MAE 112 PROPULSION

FINAL EXAM

December 9, 2022

Do all parts of the four problems in 120 minutes. Open books and notes are allowed. Calculators without communication capability are allowed. Cellphones, tablets, and laptops should not be available. The ratio of specific heats for monoatomic gases is 5/3; the ratio of specific heats for diatomic gases is 7/5.

I. (30 points) Consider a turbine stage that has a polytropic efficiency of 0.95 for the stator (nozzle) and for the rotor flow. 30% of the total static enthalpy drop through the stage occurs in the rotor portion. The initial and final velocities for the stage are axial and have no swirl (tangential component). Assume that only the tangential component of velocity changes through the stator (nozzle) portion. The flow has $\gamma = 1.3$ and $c_p = 0.30$ Btu/1bm°R; the incoming flow has a static temperature of 2800°R, a static pressure of 30 atmospheres, and a velocity of 200 ft/sec. The average rotational velocity of the rotor blade is 2000 ft/sec. The flow exiting the stage has a static pressure of 20 atmospheres.

(a) (7.5 points) What are the temperature drop and enthalpy drop across the stator?

(b) (7.5 points) What is the tangential velocity at the position between the stator and the rotor measured in a frame of reference fixed to the stator?

(c) (7.5 points) What are the enthalpy drop, temperature drop, and the pressure drop across the rotor?

(d) (7.5 points) What is the power output per unit mass flux?

II. (30 points) Consider a turbofan engine flying at a Mach number of 2.00 with ambient pressure of 0.7 atmosphere and ambient temperature of 250 K. The inlet design involves first a wedge that deflects the stream by an angle of 15 degrees followed by a diffuser with diverging cross-sectional area and a normal shock at the entrance. Just downstream of the air intake wedge and diffuser, the air divides with a bypass ratio of 3 into a primary and a secondary (or bypass) flow at the air intake exit. The primary flow passes through a fan and compressor with an overall pressure ratio of 25 and polytropic efficiency of .97 while the secondary flow passes through a fan with pressure ratio of three and efficiency of .98. The primary flow burns at constant pressure with liquid fuel (heating value = 45000 kilojoules/ kgm) with a final combustor temperature of 1500 K and then expands through a turbine and ultimately through the primary nozzle to ambient pressure. Burner efficiency is .99 while the polytropic efficiencies of the turbine and the nozzle are each .97. All work taken from the turbine flow is employed to drive the fan and compressor. The secondary flow expands isentropically to ambient pressure through a secondary nozzle. $c_p = 0.24$ cal/gm°K for air; $c_p = 0.31$ cal/gm°K for products; $\gamma = 1.4$ for air; $\gamma = 1.25$ for products.

(a) (7.5 points)What is the stagnation pressure at the downstream end of the intake diffuser?

(b) (7.5 points) Calculate the stagnation temperature of the secondary flow at the fan exit.

(c) (7.5 points) Calculate the stagnation temperature of the primary flow at the compressor exit.
(d) (7.5 points) What is the temperature at the turbine exit?

See next page.

III. (20 points) A Hall thruster has a crossed E and B field with the electric field vector pointing in the positive y-direction and the magnetic field vector pointing in the positive z-direction. E = 1000 volt/meter and B = 1000 webers/m^2. The electron charge-to-mass ratio is q / m = 1.76 x10^{11} coulombs/kgm. Assume collision frequency is $\nu = 10^8$ collisions per second. σ = 2000 per ohm-meter. *Note that one weber = Newton-second-meter per coulomb; one ohm = volt-sec per coulomb; and one joule = Newton-meter = volt-coulomb.*

(a) (5 points) What is the gyro frequency of the electron? Does the comparison with collision frequency allow for a useful Hall thruster?
(b) (5 points) What is drift velocity in the *y*-direction?
(c) (5 points) What is the Hall current magnitude j_y that results here?
(d) (5 points) What is the Lorentz force in the *x*-direction due to the Hall current?

IV. (20 points) Compare the choked-nozzle flow for three cases: (i) a solid-core nuclear rocket using helium as the propellant, (ii) a solid-core nuclear rocket using hydrogen as the propellant, and (iii) liquid-propellant rocket engine using a stoichiometric proportion of hydrogen and oxygen. In all three cases, the pressure and temperature entering the nozzle are 75 atmospheres and 3200 K for each rocket. All three nozzles exit to the ambient pressure with an exit Mach number equal to 6.0. Each nozzle flow is isentropic and has the same normalized cross-sectional-area variation A/A* as a function of downstream position x. The ratio of specific heats is 1.25 for the chemical.

(a) (6 points) What are the three exhaust temperature values?
(b) (6 points) What are the three ratios of nozzle exit area to nozzle throat area, A_e/A^* ?
(c) (8 points) What are the three specific impulses?

END.