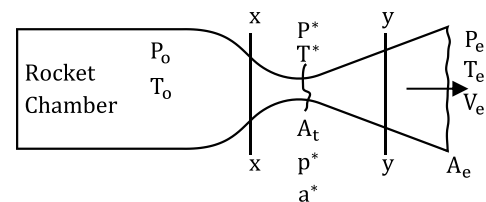
$m_f \rightarrow$ Final mass

$m_p \rightarrow$ Propellant mass

$m_s \rightarrow$ Structural mass

$m_L \rightarrow$ Pay load mass

9. Ideal Nozzle flows (Isentropic Flows)



$$\frac{A_x}{A_y} = \frac{M_y}{M_x} \sqrt{\left[\frac{1 + \frac{\gamma-1}{2} M_x^2}{1 + \frac{\gamma-1}{2} M_y^2} \right]^{\frac{\gamma+1}{\gamma-1}}}$$

$$\dot{m}_p = p^* a^* A_t$$

$$\dot{m}_p = \frac{P_o}{\sqrt{RT_o}} \sqrt{\gamma} \left(\frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{2(\gamma-1)}} A_t \left(\begin{array}{c} \text{Chocked} \\ \text{Flow} \\ \text{Rate} \end{array} \right)$$

$P_o \rightarrow$ Chamber pressure

$T_o \rightarrow$ Chamber temperature

$A_t \rightarrow$ Throat area

PARAMETERS

1. Characteristics Velocity:

$$C^* = \frac{P_o A_t}{\dot{m}}$$

$A_t =$ Throat area

$p_o =$ Chamber pressure

$\dot{m} =$ Mass flow rate

$\{\because F = \dot{m}V \text{ and } p_o A_t = F\}$

2. Thrust Coefficient,

$$C_F = \frac{F}{p_o A_t}$$

3. Exit Velocity:

$$C_j = C_F \times C^*$$

$$C_F = \frac{F}{p_o A_t}$$

$$C_F = \frac{F}{\dot{m} C^*} = \frac{C_j}{C^*}$$

STAGING

1. Serial Staging:

$m_L \rightarrow$ True payload

$m_{o,i} \rightarrow$ Initial mass of i^{th} stage

$m_{f,i} \rightarrow$ Final mass of i^{th} stage

$m_{p,i} \rightarrow$ Propellant mass of i^{th} stage

$m_{s,i} \rightarrow$ Structural mass of i^{th} stage

$m_{L,i} \rightarrow$ Payload mass of i^{th} stage

$$\mu_i = \frac{m_{f,i}}{m_{o,i}}$$

$$m_{o,i} = m_{s,i} + m_{p,i} + m_{L,i}$$

$$m_{f,i} = m_{o,i} - m_{p,i}$$

$$m_{L,i} = m_{o,i+1}$$

2. Payload Ratio:

$$\lambda = \frac{m_L}{m_o - m_L} = \frac{m_L}{m_p + m_s}$$

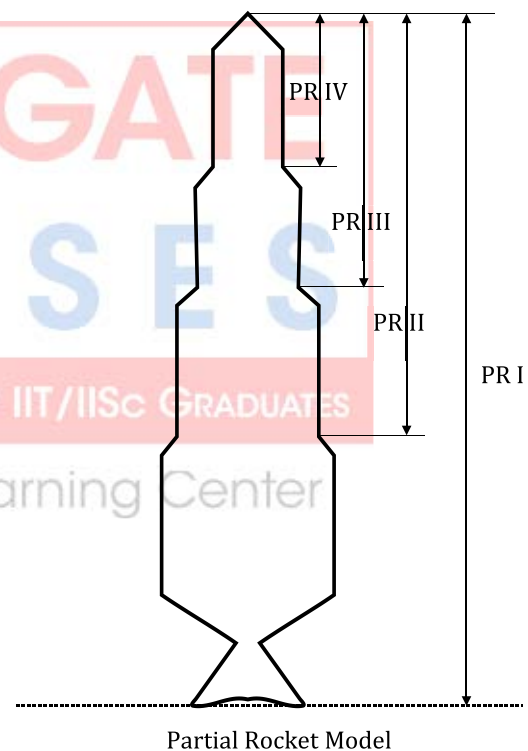
3. Structural Coefficient:

$$\varepsilon = \frac{m_s}{m_o - m_L} = \frac{m_s}{m_p + m_s}$$

4. Rocket Equation Alternate Form

$$\mu = \frac{\varepsilon + \lambda}{1 + \lambda}$$

$$\therefore \Delta V_e = C_j \ln \left(\frac{1 + \lambda}{\varepsilon + \lambda} \right) \text{ can be obtained}$$



i^{th} Stage:

$$\Delta V_i = C_{ji} \ln \left[\frac{m_{o,i}}{m_{o,i} - m_{p,i}} \right] = C_{ji} \ln \left[\frac{1}{\mu_i} \right]$$

