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QUICK REVISION

FORMULA SHEET

for

GATE-AE ROCKET PROPULSION

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ROCKET PROPULSION

BASICS

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**

$$I_{sp} = \frac{F}{\dot{m} g_o}$$

3. **Effective Exhaust Velocity**

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

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:**

$$\mu = \frac{m_f}{m_0} = 1 + \frac{m_p}{m_o}$$

6. **Propellant Mass Ratio:**

$$\xi = \frac{m_p}{m_0} = \frac{m_p}{m_p + m_f}$$

7. **Propulsive Efficiency:**

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

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

$U =$ 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

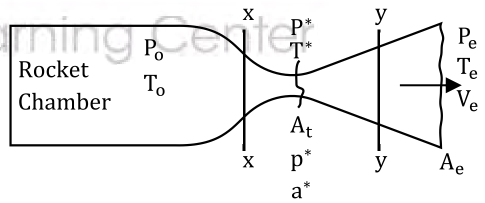
$m_f \rightarrow$ Final mass

$m_p \rightarrow$ Propellant mass

$m_s \rightarrow$ Structural mass

$m_L \rightarrow$ Pay load mass

9. **Ideal Nozzle flows (Isentropic Flows)**



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

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

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

$P_o \rightarrow$ 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:**

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

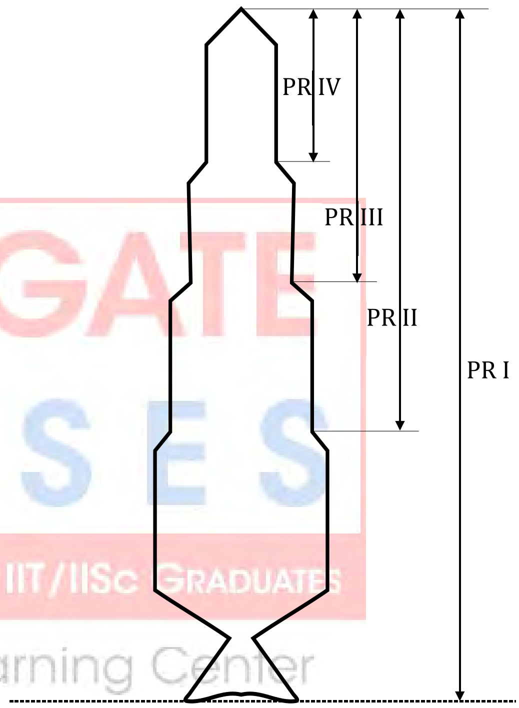
3. **Structural Coefficient:**

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

4. **Rocket Equation Alternate Form**

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

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



Partial Rocket Model

i^{th} Stage:

$$\Delta V_i = C_{ji} \ln\left[\frac{m_{0,i}}{m_{0,i} - m_{p,i}}\right] = C_{ji} \ln\left[\frac{1}{\mu_i}\right]$$

$m_{0,i+1} = m_{f,i} - m_{s,i}$ (Initial mass of $(i+1)^{th}$ stage).

$$\mu_i = \frac{m_{f,i}}{m_{0,i}} = \frac{\epsilon_i + \lambda_i}{1 + \lambda_i}$$

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

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

5. **Total Change in velocity of a serial rocket staging**

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

6. **Total Payload Ratio:**

$$\lambda^* = \frac{m_{L,n}}{m_{o,i}} = \frac{m_{L,n}}{m_{o,i}} \times \frac{m_{o,i}}{m_{o,i-1}} \times \frac{m_{o,i}}{m_{o,i-2}} \times \dots \frac{m_{os}}{m_{o2}} \times \frac{m_{o2}}{m_{01}}$$

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

7. **Parallel Staging:**

Thrust

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

$k \rightarrow$ Number of parallel stages.

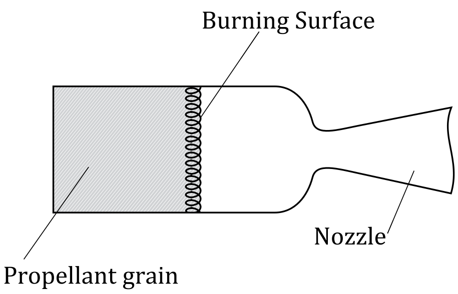
8. **Effective Exhaust Velocity:**

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

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

SOLID PROPELLANT ROCKETS

1. **Solid Propellant Motor:**



2. **Burn Rate:**

$r_b = aP_c^n$ in mm/s or cm/s

$P_c \rightarrow$ Chamber pressure

$a \rightarrow$ Empirical constant

$n \rightarrow$ Burn rate exponant

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

$\rho_p \rightarrow$ Propeliant Density

$r_b \rightarrow$ Burn Rate

Mass Generated - Mass Ejected in nozzle

= Mass accumulation in the system

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

Chamber Pressure (at equilibrium)

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

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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OUR COURSES

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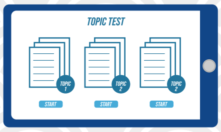
Course Features



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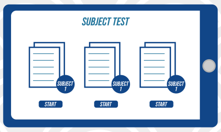

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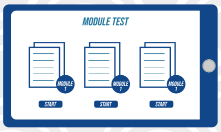

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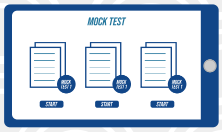

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