EAS 4300 Project

<u>Due last day of classes (Tuesday, April 26th, 2016)</u>

Ramjet design

A ramjet engine flow path is to be specified having a geometry as shown in Fig. 1.

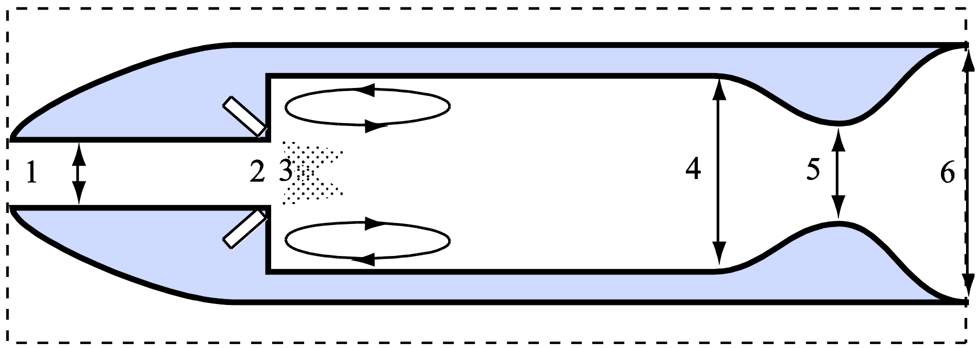

Figure 1: ramjet schematic

Station a: ambient
Station 1: inlet
Station 2: exit of the entrance path, same cross-sectional area as station 1
Station 3: entrance of the combustor, fuel injected and combustion occurs between station 3 and 4
Station 4: exit of the burner, same cross sectional area as station 3
Station 5: throat of the exhaust nozzle
Station 6: exit of the exhaust nozzle

The inlet duct feeds into a sudden expansion that acts as a flame holder due to the recirculation zones produced by the sudden expansion. The total pressure losses between 0a and 02 are governed by the following empirical correlation:

$$r_d = 1 - 0.075(M_a - 1)^{1.35}.$$

Stations 2 and 3 are very close together, but differ in cross-sectional area. Note that the flow at station 3 is not one dimensional, uniform flow exists across the area A_2 which is a smaller area than A_3. The pressure is uniform across the area A_3 and is equal to P_2. This is the only part of the engine that deviates from one-dimensional flow. Fuel is sprayed into the combustor as shown in the figure between stations 3 and 4, where combustion also occurs. The combustor has a constant cross-sectional area $A_3 = A_4$. Station 4 is the exit of the combustor and the inlet of the exhaust nozzle. Station 5 is the throat of the nozzle, and station 6 is the exit plane of the converging/diverging nozzle. For this engine, the thrust producing surfaces include the sudden expansion surface area (A_3-A_2), and the projected area of the nozzle (A_6-A_5), although the nozzle is counteracted by the upstream convergent area (A_5-A_4), hence it is not clear if the nozzle produces any net thrust. Some design constraints:

1. A gross thrust (i.e. excluding external drag generated by the external engine shape) of 10,000 lb_f (max).
2. Due to total engine volume limitations and external drag, $A_3 < 10A_1$.
3. The design flight Mach number is 4.
4. The nozzle is to be ideally expanded at an altitude of 40,000 ft with a limit exhaust area of $1m^2$.

You are to determine the areas A_1, A_4, A_5, and A_6 that satisfy the design requirements yet minimize the TSFC. The maximum temperature in the engine is 2300 K. You are to use control volume-based analysis using conservation of mass, momentum, and energy. The exhaust nozzle is isentropic (hint: you do not need to apply conservation of momentum through the nozzle, which would require the knowledge of the static pressure distribution along the nozzle wall).

Additional information:

1. Use a throat area that is equal to the inlet area (A_1=A_5).
2. Apply conservation of momentum on a control volume that is shown in Fig. 1. Define thrust, specific thrust, TSFC, etc. based on this control volume.

Determine the areas of the engine that provides the minimum TSFC (or minimum A_6) while maintaining the desired thrust. Report the process that was used to determine the optimized engine configuration (for one-person take f = 0.06). Then consider the fixed exhaust nozzle engine as it operates over a range of Mach numbers at the design altitude. Assume there is no shock in the nozzle.

Plot I, TSFC, η_{th}, η_p, and η_o as a function of M_a. Plot the ideal ramjet I for comparison.

Plot the Mach number at the inlet of the combustor, M_2 as a function of M_a.

Plot f_b as a function of M_a.

Plot r_b as a function of M_a.

Format:

I encourage you to discuss this project with your classmates, but all formulas, analysis, computer coding, or reports should be done individually. The best way to really learn is through doing it yourself. Please show all your relevant work and steps of how you solved the problem.