MAE 112 PROPULSION MIDTERM EXAM

November 13, 2024

Do all three problems in eighty minutes. Books, tables, and notes in paper form, and calculators (without communication capability) can be used. Cell phones, tablets, and computers cannot be used or be visible.

1. (30 points) Consider a liquid-propellant rocket engine where liquid methane plus 1 kg/s of liquid oxygen flows into the combustion chamber at 20 atmospheres of pressure. The stoichiometric amount of liquid methane is injected continuously into the chamber. The liquids, methane and oxygen, are heated upstream of injection to the combustion chamber and introduced to the combustion chamber as gases at their boiling points: 111 K and 90 K, respectively.

Heats of formation (kJ/kmol) are: CH_4: -74,831; CO_2: -393,546; H_2O: -241,845;
Specific heats (kJ/kmol-K) are: CH_4: 35.800; O_2: 29.315; CO_2: 58.836; H_2O: 48.035.

The gaseous flow through the combustor has a very low Mach number. Assume complete conversion of the oxygen to the primary products without dissociation in the combustor. Also, assume perfect expansion through the nozzle with $\gamma = 1.25$ and 100% efficiency. Determine:

(a) the products of combustion with mass flux units (kg/s) for each chemical component in the products;
(b) the peak temperature in the combustor;
(c) the throat area of the choked nozzle; and
(d) the thrust for the condition of perfect expansion with a 0.5 atmosphere environment.

2. (40 points) Consider a ramjet in flight at a Mach number of 2.25 with ambient conditions at 298 K and one atmosphere of pressure. The air capture area in the free stream is 1.0 square meter. The inlet design involves first a wedge that deflects the stream by an angle of 15 degrees followed by a divergent diffuser. The air intake occurs only on one side of the wedge. $\gamma = 1.4$.

(a) What is the stagnation temperature of the adiabatic flow through the inlet / diffuser?
(b) What are the stagnation pressure values ahead of and immediately behind the first shock?
(c) What is the flow Mach number immediately behind the first shock?
(d) What is the Mach number behind the second shock during normal (design) operation?

3. (30 points) Consider a compressor with inflow air pressure and temperature of 1.5 atmospheres and 550°R. The overall pressure ratio across all stages is 12. The value of $\gamma = 1.4$ and the value of $c_p = .24$ Btu/1bm °R. Assume 96% polytropic efficiency. Calculate:

(a) the final temperature,
(b) the power per unit of mass flow,
(c) the gain in entropy across the compressor.

END