EAS 4300 Homework 6:
Air-breathing Propulsion and the Ramjet Engine

Due Thursday, March 31st at the beginning of class
NOTE: include a copy of your equations and code with your plots

1. (10 points) Problem 2 in chapter 5 of the book (see answer in the back of the book).
2. (10 points) Problem 12 in chapter 5 of the book.
3. (40 points) Consider an ideal ramjet engine flying at an altitude of 10,000 m (see local atmospheric conditions in appendix III of the textbook). The jet fuel used has a heat of combustion of 43,000 kJ/kg, and a stoichiometric fuel to air ratio of 0.06. The maximum temperature of the ramjet is 2600 K. Assume the specific heat ratio up to the combustion chamber is 1.4, and that the specific heat ratio through the rest of the engine (including the combustor) is 1.33. The specific heat at constant pressure for the gases in the combustor can be calculated using the following equation:

$$C_p = \left(\frac{\gamma}{\gamma - 1}\right) R \,,$$

   where R is assumed to be 0.287 kJ/kgK throughout the engine. Calculate the specific thrust and TSFC as a function of flight Mach number from a range of 1 to 6. Note that the fuel to air ratio can not be above the stoichiometric value (i.e. we can't burn more fuel than that at an equivalence ratio of unity). Some operating points may require a higher value of f than the stoichiometric value to reach the temperature limit. Under this condition, f should be set to the stoichiometric value, and the combustor exit temperature T_{04} should be calculated from the energy equation. Otherwise, the maximum temperature is used and f is calculated from the energy equation. Using a procedure and an if/then/else approach in EES might be ideal for this. Include the following plots:

   1. Specific thrust (I) vs. M_{flight}
   2. TSFC vs. M_{flight}
   3. T_{04} vs. M_{flight}
   4. A_{exit}/A_{throat} vs. M_{flight}
   5. η_{th}, η_p, and η_o vs. M_{flight}

4. (30 points) Conduct a sensitivity study of the performance of the ramjet engine with respect to combustion effiency η_b and the exhaust nozzle total pressure ratio r_n. Using the conditions and properties listed for problem 2 as a starting point, construct plots of

$$\frac{d(I)}{d\eta_b}, \frac{d(I)}{dr_n}, \frac{d(TSFC)}{d\eta_b}, \frac{d(TSFC)}{dr_n},$$

as a function of flight Mach number from 1 to 6. The derivatives can be approximated using small but discrete changes, such as

$$\frac{d(I)}{d\eta_b} \approx \frac{\Delta I}{\Delta \eta_b}.$$

Use baseline η_b and r_n values of one, and use delta values of 0.01. Make plots of the normalized sensitivity coefficient (e.g. derivative) as a function of flight Mach number:

1. $\frac{1}{I}\frac{d(I)}{d\eta_b}$ vs. M_{flight}
2. $\frac{1}{I}\frac{d(I)}{dr_n}$ vs. M_{flight}
3. $\frac{1}{TSFC}\frac{d(TSFC)}{d\eta_b}$ vs. M_{flight}
4. $\frac{1}{TSFC}\frac{d(TSFC)}{dr_n}$ vs. M_{flight}