GE 308 Thermodynamics Term Project

Due Date: 30 April 1998

Background Information

The idealized Diesel, Otto and Wankel (rotary) engines can be used to describe most automobile engines, even though an automobile engine is an irreversible engine. These idealized engines assume that the working substances are ideal gases, all processes are reversible, and there is no friction.

The Diesel engine has six processes:

- Process 1: The *intake stroke* in which air is drawn into the combustion chamber by the motion of the piston. The process is isobaric and isothermal.
- Process 2: The *compression stroke* in which the air in the combustion chamber is compressed by the motion of the piston. The compression continues until the temperature of the air is high enough to ignite the oil that will be sprayed into the chamber in the next process. This process is adiabatic.
- Process 3: The *explosion* in which the oil that is sprayed into the combustion chamber is ignited. The volume of the combustion chamber changes so that the pressure remains constant, and hence the process is isobaric.
- Process 4: The *power stroke* in which the hot gases cause the piston to move. This process is adiabatic.
- Process 5: The *valve exhaust* in which there is a drop in pressure and temperature caused by the quasistatic (reversible) ejection of heat due to the opening of the exhaust valve. This process is isochoric.
- Process 6: The *exhaust stroke* in which the piston moves, pushing out the combustion gases. This process is isobaric and isothermal and cancels Process 1.

The Otto engine represents an idealized gasoline engine and consists of six processes:

- Process 1: The *intake stroke* in which a mixture of gasoline vapor and air is drawn into the combustion chamber by the movement of the piston. The process is isobaric and isothermal.
- Process 2: The *compression stroke* in which the piston moves, compressing the gas mixture. This process is adiabatic.
- Process 3: The *explosion* in which an electric spark ignites the mixture. The piston does not move. This process is isochoric.
- Process 4: The *power stroke* in which the hot gases cause the piston to move. This process is adiabatic.
- Process 5: The *valve exhaust* in which there is a drop in pressure and temperature caused by the quasistatic ejection of heat due to the opening of the exhaust valve. This process is isochoric.

- Process 6: The *exhaust stroke* in which the piston moves, pushing out the combustion gases. This process is isobaric and isothermal and cancels Process 1.

The Wankel engine represents an idealized rotary gasoline engine and also has six processes:

- Process 1: The *intake stroke* in which a mixture of gasoline vapor and air is drawn into the combustion chamber by the movement of the rotor. The process is isobaric and isothermal.
- Process 2: The *compression stroke* in which the rotor moves, compressing the gas mixture. This process is adiabatic.
- Process 3: The *explosion* in which an electric spark ignites the mixture. The rotor does not move. This process is isochoric.
- Process 4: The *power stroke* in which the hot gases cause the rotor to move. This process is adiabatic.
- Process 5: The *vent exhaust* in which a drop in pressure and temperature is caused by the quasistatic ejection of heat due to the contact of the combustion gases with the surroundings. This process is isochoric.
- Process 6: The *exhaust stroke* in which the rotor moves, pushing the combustion gases out of the chamber. This process is isobaric and isothermal and cancels Process 1.

Although the Otto engine and the Wankel engine physically differ, the thermodynamic processes are identical.

In the CUPS software package which you will use, there are four programs: DIESEL, OTTO, WANKEL and ENGINE. These programs have been written in the Pascal language for MS-DOS platforms. The language is Borland/Turbo Pascal, and the minimum hardware configuration is an IBM-compatible 386-level machine preferably with math coprocessor, mouse, and VGA color monitor. Before you start, make sure your PC sees its mouse. If it does not, you must check to see if your CONFIG.SYS file includes a command for the mouse file, and if the mouse file actually exists in the specified path.

