AE 330/708 AEROSPACE PROPULSION
End semester examination (Total marks: 25)
22/11/2020, 3.30 pm to 6.30 pm

Constants: Gravitational acceleration = 9.81 m/s^2, Sea level ambient pressure = 0.1013 MPa, Universal gas constant = 8.314 J/mol.K

Q1] Performance: [4 marks]
A single stage rocket is used as a sounding rocket to make measurements in the earth's atmosphere. It carries sensors and electronic packages which can withstand a maximum acceleration of 10g. It develops a constant thrust of 6 kN and has a total impulse of 90 kN-s. It is launched vertically. If the mass of the empty rocket (excluding the payload and the propellant) is 40 kg, what would be the constraint on the payload that the sounding rocket can carry so that its acceleration does not exceed 10g? (Neglect drag and assume constant gravity)

Q2] Multistage vehicle: [5 marks]
A four-stage launch vehicle is used to launch the satellite of mass 700 kg. The details of the stages are given below:

Stage	Structural mass (kg)	Propellant mass (kg)	Specific impulse (sec)
First stage	25,000	1,40,000	264
Second stage	8,200	40,000	292
Third stage	1,400	7,000	293
Fourth stage	2,200	1,200	304

Determine: 1) velocity increment provided by each stage and the total vehicle, 2) Initial acceleration of the vehicle if the thrust of the first stage is 4,800 kN. (Assume constant gravitational acceleration at sea level)

Q3] Solid rocket motor: [8 marks]
A solid rocket motor of a missile burns a composite propellant at 6 MPa. The burn rate is given by $r = 4.5\ P_1^{0.3}$, where r is in mm/s and P_1 is in bars. The specific gravity of the propellant is 1.75 and the burning surface area is 1 m^2. The cruise altitude for the missile is 20 km where the nozzle is expected to be optimally expanded. The burning of the propellant is neutral. Determine the characteristic velocity, nozzle area expansion ratio, thrust and the specific impulse while cruising if the throat area is 0.009 m^2. The molecular weight and the specific heat ratio of combustion gases may be assumed to be 19 g/mol and 1.2 respectively.
The simplest grain configuration for neutral burning is the end-burning configuration. However, it suffers from a major drawback. What is the drawback? Which alternative grain geometry would you suggest to overcome this drawback?
The missile needs a simple, low-actuation-power thrust-vectoring system. Which trust-vectoring technique is suitable?
(Use atmospheric pressure variation with altitude from the next problem.)

Q4] Liquid propellant rocket engine: [8 marks]
A fuel-rich mixture of kerosene ($C_{12}H_{24}$) and oxygen at a mixture ratio of 2.5 is burnt in a rocket chamber. Determine characteristic velocity if the product mixture includes H_2O, CO_2 and CO. Assume initial reactant temperature as 298 K.

Species	Kerosene	H_2O	CO	CO_2
Heat of formation kJ/mol	-159	-241	-112	-390

Specific heat J/mol-K	--	58	37	63

The engine operates with a chamber pressure of 6 MPa and a mass flow rate of 200 kg/s. while generating the sea-level specific impulse 270 sec. The vacuum specific impulse is 300 sec.

1. Design the nozzle.
2. Determine the altitude for optimum expansion condition. (Pressure (in Pascals) at altitude h (meters) is given as, $\boldsymbol{P=101325e^{(-h/8435)}}$)
3. Since the engine operates for a long duration at relatively low altitudes, what would be the best strategy for cooling the engine?
4. In the practical scenario, if the kerosene and the oxygen enter the combustor in liquid and gas phase respectively, what would be the preferred atomization technique?