Pressure and Volume are recorded to plot a PV diagram.

Power output and torque as function of temperature.

Stirling cycle:

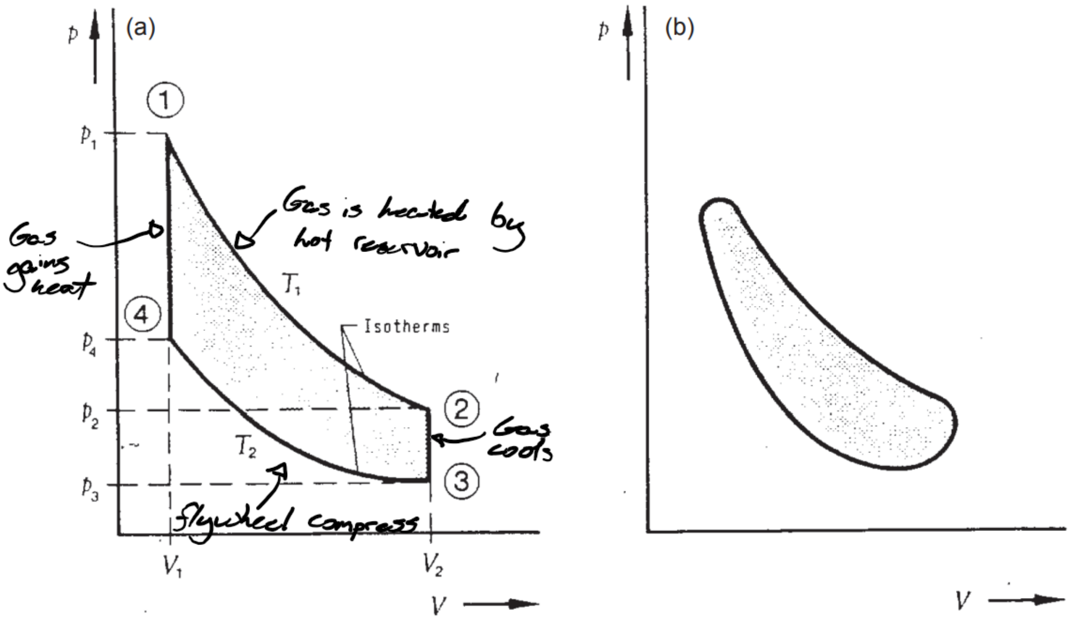

Figure 1: pV diagram of the Stirling cycle. (a) Ideal cycle; (b) A representation of the actual cycle. All images taken from [3].

There are a number of reasons why the Stirling engine in this experiment falls short of the Carnot efficiency. In your report, you should discuss the main mechanisms that lead to inefficiencies, and use your experimental data to characterise them. One can define three other values of efficiency

Task 1. **Discuss within your group and answer the following question, note down answers and queries in your logbook**

1. Suppose that the air in the Stirling engine can be treated as an ideal gas and that the pressure and volume for each point of the cycle are known. Write down an expression that lets you evaluate the heat absorbed or released between any two points on the PV diagram of the cycle.
2. What do you think the main causes of inefficiency will be in the engine?
3. Describe how the different efficiencies defined above could be used to quantify their contributions to a less-than-perfect efficiency.

1) Given P and V is known, points a to b

$PV = nRT$ $\quad$ $Q = mc\Delta T$

$\Delta Q = \frac{mc}{nR} \Delta(PV)$ $\quad$ (a to b)

$$Q = \frac{mc}{nR} \int_a^b P\, dV$$

2) Waste heat
Friction /

Task 2. **Getting started**

1. Turn on the CASSY board, and open up the CASSY software on the desktop. The software should recognise the board and bring up a dialogue box, on which you can click the A and B inputs in order to activate them (in the upper and middle boxes on the right-hand side of the schematic). Before you close the dialogue box, click also on 'Show Measuring Parameters' to open up the settings panel on the right. In the settings panel, you will see a number of options for the output of the rotary motion sensor. Probably the most useful will be the *path* (in cm). By manually rotating the flywheel, check that the measured path values lie within the specified range, and adjust the range if it does not. For later reference, you may want to note the path readings when the working piston is fully up and fully down.
2. Use the settings panel to set the measurement interval (i.e. sampling rate) for each sensor, and choose whether the measurement runs are to be terminated manually or automatically (by specifying the measurement time or the number of measurements). Once you see the engine in operation, you will need to decide what an appropriate sampling rate would be and what length of data is useful.
3. The CASSY software can be used to plot pV diagrams and to calculate the enclosed area. Alternatively, you can use your own script to do the plots after you export the data, but you will then need to develop your own technique for determining the enclosed area. To do volume plots in CASSY, you will first need to define the volume as a 'New Formula' (Settings → Calculator → Formula). The generate the pV plot, you will need to 'Add new Curve' after choosing 'New' display (Settings → Display) and set the axes appropriately.
4. Turn on the pump and ensure there is a flow of water from the output pipe.
5. Measure the temperature of the water in the tank (you may like to check this again later to see if it has changed).

