End Semester Examination

ANSWER ALL QUESTIONS

1. a. State the principle used to generate ions in a Hall thruster. How is thrust generated in the Hall thruster? What are its advantages?

    b. Why is neutralization of the charge in the exhaust of an electrical thruster necessary?

    c. If the electric field between the accelerating and extraction grids of an ion thruster is 10 kV/cm, determine the force experienced by an electric charge of 4×10^{-6} C placed in the electric field between the two grids. State the units clearly.

    d. Determine the velocity at which a charged mass of gas 0.08 C must be admitted normal to a magnetic field of 0.02 Tesla to generate a thrust of 2 mN (milli-Newton). If the extent of the magnetic field is 0.2 m, determine the beam current due to the moving charge.   *(6)*

2. a. In the expression $p' = \hat{p}e^{(\alpha + i\omega)t}$, what does α and ω represent?

    b. What do you understand by the terms "detuning" a combustion chamber and "gain stabilization" of combustion process? How does "detuning" and "gain stabilization" help in preventing combustion instability in chemical propellant rockets?

    c. A liquid propellant rocket has a length between the injector and the nozzle throat of 0.5 m. The temperature of the hot combustion products is 3200 K and the mean molecular mass of the gas is 25 g/mole. The specific heat ratio of the combustion product is 1.28. If the universal gas constant $R_0 = 8.314$ J/(mole K), determine the frequency of the fundamental and the first harmonic of the standing wave mode of axial oscillations.

    d. Plot the pressure wave forms showing the nodes and antinodes for the fundamental and first harmonic. Indicate the wavelength λ in the sketch.   *(6)*

3. a. Show that the value of time available for combustion to take place (residence time τ) in the combustion chamber of a solid/liquid propellant rocket can be written as:

$$\tau = \frac{L^*}{\Gamma^2 C^*}$$

where L^* is the characteristic length of the rocket ($L^* = V_c/A_t$, V_c being the volume of the combustion chamber and A_t the throat area) and C^* is the characteristic velocity of the propellant. Γ, which is a function of the specific heat ratio is related to the chamber temperature T_c by the relation $C^* = \sqrt{RT_c}/\Gamma$, R being the specific gas constant.

b. What is the difference between action time and web burn time of a solid propellant rocket?

c. In a liquid propellant rocket, the fuel and oxidizer are injected in three annular streams having mixture ratios of 1.8, 1.6 and 1.2 respectively. The stream having the mixture ratio of 1.8 contains 50% of the total propellant flow rate, while the adjacent annular stream of mixture ratio 1.6 contains 30% of the total propellant flow rate. The stream adjacent to the walls contains the balance of 20% propellant flow rate at the mixture ratio of 1.2. If the C* values at mixture ratios of 1.8, 1.6 and 1.2 are 2500, 3000 and 1500 m/s respectively, determine the net C* due to the above distribution of mixture ratio.

d. What is the purpose in distributing a low value of mixture ratio in the outer stream adjacent to the walls? *(6)*

4 a. Determine the throat diameter and volume of the combustion chamber of a liquid bipropellant rocket using Liquid Oxygen (LO$_2$) and kerosene for the conditions given below:

           Thrust (F) = 60 KN
           Chamber Pressure (p_c) = 5 MPa
           Thrust coefficient (C_F) = 1.2
           Characteristic Length of the kerosene –LO$_2$ rocket (L^*) = 1.7 m.

b. If the mixture ratio of the propellant combination is 2 and the density of LO$_2$ and kerosene are 1140 and 800 kg/m^3 respectively, determine the volumetric flow rates of LO$_2$ and kerosene into the combustion chamber. You can assume the Characteristic Velocity of the propellant (C^*) to be 2800 m/s.

c. If doublet injection elements of diameter 2mm are used for injecting kerosene into the combustion chamber, determine the number of injection holes (elements) in the injector for kerosene. The discharge coefficient (C_d) of the kerosene injection elements is 0.64 and the supply pressure of kerosene to the injector is 7.5 MPa. *(8)*

5. a. A radial burning solid propellant grain used in a rocket has a cylindrical port of diameter 100mm. The outer diameter of the propellant grain is 300 mm. The length of the grain is 0.5 m. The throat diameter of the nozzle is 40 mm.

The burn rate r in mm/s of the solid propellant is given by $r = 0.02 \ p^{0.35}$, where p is the pressure in Pa. Determine:

    i.) Chamber pressure in MPa at ignition
    ii.) Chamber pressure in MPa at burnout
    iii.) Burn duration of the propellant grain.

The propellant density (ρ_p) is 1700 kg/m^3 and the characteristic velocity (C^*) of the propellant is 2000 m/s.

b. Give the essential differences between (i.) composite propellant, (ii.) double base propellant, and (iii.) nitramine propellant.   *(8)*

6. Determine the heat released per kg of hydrazine and the mean molecular mass of the combustion products of a fuel-rich mixture of fuel hydrazine and oxidizer N_2O_4 at a mixture ratio of 1.025? The products of combustion are nitrogen, water and hydrogen. The heats of formation of hydrazine (N_2H_4), N_2O_4 and water are +55 kJ/mole, +10 kJ/mole and –290 kJ/mole respectively. The atomic mass relative to hydrogen of N, O and H are 14, 16 and 1 respectively.   *(10)*

7 a. What is the difference between frozen flow and shifting equilibrium flow in the rocket nozzle? Would frozen or shifting flow occur preferably in the convergent or the divergent portion of the nozzle and why?

b. What is the reason for preferring a fuel-rich composition for a chemical propellant? Illustrate with sketches.

c. A conical convergent nozzle with a half divergence angle of 15° is designed for optimum expansion at an altitude of 5 km for which the ambient pressure is 0.054 MPa. Determine using Summerfield criterion, whether the flow in the divergent would separate during take-off from the ground assuming that steady state thrust is achieved in the chamber during take-off? The ambient pressure at ground level is 0.1 MPa.

d. What is the divergence loss of the above conical nozzle?

e. What is the principle used in the design of a contour nozzle and why is it that flow separation is not a major issue in a contour nozzle?   *(6)*