AME 101 Fall 2017
Problem Set #1
Assigned: 9/1/2017
Due: 9/8/2017, 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)

Problem #1 (10 points) (from a previous year's first midterm exam)

A quantity called BMEP is often used to quantify the performance of internal combustion engines. Its definition is

$$BMEP = \frac{2(Power)}{VN}$$

where "Power" is the engine power, V the displacement volume (units length^3) and N is the rotation rate (units 1/time).

(a) What are the units of BMEP in the SI system?
(b) If P = 200 horsepower, V = 350 in^3 and N = 3600/min, what is BMEP in SI units?

Problem #2 (15 points)

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 (units of force x length).

(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) For a shaft supplying 100 ft lbf of torque at 3000 rev/min, what is the power in units of horsepower?
(c) Based on your answer to part (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

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

Problem #3 (50 points)

(a) The battery in a Chevy Bolt weighs 960 lbf and when fully charged has an energy content of 60 kilowatt hours (notice that kilowatt hours is power x time, i.e. a unit of energy). What is the energy storage density of the battery in units of Joules per kg?
(b) Gasoline has an energy content of 115,000 BTU per gallon and a density of 739 kg/m^3. What is the energy storage density of gasoline in units of Joules per kg?
(c) The energy (E) stored in a compressed gas of volume V_1 and pressure P_1 that can be extracted by expanding the gas to a lower pressure P_2 is

$$E = \frac{P_1 V_1}{\gamma - 1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}\right]$$

where γ is the *specific heat ratio* of the gas (dimensionless), whose value is about 1.4 for air.

(i) What volume (V_1) of air would be required to have the same energy content as one gallon of gasoline if P_1 = 200 atmospheres and P_2 = 1 atmosphere?

(ii) What would the mass of this air be? To determine this, recall that the ideal gas law can be written in the form $m = P_1V_1/RT_1$, where m is the mass of gas and $R = \Re/\mathcal{M}$ is the mass-based ideal gas constant ($\Re$ = universal gas constant, $\mathcal{M}$ = molecular mass = 28.97 g/mole for air) and T_1 = ambient temperature (say 70˚F).

(iii) From the results of (i) and (ii), calculate the energy storage density of compressed air in units of Joules per kg?

(d) A unit of energy called an electron volt (eV) is the energy required to move one electron through an electrical potential (that is, a voltage difference) of 1 Volt, i.e. 1 electron volt = qV, where q = the charge on one electron and V = 1 volt. The energy release of fission of uranium 235 is 202.5 x 10^6 eV **per atom** and the molecular mass of U_{235} is 235 g/mole.

(i) What is the conversion between eV and Joules?

(ii) What is the mass (in kg) of **one** U_{235} atom?

(iii) What is the energy storage density of U_{235} in units of Joules per kg?

From these results, you may gain a better appreciation for why it is so challenging to replace hydrocarbon fuels with any other energy source except than nuclear ones!

Problem #4 (25 points) (from a previous year's first midterm exam)

I calculated the net power output (in Watts) for a new type of automotive engine as follows:

$$Power = \left(P_{ex} - P_{in}\right) - \dot{m}_f Q_R + \dot{m}_f C_P \left(T_{ex} + T_{in}^2\right) + \left[FMEP\right] N^2 V_d + 7 \text{ Watts}$$

where P_{ex} = exhaust pressure (units N/m^2), P_{in} = intake pressure (units N/m^2), $\dot{m}_f$ = mass flow rate of fuel (units kg/sec), Q_R = fuel heating value (units Joules/kg), C_P = heat capacity (units J/kg˚C), T_{ex} = exhaust temperature (units K), T_{in} = intake temperature (units K), FMEP = Friction Mean Effective Pressure (units of pressure, e.g. N/m^2, a measure of friction losses), N = engine rotation rate (units 1/s), and V_d = engine displacement (units of volume, e.g. m^3).

Using "engineering scrutiny," what "obvious" mistakes can you find with this formula? There are at least 7, but list **only the 5** of which you are most certain.