1. (10 points) The overall reaction order n for a global one-step hydrocarbon-air mechanism is given to be $n = 1.75$, where the global reaction rate is expressed in standard Arrhenius form: $k(T) = A\exp\{\frac{-E_A}{R_U T}\}$. What are the units (SI units, as we have been using in lecture) for the pre-exponential factor A in this case?

2. (10 points) Consider a steady one-dimensional laminar premixed flame with hydrocarbon-air reactants (a non-methane paraffin fuel). For a reference condition of ambient pressure and temperature reactants (p = 1 atm, T_u = 298 K) and no dilution (Y_{dil} = 0), the laminar flame speed is approximately $s_{l,ref}$ = 0.5 m/s at an equivalence ratio of Φ = 1.1. Use the Metghalchi & Keck laminar flame speed correlation (with B_M = 0.5 m/s, B_2 = -3 B_M , Φ_M = 1.1) to estimate the laminar flame speed s_l for each of the following sets of conditions:
   a. p = 1 atm, T_u = 600 K, Φ = 1.1, Y_{dil} = 0
   b. p = 10 atm, T_u = 298 K, Φ = 1.1, Y_{dil} = 0
   c. p = 1 atm, T_u = 298 K, Φ = 0.7, Y_{dil} = 0
   d. p = 1 atm, T_u = 298 K, Φ = 1.1, Y_{dil} = 0.10

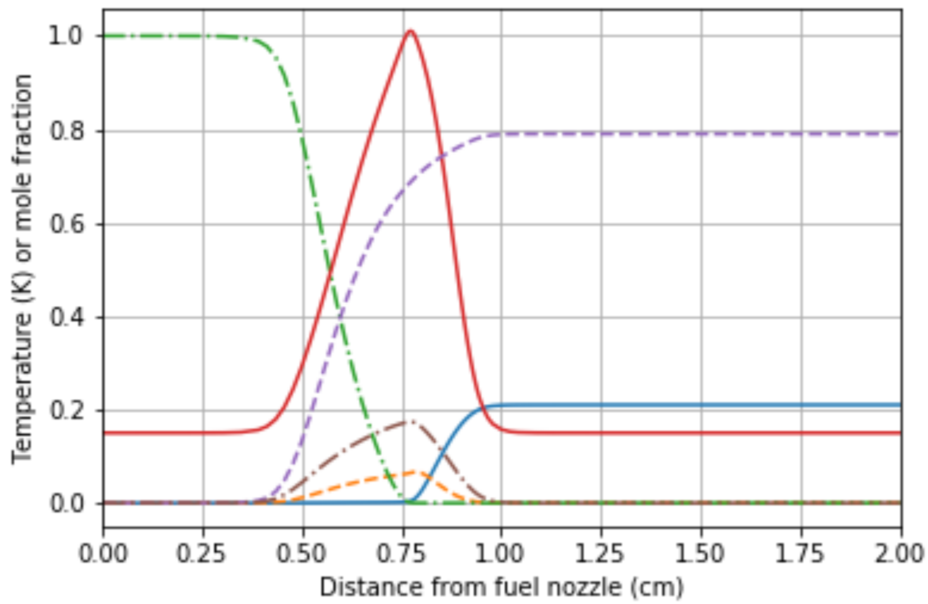
3. (10 points) Consider a *fully turbulent* momentum-dominated axisymmetric hydrocarbon-air jet flame. By approximately what factor does the mean flame length change with:
   a. A factor of two increase in fuel nozzle diameter (fixed flowrate and fuel type)?
   b. A factor of two increase in fuel flow rate (fixed nozzle diameter and fuel type)?
   c. A switch in fuel from propane to hydrogen (fixed nozzle diameter and flowrate)?
   d. A switch in fuel from propane to methanol (fixed nozzle diameter and flowrate)?

Note: For the remaining questions, please provide your answers directly on these pages. You can then either scan or photograph the pages, and include them with the solution that you submit.

