AME 101 Fall 2018
Homework Set #1
Assigned: 8/30/2018
Due: 9/7/2018, 4:30 pm, in drop-off box in OHE 430N (back room of the OHE 430 suite of offices, where the Xerox machine is located).

<u>Problem #1 (15 points) (from a previous year's first midterm exam)</u>

The friction factor (f) for flow of a fluid with density ρ (units mass/volume), velocity v, in a pipe of length L and inside diameter d, resulting in a pressure drop ΔP, is defined as

$$f \equiv \frac{\Delta P}{\frac{\rho v^2}{2}\frac{L}{d}}$$

(a) What are the units of the friction factor f in SI units?
(b) For a fluid with density $\rho = 62.4$ lbm/ft^3, velocity v = 1 m/s, flowing in a pipe of length L = 20 ft and diameter d = 1 inch, resulting in a pressure drop $\Delta P = 17.39$ lbf/in^2, what is the friction factor f in SI units?

<u>Problem #2 (15 points) (from a previous midterm)</u>

I calculated the power production from a new type of steam turbine as

$$Power = \left(\frac{v_{out}^2}{2} - \frac{v_{in}^2}{2}\right) + \dot{m}C_P\left(T_{out} + T_{in}\right) + \frac{\dot{m}}{\rho}\left(P_{out} - P_{in}\right) - \frac{\dot{m}}{\mu}\left(Nd\right)^2 + 1$$

where T_{in}, P_{in} and v_{in} are the temperature, pressure and velocity of the steam going into the turbine, T_{out}, P_{out} and v_{out} are the temperature, pressure and velocity of the steam leaving the turbine, C_P is the heat capacity of the steam (units Joules/kg°C), $\dot{m}$ the mass flow rate of steam through the turbine (units kg/s), ρ the steam density (kg/m^3), μ the coefficient of dynamic friction in the rotating shaft, N the rotation rate of the shaft (units 1/s) and d the shaft diameter.

Using "engineering scrutiny," what "obvious" mistakes can you find with this formula? There are at least 5, but list **only** the 4 of which you are most certain.

<u>Problem #3 (20 points)</u>

The power transmitted by a rotating shaft is given by

$P = 2\pi N\tau$

where P is the power, N is the number of revolutions per unit time and **τ** is the torque.

(a) Verify that the units are consistent, *i.e.*, show that the units on the left side of the equation are the same as on the right side of the equation.

(b) If N is in units of revolutions per minute (RPM) and τ in units of ft lbf, what conversion factor is needed to obtain P in units of horsepower? In other words, find ???? in the following relation

$$\text{Power (horsepower)} = \frac{\text{Torque (ft lbf)} \times \text{RPM (rev/min)}}{????}$$

(c) Look up the horsepower and torque of any automobile engine. Is your formula consistent with these specifications? (The answer will most likely be NO).

(d) Can you explain this discrepancy? (You need to think carefully about how to interpret the manufacturer's specifications.)

Problem #4 (10 points)

The solar power transmitted to the ground at high noon at the equator is about 1000 Watts per square meter. How many square feet of solar collector area would be required to power your car, assuming a 100 horsepower motor and a conversion efficiency of solar power to motor shaft power of 15%?

Problem #5 (15 points)

You probably found that the solar collector area was prohibitive (which is why we're not driving around in solar powered cars.) So let's try batteries instead. Look up the specifications (volts, amp-hours and weight or mass) for any type of rechargeable battery.

(a) The energy delivered by the battery is volts x amp-hours. Compute this energy and convert to units of Joules.

(b) Divide by the mass of the battery and convert the result to units of Joules/kg. Compare this to the heating value of gasoline, about 4.3×10^7 J/kg. (This comparison shows you why most of us don't drive around in battery powered cars.)

Problem #6 (25 points)

Hydrogen is considered to be a good choice for fuel cell vehicles. The work (W_{1-2}) per unit mass (m) required to compressed a gas at pressure T_1 and pressure P_1 to a higher pressure P_2 is

$$\frac{W_{1-2}}{m} = \frac{RT_1}{\gamma - 1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}\right]$$

where γ is the *specific heat ratio* of the gas (dimensionless), whose value is about 1.4 for hydrogen, and R is the mass-based ideal gas constant for the gas.

(a) Recalling that $R = \mathfrak{R}/\mathcal{M}$ ($\mathfrak{R}$ = universal gas constant = 8.314 J/moleK, $\mathcal{M}$ = molecular mass = 2 g/mole for hydrogen, compute R for hydrogen.

(b) Compute the work per unit mass (W_{1-2}/m) in units of J/kg required to compress hydrogen from P_1 = 1 atm to P_2 = 10,000 lbf/in^2 assuming T_1 = 70˚F. (Your answer should be negative because work is defined as negative if it's **into the system**, *i.e.*, into the gas in this case). Compare the magnitude of this work to energy content (heating value) of hydrogen, 1.2 x 10^8 J/kg.

(c) The mass of hydrogen stored by the Toyota Mirai hydrogen fuel cell car is 5 kg. Recalling that the ideal gas law can be written in the form $m = PV/RT$, calculate the volume V (in gallons) of hydrogen at P = 10,000 lbf/in^2 and T = 70˚F.

(d) For this 5 kg of hydrogen, compute the energy per gallon and compare to gasoline (1.25 x 10^8 J/gallon).