The software is installed on the 4th floor Computer Lab on the E: drive under directory CUPS. (If you prefer to work at your own PC at home or elsewhere, please contact the teaching assistant Tolga Ekmekçi to get a copy of the software.)
The driver program (cupstp.exe) for running all programs can be found in the CUPSTP subdirectory under CUPS. You may run any of the programs using this driver program. There will be several subdirectories under \CUPS\CUPSTP. For this project, you will only be using the programs under the ENGINES subdirectory (but you may of course play with the other programs if you so choose). Instead of running the driver program, alternatively you may go to the ENGINES subdirectory and type in the file name (such as OTTO, WANKEL, DIESEL, ENGINE) to execute the program you wish to run.

The programs DIESEL, OTTO and WANKEL model idealized versions of common automobile engines. They demonstrate the relations between the movements of idealized physical engines and their thermodynamic properties. These programs provide animations of each of these types of engine. DIESEL illustrates an idealized DIESEL engine, OTTO illustrates an idealized gasoline engine, and WANKEL illustrates an idealized Wankel or rotary gasoline engine. The default initial conditions are T = 300K and $P = 1$ atm for the programs but these can be changed easily.

The program ENGINE allows the user to define an ideal gas engine cycle and study its thermodynamic properties. Use ENGINE to design an engine cycle for an ideal gas. The gases allowed are helium, argon, nitrogen, and steam. The processes allowed are adiabatic, isobaric, isochoric, and isothermal. The engine can be either reversible or irreversible. Irreversibility is simulated by a heat loss during the isobaric, isochoric, and isothermal processes. The user controls the percentage of heat loss.

The program ENGINE provides a graph of T versus S and P versus V during the cycle, and a list of the step number, process type, the final pressure, the final volume, the final temperature, the final entropy, the work done by the gas during the process, the heat absorbed by the gas during the process, and the change in internal energy of the gas. When the cycle is complete, i.e. the gas returns to its initial condition, the program determines if the cycle is an engine (the gas does work on its surroundings) or a refrigerator (the surroundings do work on the gas) and computes either efficiency of the engine or the coefficient of performance of the refrigerator.

The user defines the gas's initial temperature and volume, then builds the engine by specifying a series of processes and their durations. To select a process, the user needs to click the mouse when the cursor is on the appropriate radio button. Once a process is selected, sliders for the temperature, volume, and/or pressure appear. They are used to determine that process's final temperature, volume, pressure, and entropy. The program checks that the values for the temperature, etc., are within the limits specified by the plots. If they are not within these limits, an error message appears on the screen.

ENGINE creates a disk file that contains data that may be helpful in the analysis of the results.

What to Do

1) **DIESEL Engine, OTTO Engine and the WANKEL Engine**
Run each of the programs DIESEL, OTTO and WANKEL to examine the relationship between the engine's physical processes and the corresponding changes in the thermodynamic properties. Briefly describe what you observe.

2) **Design Your Own Engine**
a) For the Otto engine, let T_2 be the temperature of the gas at the end of the adiabatic compression and let T_3 be the temperature of the gas at the end of the first isochoric process. Using nitrogen and reversible Otto engine, for constant T_3 and varying T_2 from 650 K to 850 K, plot the total work produced versus the efficiency, and the work produced versus the total heat absorbed. While varying the temperature, take 50 K increments. Let T_3=15XX K, 16YY K, 17XX K, 18YY K, 19XX K, and 2000 K. (XX and YY are the last two digits of your and your project partner's ID numbers). Include all plots in your report but do not include all the output files. Instead, extract the total work, total heat and efficiency values from the output files and tabulate these.

b) Repeat using a reversible Diesel engine. For the Diesel engine, T_2 is again the temperature of the gas at the end of the adiabatic compression. T_3 is the temperature of the gas at the end of the isobaric process. There may not be a solution for some pairs (T_2, T_3). That is, during some part of the cycle, the temperature, volume, pressure, or entropy may go out of the graph's limits. In this case, take the largest value possible that remains within the limits.

c) Analyze the results. If they are unusual, try deriving the expression(s) to explain the results.