1) Recommended setup was complete
↳ Range of 10cm path, 2000hPa pressure

2) Sample rate set to 50ms to start
Time of 20seconds

3) V was calculated converting path to m^3 Volume.

4) Done

5) $(25 \pm 1)^\circ C$ RSPRO

Task 3. **Record data.**

1. For an initial run, hook up the heater to 12 volts and switch on the transformer. Once the element is glowing (no more than 30 s), turn the flywheel by hand to start the motor. If it does not start after 2-3 attempts, switch off the heater immediately and seek assistance.
2. Note what happens to the colour of the element after you set the engine in motion. Can you explain this behaviour?
3. After you have set the flywheel in motion, allow the engine to reach a steady state and record a few seconds of data by clicking on the button with the stopwatch icon.
4. You will need to save/export your data between each run. The simplest way to export the data may be to paste the tabulated data into notepad.
5. To determined the enclosed area on the PV curve, choose 'Calculate Integral' → 'Peak Area' on the 'Diagram' menu. Select enough points such that the area you want to calculate is highlighted. You can also calculate the area down to the x-axis if needed.
6. Try running the engine with the heater at a few different voltages in the range 4V to 16 V. Make sure that you turn the transformer off before unplugging the leads.
7. **When you stop your measurements for a considerable time, you can turn off the power supply but you must continue the flow of cooling water for at least a further half hour.**
8. Import your data into your favorite software (eg Matlab) and generate a PV-diagram.

Day 2 method: Let it reach steady state

- Let it record for 1s
- Record area
- Repeat

(HPa cm^3)

V	1	2	3	4
10	20590	19490	22060	23260
12	35700	37020	36790	37940
14	37540	42330	42390	41080
16	45540	43300	47550	44250

(Note CASSY software gave extremely bad values, so we decided I would make a Matlab script)

Efficiencies:

$$\text{Practical} = \frac{W_{PV}}{Q} \quad Q \longrightarrow P_R \times t$$

$$\text{Carnot} = 1 - \frac{T_C}{T_H}$$

$$\text{Actual eff} = \frac{W_{PV}}{Q_{PV}}$$

2.2.2 The practical efficiency

The practical efficiency of a heat engine is the ratio of the useful work produced by a real machine (benefit) to the total heat supplied by the fuel (which is the heating element as in this case) to the hot reservoir in order to achieve this work (cost) [1]:

$$\eta_{\mathrm{pr}} \equiv \frac{W_{\mathrm{pr}}}{Q_{\mathrm{H,sup}}} \tag{2}$$

2.3 Internal efficiency

It can be helpful to define an internal efficiency η_{i} based on the actual amount of heat that the gas receives from the hot reservoir during a cycle. This heat will differ form the heat supplied to the hot reservoir because some heat will be lost to the environment.

$$\eta_{\mathrm{i}} \equiv \frac{W_{\mathrm{pr}}}{Q_{\mathrm{H,g}}}, \tag{3}$$

2.4 Internal Carnot efficiency

An internal Carnot efficiency

$$\eta_{iC} \equiv 1 - \frac{T_{\mathrm{C,g}}}{T_{\mathrm{H,g}}}, \tag{4}$$

based on the highest and lowest temperatures the gas actually reaches during a cycle.

In practical applications, it is often not efficiency that we are most concerned about, but the **output power**, which is the rate at which the engine does work $P_w = W/\Delta t$, where Δt is the duration of one cycle.

Task 4. **Analyse the data set.**

1. The work done per cycle corresponds to the area enclosed by the PV curve. You will need to devise a method of obtaining this from your plots, if you didn't do this already using the CASSY software, and to estimate the uncertainty.
2. Is the work done sensitive to any systematic error in the total volume? Explain.
3. Calculate the work power and the input power to the heater, and from these find the practical efficiency η_{pr}. Suppose the hot reservoir was at a temperature of 200 °C: estimate the Carnot efficiency η_{C}, and compare to the practical efficiency.
4. Using your PV diagram, determine the actual heat absorbed by the air during one cycle, and from this work out the internal efficiency η_{i}. What does this tell you about where most of the energy is wasted?

$\frac{W_{pr}}{Q_{H,sup}} = \frac{W}{Q_{in}} = \_\_\_\_$

$Q = \frac{mc}{nR}\int_a^b P\,dV$

Input Power:

$Q = mc\Delta T$ $\quad P = VI = \frac{V^2}{R}$

$PV = nRT$ constant $\quad P_I V_I = nRT = P_f V_f$

$0.65 \pm 0.01\ \Omega$

55°C at 10V
63°C at 12V
70°C at 14V
78°C at 16V