BITS Pilani, Pilani Campus
Mid-semester Exam, Second Semester (2021-2022)
ME F418: Rocket and Spacecraft Propulsion
(Closed Book)

Total Marks – 30 Time - 90 minutes, 11th March 2022, Time: 2 pm -3.30pm

Instructions:

All questions are compulsory.
Wherever required draw neat sketch.
Take suitable assumption, if required. However, it should be stated clearly.

1. What is the difference between serial and parallel rocket staging? List down at least three benefits or reasons for using multistage rocket in comparison to a single stage rocket. [3]

2. First stage of a rocket engine is designed for an optimum expansion at an altitude of 20 km. Plot the variation of Mach number, pressure, density and temperature inside the nozzle just after the lift-off, when the exhaust gas velocity at the throat is sonic and at exit the velocity is subsonic. [4]

3. What is shock diamond? What does it indicate about the performance of a rocket propulsion system? Discuss the formation of shock diamonds in case of an over-expanded nozzle with the help of a neat sketch. [5]

4. Air enters a converging–diverging nozzle, at 1.0 MPa and 800 K with negligible velocity. The flow is steady, one-dimensional, and isentropic with γ=1.4. For an exit Mach number of Ma = 2 and a throat area of 20 cm^2, determine (a) speed at the throat and at the exit plane of nozzle and (b) diameter of nozzle exit. The gas constant for air is 287 J/kg-K. [4]

5. A four stage rocket is used to put up a satellite of 100 kg mass in a Low Earth Orbit (LEO). The approximate values of mass of the propellant, mass of structure, specific impulse and propellant burn time for each stage are given below:

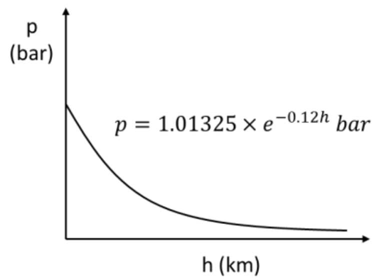
Stage	I	II	III	IV
Mass of rocket structure including inerts (kg)	2000	1000	500	100
Mass of propellant (kg)	10000	4000	2000	400
Specific Impulse (s)	420	440	460	480
Propellant burn time (s)	200	210	300	320

Assuming mass flow rate of propellant to be constant in each stage and constant gravitational acceleration throughout the altitude, the divergence losses in the nozzle of rocket engine for each stage is 95%. Determine the (a) thrust produced in each stage (b) the overall incremental speed and (c) acceleration of the rocket at an instant 10s after beginning of second stage of burn out. [6]

6. The convergent-divergent nozzle of a first stage rocket engine is designed for optimum expansion at an altitude of 20 km with throat area of 0.001m^2. The variation in pressure with altitude is shown in the plot and given by the relation $p = 1.01325 \times e^{-0.12h}\ bar$, where h is altitude in km and $e = 2.71$. The temperature of the hot gases is 3200K with specific heat ratio of 1.2 and molecular weight of 21 gm/mole. The mass flow rate of propellant is 0.2kg/s and the C* efficiency is 95%. Determine (a) chamber pressure of hot gases

(b) the diameter of the nozzle exit (c) the thrust produced by the nozzle at an altitude of 20km and (d) percentage reduction in thrust coefficient from optimum value at an altitude of 40km.

[8]



Formulae:

$$V_J = \sqrt{\frac{2\gamma R_o T_c}{(\gamma-1)M_W}\left[1-\left(\frac{p_e}{p_c}\right)^{\frac{\gamma-1}{\gamma}}\right]}, C = \sqrt{\gamma RT}, F_{actual} = \lambda F_{ideal},$$

$$C^* = \frac{1}{\Gamma}\sqrt{\frac{R_o T_c}{M_W}} = \frac{P_c A_t}{\dot{m}}, where\ \Gamma = \sqrt{\gamma}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}, R_o = 8.314\ J/mol.K$$

$$\dot{m} = \frac{\sqrt{\gamma}\ p_c A_t}{\sqrt{RT_c}}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}$$

$$C_F = \sqrt{\frac{2\gamma^2}{\gamma-1}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}\left[1-\left(\frac{p_e}{p_c}\right)^{\frac{\gamma-1}{\gamma}}\right]} + \left(\frac{p_e}{p_c}-\frac{p_a}{p_c}\right)\frac{A_e}{A_t}$$

$$\varepsilon = \frac{\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}\left(\frac{p_c}{p_e}\right)^{\frac{1}{\gamma}}}{\sqrt{\frac{\gamma+1}{\gamma-1}\left[1-\left(\frac{p_e}{p_c}\right)^{\frac{\gamma-1}{\gamma}}\right]}}$$

$$\frac{T_o}{T} = 1+\left(\frac{\gamma-1}{2}\right)Ma^2, \frac{p_o}{p} = \left[1+\left(\frac{\gamma-1}{2}\right)Ma^2\right]^{\gamma/(\gamma-1)}, \frac{\rho_o}{\rho} = \left[1+\left(\frac{\gamma-1}{2}\right)Ma^2\right]^{1/(\gamma-1)}$$

All the symbols have their usual meanings.