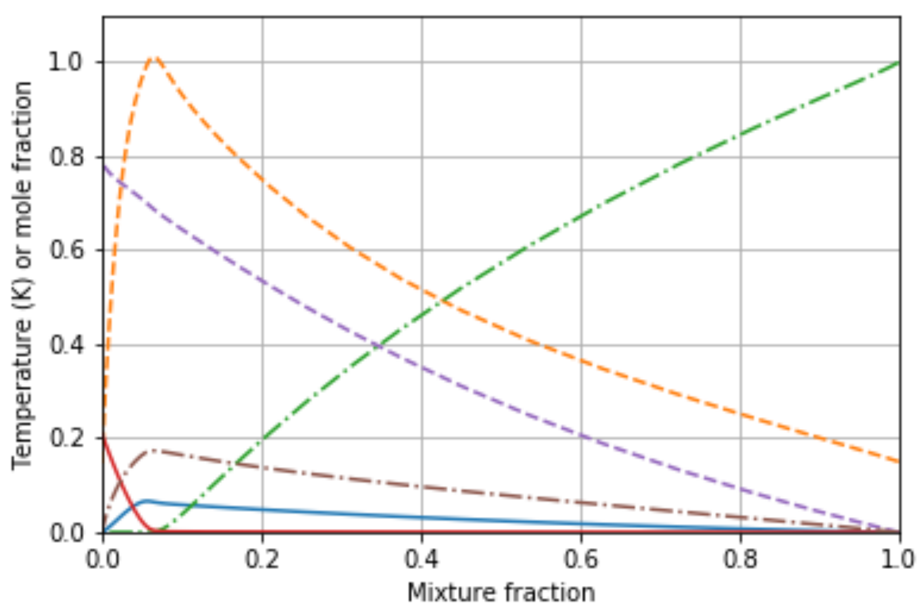
4. (15 points) Multiple-choice questions. Circle the best answer from the list of possible answers provided for each question.
   a. Which of the following quantities is most relevant in characterizing the behavior of a counterflow laminar diffusion flame?
      strain rate; laminar flame thickness; Reynolds number
   b. Which of the following assumptions in our development of the governing equations for laminar flames allowed the enthalpy equation to be written in a manner such that only gradients in enthalpy (and not gradients in species or temperature) appear in the enthalpy equation?
      constant specific heats; unity Lewis numbers for all species; equivalence ratio less than or equal to one
   c. Which of the following quantities is most relevant in characterizing the behavior of a well-stirred reactor?
      turbulence integral time scale; laminar flame speed; residence time
   d. In turbulent premixed flames, which dimensionless ratio is most closely related to the degree to which the flame surface area is increased by turbulence?
      turbulence time scale/chemical time scale; rms turbulence velocity/laminar flame speed; laminar flame thickness/turbulence integral scale
   e. The notion of flame propagation is relevant for which class of flames?
      premixed flames; nonpremixed flames

5. (15 points) Fill-in-the-blank questions. It is not necessary to show any work.
   a. The maximum temperature in a methanol-air laminar nonpremixed (or diffusion) flame occurs at approximately what numerical value of the mixture fraction? _____________
   b. In a particular turbulent premixed flame, the ratio of rms turbulence velocity to the laminar flame speed is approximately 10, and the ratio of the laminar flame thickness to the turbulence integral scale is approximately 0.1. Compared to a laminar flame at the same thermochemical conditions, by approximately what numerical factor is the mass rate of fuel consumption increased in the turbulent flame? _____________
   c. If the unburned-gas temperature is doubled, with all other quantities remaining the same, the value of the flame speed for a laminar premixed flame increases by a factor of approximately _________.
   d. In our discussion of laminar nonpremixed (or diffusion) flames, two different conserved scalars arose in the course of the problem development: a mixture fraction and ____________________.
   e. For an automotive spark-ignition engine, the combustion duration (from time of ignition through completion) is approximately one-sixth of a crankshaft revolution. This corresponds to a time of approximately 17 ms at an engine speed of 600 rev/min. To maintain the same combustion duration of one-sixth of a crankshaft revolution at 6,000 rev/min, turbulence must increase the mass rate of conversion of reactants to products by a factor of _________ compared the rate of conversion at 600 rev/min.

6. (10 points) The figure at the top of the following page shows computed temperature and species profiles along the stagnation streamline for an axisymmetric counterflow laminar diffusion flame. The fuel is methane, the oxidizer is air, and both fuel and oxidizer are at 300 K and 1 atm. There are six curves: T/2,000 K, CH_4, O_2, N_2, H_2O, and CO_2.The temperature is in units of Kelvin, and the species are in units of mole fractions. Clearly label each of the six curves on the figures. You do not need to explain your reasoning in the solution that you submit.



7. (10 points) The figure below is for the same axisymmetric counterflow laminar diffusion flame as in problem 6. There are again six curves (T/2,000 K, CH_4, O_2, N_2, H_2O, and CO_2), but here the temperature (K) and species (mole fractions) are plotted as functions of mixture fraction, instead of distance from the fuel nozzle. Clearly label each of the six curves on the figures. You do not need to explain your reasoning in the solution that you submit. The colors and dash patterns for each quantity are not necessarily the same as in problem 6.



8. (20 points) The two figures below show computed temperature and species profiles for a laminar premixed flame, where the unburned gas (reactants) is on the left and the burned gas (products) is on the right. Here the reactants are a fuel-rich (equivalence ratio $\Phi = 1.3$) mixture of propane and air at 1 atm and 300 K. There are 11 curves: $T/10{,}000$ K, C_3H_8, O_2, $N_2/4$, H_2O, CO_2, $2*CO$, $2*H_2$, $2000*NO$, $4000*H_2O_2$, and $20*OH$. The temperature is in units of Kelvin, and the species are in units of mole fractions. Clearly label each of the 11 curves on the figures. You do not need to explain your reasoning in the solution that you submit.