Assignment 7

1. i.) A space capsule is to be electrically propelled in deep space using the electrical power generated by a nuclear power plant that is carried by the capsule. The nuclear power plant works on the principle of radio-active isotope decay. The mission in deep space calls for an incremental velocity ΔV of 5 km/s to be provided in 60 days by continuous operation of the electrical rocket. The specific mass of the system comprising the space capsule, power plant, electrical power processing unit and the rocket is 100 kg/kW. Assuming the efficiency of the electrical rocket as 85%, determine the specific impulse for which the rocket is to be designed in order to obtain the maximum payload mass.

ii.) What is the maximum payload ratio? If the mass of the useful payload is 1000 kg and the power plant has a rating of 15 KW, determine the mass of propellant required for the mission.

2. A resistojet uses propellant helium heated to a 1000 K at a pressure of 1.5 MPa. The heated helium is exhausted through a convergent divergent nozzle having a throat diameter of 0.2 mm and exit diameter of 3 mm. Determine the characteristic velocity, mass flow rate of helium, specific impulse and the thrust generated. Helium has a molecular mass of $4\,kg/kmole$ and a specific heat ratio of 1.67.

3. Determine the acceleration voltage to be provided in an ion thruster of specific impulse 20000 $N\,s/kg$ in which the propellant is charged to 5×10^{4} C/kg? What is the thrust to power ratio of the thruster?

4. A combination of a cold ammonia gas and a hot ammonia gas resistojet seems to be a viable option for thrusters for attitude and orbit control and station keeping of a geosynchronous satellite. The hot ammonia resistojet is required to generate a specific impulse of 2200 $N\,s/kg$ at a thrust of 10 N. The expansion ratio of the nozzle is 80. If the pressure at which ammonia is heated is 0.5 MPa, determine the electrical power supply to the resistojet assuming the efficiency of the electrical heating of ammonia to be 75%. You can neglect the decomposition of ammonia. The specific heat ratio of ammonia (NH_3) is 1.31. The ambient pressure at the geosynchronous altitude would be zero.

What is the change in specific impulse if ammonia dissociates?

5. (a.) An arc jet thruster using hydrogen gas as the propellant operates in deep space. The hydrogen is heated to a temperature of 5000 K by the arc at a pressure of 100 kPa and the heated hydrogen is expanded in a convergent divergent nozzle of area ratio 100. Assuming the throat diameter as 3 mm and no dissociation of hydrogen and frozen flow in the nozzle, determine the specific impulse of the thruster. The specific heat ratio of hydrogen can be assumed as 1.4.

(b.) In practice the hydrogen gas dissociates. If the equilibrium constant K_P (discussed in Chapter 4) for dissociation of hydrogen to monatomic hydrogen ($H_2 \rightarrow 2H$) is given as $\ln(K_P)= 14.9-55{,}870/T$, and the average specific heats at constant pressure of H_2 and H are 20 and 35 kJ/(kmole K) in the temperature range of interest, what is the fractional change in the specific impulse due to the dissociation? The flow in the nozzle can be assumed to be frozen. The specific heat ratio of monatomic hydrogen is 1.67. The temperature of the heated gases, as in the earlier problem is 5000 K.

(c.) The dissociation of hydrogen would result in part of the energy supplied by the arc discharge being not available for raising the temperature of hydrogen. Determine the fraction of the arc discharge energy in the problem (b.) above which is lost in the dissociation of hydrogen. The standard heat of formation of monatomic hydrogen ΔH_f^0 is +217.5 kJ/mole.

6. A satellite of mass 800 kg is required to be propelled from a Low Earth Orbit (LEO) to a Geo-Stationary Orbit (GSO) using electrical propulsion. The mass of the satellite includes the mass of the useful payload, the satellite structure, electrical power plant, propellant storage devices and the rocket hard-ware. The mission from LEO to GSO is to be achieved in 150 days by continuous firing of the electrical rockets. The incremental velocity required for this mission is 6 km/s. The electrical rocket has an efflux velocity of 40 km/s and the efficiency of operation is 90%. The available electrical power is 10 kW, the specific mass of the system being 20 kg/kW. Determine the mass of propellant required for the mission?

7. Determine the payload ratio for a space vehicle which achieves a velocity increment of 4 km/s by operating an electric propulsion unit in a continuous mode over a period of 8 days. The specific impulse of the electrical rocket is 20 $kN\,s/kg$ and the specific mass of the space capsule is 0.09 kg/W. The efficiency of the electric propulsion system is 90%. The power supplied to the rockets is 10 kW.

8. A micro resistojet for satellite applications has been reported using MEMS (Micro Electrical Mechanical Systems) technology. In this water was vaporized to generate small amount of thrust. A resistor, vaporizing chamber, nozzle and micro-channels for feeding water to the vaporizing chamber were all etched in silicon wafers. The water was vaporized by electrical heating using the resistor. The nozzle terminated at the throat. The throat had a square cross section.

Determine the throat dimension and the thrust generated in such a vaporizing water micro-thruster when the power dissipated in the resistor is 20 W and the water flow rate is 5 mg/s. The efficiency of the heating is 79%. The pressure in the vaporizing chamber is 0.20MPa. The thruster operates in deep space.