3) **Efficiencies of Different Cycles**
Rate the efficiencies of the different engine cycles. Design your own reversible engine cycles which are different than those in part 2. Make sure their thermodynamic parameters stay within the limits of the plots. Whenever possible, use the same upper and lower temperatures for each engine.
Try to achieve an efficiency that is as close to the equivalent Carnot cycle efficiency as possible. (i.e. a Carnot cycle operating between the same upper and lower temperatures.) Try to exceed the Carnot efficiency and see that this is not feasible.

4) **Irreversible Engines**
Select an irreversible engine and study the effects of heat loss on the engine's efficiency by varying the percentage of heat loss. Plot the efficiencies versus heat loss percentages for identical cycles. Vary heat loss percentage from 0 to 99 with 5 % increments.

5) **Effects of Different Gases**
Choose an engine cycle and study the effects of changing the gas on the engine's efficiency. What accounts for the differences?

6) **Refrigerators**
Reverse the cycles in step 3) and study the coefficient of performance of each cycle.

For each step of the project, write what you have done and what you have observed clearly and briefly. Interpret your results in detail. Use any wordprocessor for writing your report. For the plots, use one of MATLAB, EXCEL or XVGR. For each part of the project, include all plots, tabulated results and a representative output file. Keep all your other output files until your project is graded. All plots should be labeled and scaled properly.

Details of the Programs:
ENGDRV is the driver program that can be used to call the programs: DIESEL, OTTO, WANKEL, and ENGINE (Design Your Own Engine). These programs also can be called directly by typing their names.

Maximum operating temperature of the engine: Integer between 1000 and 2000

Compression ratio: Number between 15 and 25 for Diesel engine
Number between 5 and 12 for the Otto or Wankel engines.

The compression ratio equals V_1/V_2, where V_1 is the initial volume and V_2 is the final volume after adiabatic expansion. This data combined with the initial conditions (T=300 K and P=1 atm) is sufficient to define the engine's cycle.

Input Screen Options for ENGINE

Select engine type	Reversible engine
	Irreversible engine
Select Gas	Helium (He)
	Argon (Ar)
	Nitrogen (N)
	Steam
Initial Conditions:	
Temperature (K)	A number between 300 and 2000 for He, Ar, or N
	A number between 500 and 2000 for steam
Pressure (atm)	A number between 1 and 75
% of heat loss	A number between 0 and 99
	(for irreversible engines only)
Output file name	The output disk file name
	The output file name only appears at the
	beginning of the program. Its default is ENGINE.DAT

The following information maybe helpful in selecting variables. Helium and Argon are monatomic molecules, nitrogen is diatomic molecule, and steam is a triatomic molecule. Nitrogen's characteristics (specific heats, atomic mass) closely resemble those of air. The lower limit of the temperature is 300 K for helium, argon, and nitrogen, and 500 K for steam. The percentage of heat loss (irreversible engine only) is a number between 0 and 99 and is the percentage of heat lost during an isobaric, isochoric, or isothermal process.

During the operation of the program, there are radio buttons to select the process type (adiabatic, isobaric, isochoric, and isothermal) and sliders to change a thermodynamic variable (temperature, pressure or volume). To the right of each slider, there is a box containing the current value of the variable. By clicking the mouse in the box, the user can type in a value for that variable. The user must press the **Enter** key to continue. The program checks that the inputted value of the thermodynamic variable does not cause any of the other thermodynamic variables to exceed their graphical limits.

The volume's upper limit is determined by the initial temperature.

Output Data File

The output data file includes the following:

- the engine type (reversible or irreversible)
- the gas (helium, argon, nitrogen or steam)
- the specific heat of the gas (J/K)

- the value of $\gamma = c_p/c_V$.
- the mass of a molecule of the gas
- a table listing the processes in the cycle, the gas's volume, pressure, temperature, entropy (J/K), the work done (J), the heat, and the change in the gas's internal energy going from the gas's previous state to its current state.
- whether the cycle is an engine or a refrigerator
- if the cycle is an engine, the total work done to the surroundings, the total heat absorbed by the gas, the heat absorbed by the gas, and the engine's efficiency.
- if the cycle is a refrigerator, the work done to the gas, the heat extracted from the colder heat source, and the coefficient of performance.

