NAME:
AERO 360
Examination 2
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Use any and all pertinent charts and tables on this examination where appropriate.

1. A converging-diverging nozzle has been designed to operate with an exit Mach number of $M = 2.5$ when the stagnation pressure and temperature are 1000 $psia$ and $100°F$. The area of the throat is 1.3 ft^2. The working fluid is CPIG air. The atmospheric pressure is 14.7 $psia$.

- What is the exit area?
- What is the thrust developed at design conditions?
- If the back pressure is raised such that the exit Mach number is 0.50, what is the cross-sectional area at the position where a normal shock sits in the duct? What is the entropy change across this shock? What is the new thrust value?

2. Consider the following problem which is applicable to a re-entry vehicle at an altitude of near 30 km:

Air flowing horizontally at $u_1 = 2,500\ \frac{m}{s}$, $P_1 = 1.2\ kPa$, $T_1 = 200\ K$ encounters an oblique shock inclined at an angle of 60° to the horizontal. Take the air to be ideal with $P = \rho RT$; $R = 287\ \frac{J}{kg\ K}$.

- If the gas were calorically perfect with $\gamma = 7/5$, calculate the post shock temperature, pressure, and corresponding wedge angle.
- Now consider the more realistic *calorically imperfect* problem: Take

$$e = a_0 + a_1 T + a_2 T^2;$$

  $a_o = 4640\ \frac{J}{kg}, a_1 = 706\ \frac{J}{kg\ K}, a_2 = 0.062\ \frac{J}{kg\ K^2}$. Pose the calorically imperfect system as five algebraic equations for the five unknowns $P_2, \rho_2, T_2, e_2, U_2$. Here take U_2 the be the *magnitude* of the *total* post-shock velocity. It is not necessary to numerically solve this problem.

- If one completed the analysis including the effects of variable specific heat, would one realize a higher or lower post shock temperature relative to the calorically perfect analysis? Give a brief physically (not mathematically) motivated reason.

3. Argon (CPIG, $\gamma = \frac{5}{3}$, $R = 38.68\ \frac{ft\ lbf}{lbm\ R}$) flows adiabatically in a 2 in diameter commercial steel pipe. At the inlet the pressure $P_1 = 20\ psig$, the temperature $T_1 = 70°F$, and the velocity $u_1 = 30\ \frac{ft}{s}$. The Darcy friction factor for such a flow is known to be $f = 0.00333$. Find the maximum possible length of the pipe and the pressure and velocity of the argon and the end of a pipe of such length.