ME3239 Project, Spring 2010
Simulating the Auto-ignition in HCCI Engines

No group work is allowed for this project. You may discuss with others the course materials and ideas on solving the problem, but must write your own code and analysis. It is your responsibility to keep your codes and analysis private. Identical or nearly-identical submissions will result in a failing course grade.

Submission

Part I: April 13, Tuesday. We will have the second midterm exam. All the background knowledge required by this project will be covered in the exam. The specifics of problem described in the project description and the preliminary approach to solve the problem will also be included in the exam.

Part II (50%): due before class on April 20, Tuesday.
A working matlab code to simulate the 0-D reactor should be submitted through **huskyct mail**. Make sure you receive a confirmation from the TA within 24 hours of the code submission.

Part III (50%): due in class on April 27, Tuesday.
The hard copy of the project report with the problem analysis, results, and discussions should be submitted in class and the final version of the matlab code should be submitted through **huskyct mail** before the class.

Do not send the files through UConn email.

Project description

Homogeneous charge compression ignition (HCCI) engine is a new type of engine that can reduce pollutant emission while achieving high fuel efficiency. HCCI engines can operate with various types of fuels such as gasoline, diesel, alcohols, natural gas and most alternative fuels.

HCCI engines typically operate with premixed fuel-air mixtures in fuel-lean condition. Ignition is caused by compression, and typically the high compression ratio is high, say larger than 15. The efficiency of HCCI engines is therefore quite good.

In the present project, we will write a matlab program to simulate a simplified model of HCCI engine that operates with methane-air mixture with equivalence ratio $\phi = 0.3$, based on the following specification and assumptions:

1) The engine cylinder is adiabatic, i.e. there is no heat transfer through the wall.

2) The volume of the cylinder varies with time and is described by:

$$V = V_0\left[1 + \alpha\cos(\omega t)\right] \tag{1}$$

where V_0 is a constant, $\omega = 2\pi f$ is the angular velocity and f is the rotation frequency. $0<\alpha<1$ is determined by the engine design, and the compression ratio R is defined as:

$$R = \frac{V_{\max}}{V_{\min}} = \frac{1+\alpha}{1-\alpha} \tag{2}$$

For each case of the simulation, the engine operates on fixed ω and R, while different simulations will be simulated to study the effect of using different ω and R on the auto-ignition of the mixture.

3) At time $t = 0$, the cylinder is filled with fresh methane-air mixture described above ($\phi = 0.3$) under p_0=1atm and T_0 = 300K. As the piston approaches the top dead center (TDC), where the volume reaches the minimum, pressure and temperature is high such that fast chemical reaction can occur, leading to auto-ignition of the mixture.

4) The mixture is ideal gas.

Follow the instructions below to analyze the problem and implement the matlab program:

Step 1. Write down the ODEs of the governing equations. The dependent variables include pressure, temperature, and species mass fractions. Write down the initial conditions for all the variables. The ODEs and the initial conditions should be in the following general form:

$$\frac{d\mathbf{y}}{dt} = \mathbf{f}(\mathbf{y}), \quad \mathbf{y} = \left(p, T, Y_1, Y_2, ..., Y_K\right)^T, \tag{3a}$$

$$\mathbf{y} = \mathbf{y}_0, \text{ at } t = 0, \tag{3b}$$

where **f** is a group of functions, ad K is the number of species. Since there are K+2 variables to solve, there should be K+2 equations.

Step 2. Study the template file ign.m to learn how to integrate ODEs with matlab. Change the function in ign.m to use equation (3). Try the program first with a high compression ratio, say R = 50, and a low rotation frequency, say f = 100RPM (be careful with the unit). Integrate the equations for one cycle. You should be able to see auto-ignition on the temperature plot.

Step 3: Estimate the temperature at TDC using isentropic compression by ignoring the heat release from chemical reactions. Use the ignition delays for methane-air in the lecture notes to estimate a compression ratio that will have an ignition delay in the order of about 1ms. Using the estimated compression ratio and a reasonable rotation frequency, e.g. f = 250RPM, run the simulation to see if the mixture can ignite within half a cycle. Adjust the estimated values until you are satisfied with the results.

Step 4: Based on the results in step 3. Try different values of f to find what roughly the upper limit is for f that allows the ignition to occur within the first half cycle, and what the lower limit is for f that prevents the ignition from occurring before the piston reaches TDC. Discuss the results and comment on how to optimize the engine operating conditions to achieve roughly complete combustion and good fuel efficiency based on the simulation results.

Use the matlab toolbox to compute chemical reaction rates and species properties whenever needed in the program.