$m_{o,i+1} = m_{f,i} - m_{s,i}$ (Initial mass of $(i+1)^{\text{th}}$ stage).

$$\mu_i = \frac{m_{f,i}}{m_{o,i}} = \frac{\varepsilon_i + \lambda_i}{1 + \lambda_i}$$

$$\lambda_i = \frac{m_{L,i}}{m_{0,i} - m_{L,i}}$$

$$\epsilon_i = \frac{m_{S,i}}{m_{0,i} - m_{S,i}}$$

5. Total Change in velocity of a serial rocket staging

$$\Delta V = \sum_{i=1}^n \Delta V_i$$

6. Total Payload Ratio:

$$\lambda^* = \frac{m_{L,n}}{m_{0,i}} = \frac{m_{L,n}}{m_{0,i}} \times \frac{m_{0,i}}{m_{0,i-1}} \times \frac{m_{0,i}}{m_{0,i-2}} \times \dots \times \frac{m_{0,s}}{m_{0,2}} \times \frac{m_{0,2}}{m_{0,1}}$$

$$\lambda^* = \prod_{i=1}^n \left(\frac{\lambda_i}{1 + \lambda_i} \right)$$

7. Parallel Staging:

Thrust

$$F^* = \sum_{i=1}^k \dot{m}_{pi} V_{ei}$$

$k \rightarrow$ Number of parallel stages.

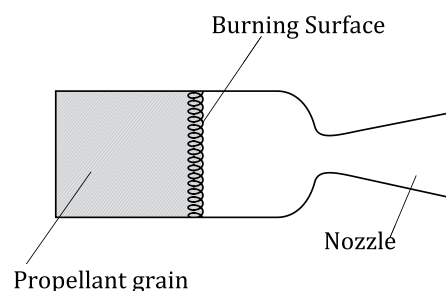
8. Effective Exhaust Velocity:

$$C_j = \frac{F^*}{\dot{m}_p}$$

$$\dot{m}_p = \sum_{i=1}^k \dot{m}_{pi}$$

SOLID PROPELLANT ROCKETS

1. Solid Propellant Motor:



2. Burn Rate:

$$r_b = ap_c^n \text{ in mm/s or cm/s}$$

$p_c \rightarrow$ Chamber pressure

$a \rightarrow$ Empirical constant

$n \rightarrow$ Burn rate exponent

Note

$n > 1 \rightarrow$ unstable burning

$n < 1 \rightarrow$ stable burning

$n = 1 \rightarrow$ Neutral burning

3. Mass of Generated Gas:

$$\dot{m}_g = \rho_p \times A_b \times r_b$$

$A_b \rightarrow$ Burn Area

$\rho_p \rightarrow$ Propellant Density

$r_b \rightarrow$ Burn Rate

Mass Generated - Mass Ejected in nozzle

= Mass accumulation in the system

$$\rho_p \times A_b \times r_b - \frac{p_o \cdot A^*}{C^*} = \frac{dm}{dt}$$

Chamber Pressure (at equilibrium)

$$p_o = \left[\frac{a \cdot \rho_p A_b C^*}{A^*} \right]^{\frac{1}{1-n}}$$

■ LIQUID PROPELLANT ROCKET

Mixture ratio:

$$r = \frac{\dot{m}_o}{\dot{m}_f}$$

$\dot{m}_o \rightarrow$ Oxidizer mass flow

$\dot{m}_f \rightarrow$ Fuel mass flow

$$\dot{m}_p = \dot{m}_o + \dot{m}_f$$

$\dot{m}_p \rightarrow$ Propellant mass flow



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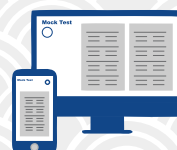
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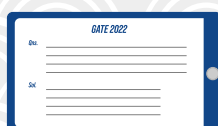
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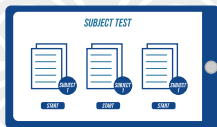
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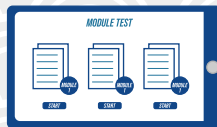
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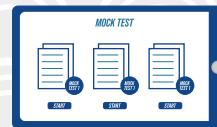
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