Walk-Through for DIESEL, OTTO, and WANKEL Programs
Programs DIESEL, OTTO and WANKEL demonstrate the relationships between the movements of idealized physical engines and their thermodynamic properties. The engine's initial conditions are $T = 300$ K and $P = 1$ atm.

- The first screen initializes the inputs which are the maximum operating temperature of the engine and the compression ratio.
- Select the default values: A maximum operating temperature of 1280.0 and a compression ratio of 15.5 for DIESEL and 9.5 for OTTO and WANKEL.
- Press **Enter** or click on OK to run the program.
- The next screen is divided into three sections. The temperature versus entropy is plotted in the upper left section. The pressure versus volume is plotted in the upper right section. An animation of an engine cylinder's cycle and a description of a cycle are drawn in the lower section.
- Select **F1-Help** hot key; a help screen about the engine's cycle appears.
- Select the **F3-Step** hot key (by mouse or keyboard) to step through the engine's cycle.
- Select the **F5-Slower** hot key (by mouse or keyboard) to slow the engine.
- Select the **F6-Faster** hot key to speed the engine.
- Select **F10-Menu** hot key to access the commands in the menu or move the mouse cursor to the appropriate menu item.
- Select **Restart Program** in the **File** drop down menu, to return to the input screen or Select **Exit Program** in the **File** drop-down menu to exit program.

Walk-Through for ENGINE Program
ENGINE lets the user design an engine cycle by specifying the processes in the cycle, the engine type, and the gas type. The first screen initializes the inputs:
1) the type of engine (reversible or irreversible)
2) the type of ideal gas used in the engine (helium, argon, nitrogen, or steam)
3) the initial temperature

4) the initial pressure
5) the percentage of heat loss (for an irreversible engine)
6) the output file name
Nitrogen's properties are most like those of air. Room temperature is approximately 300 K.

- Use the default values and press **Enter** or click on OK.
- A new screen appears which is divided into four parts. In the upper left is the temperature (T) versus entropy (S) plot. In the upper right is the pressure (P) versus volume (V) plot. In the lower left is a summary table and in the lower right are four radio buttons labeled adiabatic, isobaric, isochoric, and isothermal.

  The Summary table lists the process (i.e. adiabatic, isobaric, isochoric, or isothermal), the final pressure (P_f), the final volume (V_f), the final temperature (T_f), the final entropy (S_f), the work done by the engine, and the change in internal energy ΔU for each step in the cycle.

  Let's create an engine using the Diesel cycle:

  1. Select adiabatic by clicking on this button with the mouse. The temperature, volume, and pressure sliders appear under the radio buttons. Use the temperature slider (or input the final value in the box to the right of the slider) to raise the temperature to around 800 K. Watch the T versus S and P versus V curves move as the slider is changed.
  2. Then select isobaric and continue to raise the temperature to around 1200 K. Notice that the pressure slider disappears.
  3. Select the adiabatic again and return the volume back to its initial condition by moving the volume slider to its upper limit. Notice the pressure slider appears again.
  4. Finally, select isochoric and return either the pressure or the temperature to its initial conditions. This closes the cycle. The radio buttons and sliders disappear and the Engine Performance Summary appears in its place.
- Select **F1-Help** hot key; a help screen about the engine's cycle appears.
- Select **F10-Menu** hot key to access the commands in the menu or move the mouse cursor to the appropriate menu item.
- Select **Tutorial** in the menu; a drop-down menu appears. Click on the appropriate process for a description of that process. For example, click on **Adiabatic Process**.
- Select **Restart Program** in the **File** drop down menu, to return to the input screen or Select **Exit Program** in the **File** drop-down menu to exit program.
- After exiting program, open file ENGINE.DAT, and review the output.

Teaching Assistant for the Project

- **B. Tolga Ekmekçi**, Office: 226, Tel: 1613, e-mail: ekmekci@ee.bilkent.edu.tr