

AME 436	Assigned: Friday 4/3/09
Problem Set #5	<ul style="list-style-type: none"> • Due Monday 4/13/09 at 4:30 pm in OHE 430J • Email to the grader (Thada Suksila, suksila@usc.edu) or fax to 213-740-8071 if you're off campus • DEN students submit through the usual channels

Problem #1 (20 points)

For each of the following equations a) – c) used frequently in this course, state whether or not each of the following restrictions i) – viii) apply.

- i. Steady
- ii. one-dimensional flow
- iii. ideal gas
- iv. constant specific heats
- v. reversible
- vi. adiabatic
- vii. no work transfer
- viii. negligible change in kinetic energy

a) Thrust equation: $T = \dot{m}_a[(1+FAR)u_e - u_1] + (P_e - P_a)A_e$

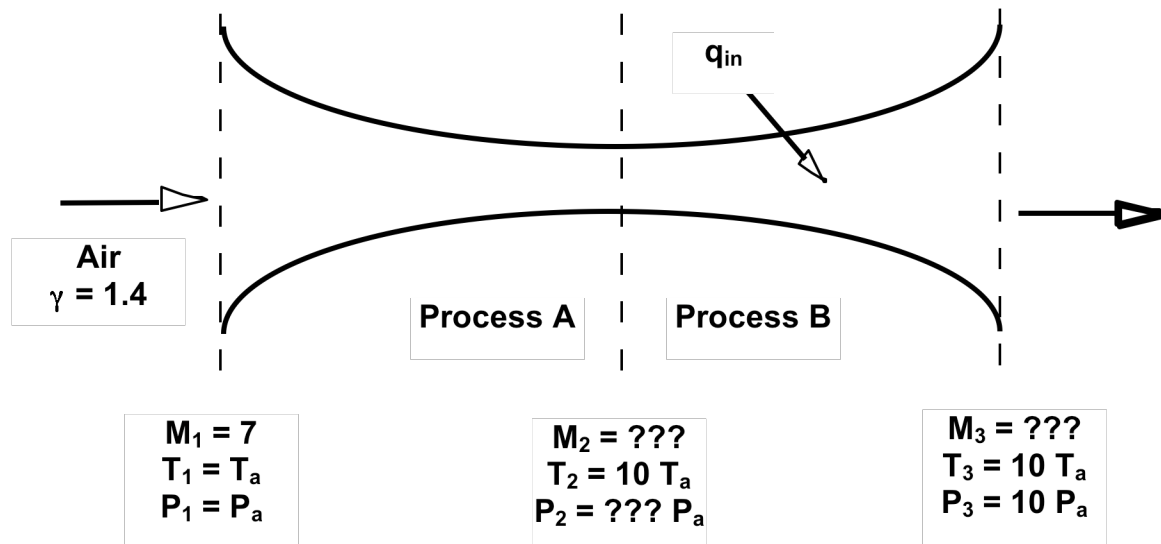
b) Enthalpy/velocity relation between states 1 and 2:

c) Temperature/pressure relation between states 1 and 2: $\frac{P_1}{P_2} = \frac{T_1^{\gamma/\gamma-1}}{T_2^{\gamma/\gamma-1}}$

Problem #2 (10 points)

Using the Brequet range equation, estimate the range of an albatross. When estimating the heating value of albatross food, note that 1 diet calorie = 1000 thermodynamic calories. (This question always throws students for a loop. The point is not to get an exact answer, but to estimate each of the terms in the Brequet range equation, and see if the result is reasonable or not.)

Problem #3 (20 points) (from last year's final exam)



Consider a simple hypersonic propulsion system for an aircraft at an initial Mach number of 7 that consists of two processes:

Process A: Decelerate the incoming flow reversibly and adiabatically until the static temperature is 10 times the ambient temperature T_a

Process B: Add heat at constant temperature until the pressure is equal to 10 times the ambient pressure

Assume air is an ideal gas with constant specific heats, and the fuel-to-air ratio (FAR) $\ll 1$.

