ENAE 483/788D POWER, PROPULSION, AND THERMAL SPECIALTY PROBLEMS – FALL, 2021

(1) A rocket engine on the first stage of a launch vehicle has a combustion chamber pressure of 300 bar and an exit pressure of 6 psi. The ratio of specific heats γ in the exhaust is 1.2. The engine burns LOX/LCH4 stoichiometrically according to the chemical formula $2O_2 + CH_4 \rightarrow CO_2 + 2H_2O$.

(a) What is the average molecular weight of the exhaust flow?

(b) Calculate the expansion ratio of this engine's nozzle

(c) If the combustion temperature of the engine is 3000K, what is its exhaust velocity?

(d) If the engine has a thrust of 500 klbs at ideal matching conditions ($P_e = P_{amb}$), what mass flow rate is required?

(e) If you wanted to lower the exit pressure to 0.5 psi, what expansion ratio would you need?

(f) How would the engine's exhaust velocity change with the new nozzle, if all other parameters in the engine were held constant?

(2) You are designing the power system for a human base at the lunar equator. The base has 336 hours of sunlight, followed by 336 hours of darkness. You are using photovoltaic arrays which track the sun during the daytime. The human base will need a continual power level of 60 kW.

(a) How much energy storage do you need in your batteries to maintain power during lunar night?

(b) If the batteries are 90% efficient at charging (i.e., only 90% of the power you supply for recharge will be stored in the battery) and 95% efficient at discharge (i.e., 5% of the capacity of the battery is unavailable for use), how does your answer to (a) change?

(c) If the batteries only tolerate a 50% depth of discharge (i.e., only half the rated storage energy is available to prevent damage to the batteries), how does your answer to (b) change?

(d) If the batteries have a specific energy of 300 W-hrs/kg, what is the mass of the batteries (as defined by your answer to (b))?

(e) How much power is required from the photovoltaic arrays to charge the batteries with a 20% energy margin?

(f) The PV arrays you have chosen have a conversion efficiency of 32% and a mass of 2.5 kg/m^2. What are the area and mass of the PV arrays? What is the total mass of your power system?

(g) For simplicity, you want to consider the option of having the photovoltaic arrays laying flat on the lunar surface, so the power collected varies as the sine of the sun's angle above the horizon. How does this change your answer to (f)?

(3) You are designing a nuclear dynamic power system for a large space station. The goal is to generate 1 MW of electrical power continuously.

(a) The best thermodynamic efficiency possible is that of the Carnot cycle, $\eta = 1 - \frac{T_{cold}}{T_{hot}}$. If T_{hot} =2100K and T_{cold} =450K, what is the efficiency?

(b) Given your answer to (a) above, how must waste heat do you need to radiate away?

(c) If the radiator is a flat plate ($\alpha = 0.25$; $\epsilon = 0.9$) that radiates to deep space on both sides without any other heat loads, what area would the radiator have to be?

(d) If the same radiator design is in low Earth orbit such that one side radiates to Earth (T_{Earth} =280K) and the other side is illuminated by the sun, what would be the new required radiator area?