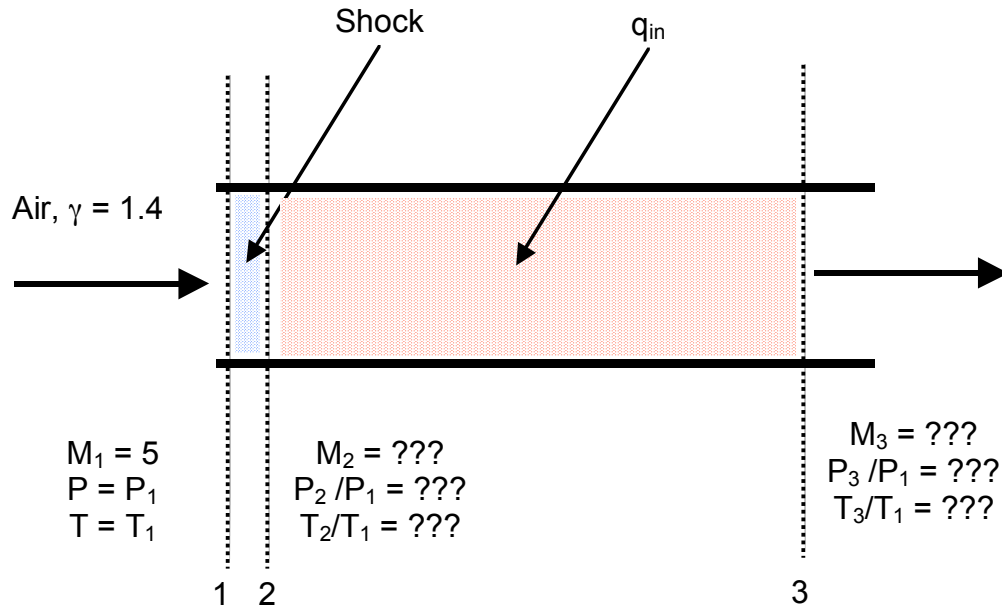
- Compute the Mach number after deceleration (station 2)
- Compute the static (not stagnation) pressure relative to P_a after deceleration (station 2)
- Compute the Mach number at the exit (station 3)
- Compute the non-dimensional specific thrust
- Compute the overall efficiency
- Are the area changes between stations 1 and 2 and between stations 2 and 3 shown in the figure qualitatively correct? Why or why not?

Problem #4 (20 points)

Consider a flowing gas with $\gamma = 1.4$, $R = 287 \text{ J/kgK}$, $M = 3$, $T_t = 840\text{K}$ and $P_t = 36.73 \text{ atm}$.

- If there is no heat addition but there is friction loss in a constant-area duct of length L , diameter d , and friction coefficient $C_f = 1 \times 10^{-6}$, what is the maximum L/d for which this flow can be transmitted? What is the stagnation pressure at the end of the duct?
- If there is no friction but heat is added at constant area until thermal choking ($M = 1$), how much heat has been added to the gas (in J/kg)? At this condition, what is the stagnation pressure?
- How much heat could be added at constant pressure (in J/kg , starting at $M = 3$, $T_t = 840\text{K}$ and $P_t = 36.73 \text{ atm}$) before the stagnation pressure in part (b) is reached?
- How much heat could be added at constant temperature (in J/kg , starting at $M = 3$, $T_t = 840\text{K}$ and $P_t = 36.73 \text{ atm}$) before the stagnation pressure in part (b) is reached?

Problem #5 (30 points)



Consider a very simple propulsion system operating at a flight Mach number of 5 that consists of 2 processes:

Process 1: Shock at entrance to duct

Process 2: Heat addition in a **constant-area duct until thermal choking occurs**

- Compute all of the following properties of this system:
 - Static (not stagnation) temperature relative to T_1 after the shock
 - Static (not stagnation) pressure relative to P_1 after the shock
 - Static (not stagnation) temperature relative to T_1 at the exit
 - Static (not stagnation) pressure relative to P_1 at the exit
 - Dimensionless heat addition $\{q_{in} \text{ divided by } RT_1 = C_p(T_{3t} - T_{2t})/RT_1 = [\gamma/(\gamma-1)](T_{3t} - T_{2t})/T_1\}$
 - Specific thrust = Thrust / $(\dot{m}_a c_1)$ (c_1 = sound speed at ambient conditions = $(\gamma RT)^{1/2}$) (assume FAR $\ll 1$ in the thrust calculation)
 - Overall efficiency
 - Draw this cycle on a T - s diagram. Include appropriate Rayleigh and Fanno curves.
- Repeat (a) if a nozzle is added after station 3 that expands the flow isentropically back to $P = P_1$.
- Repeat (a) if there is no shock and no nozzle (but still constant area heat addition.)
- Repeat (a) if there is a shock followed by **constant temperature (not constant area) heat addition** until the pressure is equal to ambient pressure. (Are we having fun yet?)
- Answer the following questions:
 - Why was no thrust generated in parts (a) and (c)?

- ii. Why did part (b) generate thrust whereas part (a) did not?
- iii. Why did part (d) generate thrust whereas part (c) did not?
- iv. Why was the performance of part (b) so much better than that of part (d)?