ASEN 3113: Pre Lab 1 - Stirling Lab

ASEN 3113: Thermodynamics and Heat Transfer
University of Colorado at Boulder

Please refer to the class schedule for lab dates and times.

IMPORTANT:
Unless otherwise stated, please turn in any pre-lab or group reports at **the beginning** of each lab session. There will be **one lab report per group**, where each group member will include a conclusion section of their own that will be submitted individually.

Objectives

- Understand the thermodynamics of the Stirling cycle.
- Describe the thermodynamics of a displacer-type Stirling engine.
- Use thermodynamics to quantitatively analyze power cycles.
- Write a technical report.

Experimental Background and Description

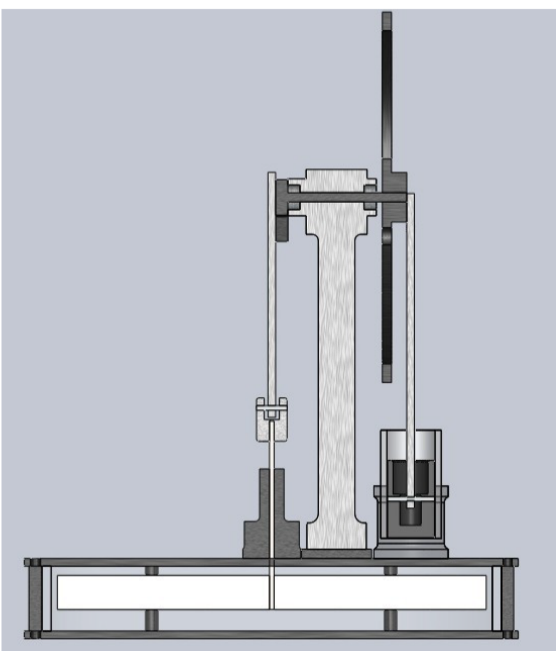


Figure 1: Gamma-type Stirling Engine

Out of the various sub-categories of Stirling engines, the one chosen for this lab is a gamma-type engine (Figure 1). This implies that the power piston is housed in its own cylinder, but both the power and displacer pistons are connected to the same flywheel. The power piston is connected to the displacer piston by the same crankshaft, but their phases are offset. In the engine used for this lab, the displacer piston is made out of an insulating material (Styrofoam) and it does not seal the inside of the large cylinder. The purpose of the displacer piston is to push the working fluid (air) from one thermal reservoir to the other. The air freely flows around the foam displacer to travel from the hot to cold side and vice versa. This displacement of the working fluid creates a forced convective heat transfer and thus creates pressure gradients across the main displacement piston housing which are used to drive the power piston. As Stirling engines are classified as an external combustion engine these engines are ideal for situations that require a very efficient non-internal combustion engine. The ideal example of this situation is providing power to spacecraft sent into deep space where solar cells become impractical.

Stirling engines have been used in many aerospace applications including providing electric power to spacecraft where solar power is not practical, and acting as a cooling system to prevent electric parts from overt-heating. A Stirling engine has the potential to produce the same amount of power as a traditional RTG, while using only one fourth the amount of plutonium (Pu-238). Though Stirling engines are extremely efficient and convenient, they are prohibitively expensive to research and produce. Due to this cost, most Aerospace companies choose to use more conventional means to power their spacecraft.

Part of this lab is based on a CAD model of the gamma-type engine that you will be testing. Included in the pre-lab is a short exercise to confirm your ability to extract the necessary measurements and data from this CAD model. If you have not used SolidWorks much before, the introductory online tutorials provided for you last week should help. Refer back to those.

The lab report must be completed in the AIAA format. Please visit the AIAA homepage* for FAQ's regarding this layout.

The following links may be useful in visualizing and understanding Stirling engines:
http://auto.howstuffworks.com/stirling-engine.htm
http://en.wikipedia.org/wiki/Stirling_engine
http://www.animatedengines.com/ltdstirling.html
http://www.ohio.edu/mechanical/stirling/engines/engines.html

*AIAA Author's Toolkit; https://www.aiaa.org/techpresenterresources/

Individual Pre-Lab

NOTE: You are not required to write a report for this part of the lab. Simply type your responses in the order they were asked. Each student will submit their own pre-lab.

1. **General Theory**
   (a) What is the difference between alpha, beta, and gamma-type Stirling engines? Please be thorough but concise.
   (b) How does the gamma-type Stirling engine work? Describe how the four thermodynamic processes of an ideal Stirling cycle are carried out by the physical device. *Hint: Open the Stirling engine assembly CAD model and analyze how the pistons move relative to each other.*
   (c) In the Stirling engine used for this lab, how does the internal volume of the system change with time?
2. **The Stirling Cycle**
   (a) Provide a sketch of an ideal Stirling cycle P-V diagram.
   (b) Using your above diagram and the real cycle P-V diagram provided (Appendix A), label each of the four processes in the Stirling thermodynamic cycle (For example, isothermal expansion is one of the four thermodynamic processes.). Don't worry about units on your ideal cycle for this pre-lab. Identify why the real cycle does not look exactly like the ideal cycle.
   (c) Using the provided wireframe of the engine you will be testing in this lab (Appendix A), label all heat/work transfers and temperatures for an engine running in a room temperature environment with $\Delta T = 10°C$. No calculations need to be made for this step.
3. **CAD Model**
   Using the provided flywheel model from the SolidWorks assembly, change the number of spokes from three to four. Using this updated model create a one page drawing with a standard three-section view that includes the dimensions that would be required for manufacturing. Use the drawing show in Appendix B as a reference for necessary dimensions and layout. **Appendix B is NOT a solution and you must add additional dimensions to receive full credit.** There are many different techniques for developing this CAD model, but one method is outlined in Appendix C for reference.

Figure 2: Three Spoke Flywheel

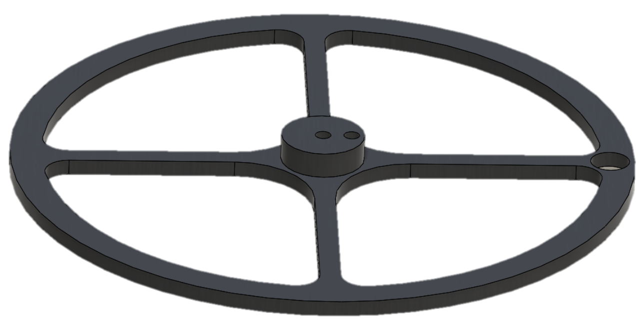
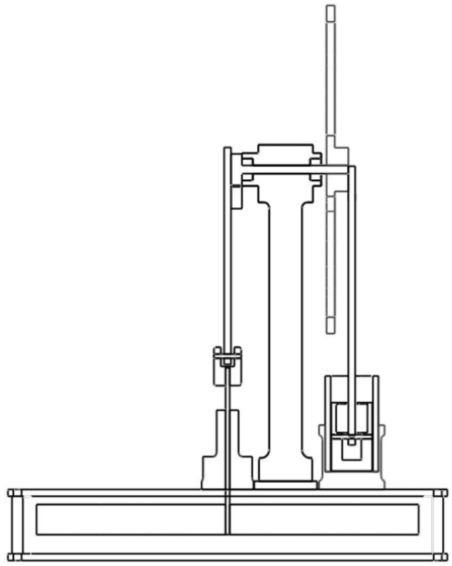


Figure 3: Four Spoke Flywheel

Appendix A



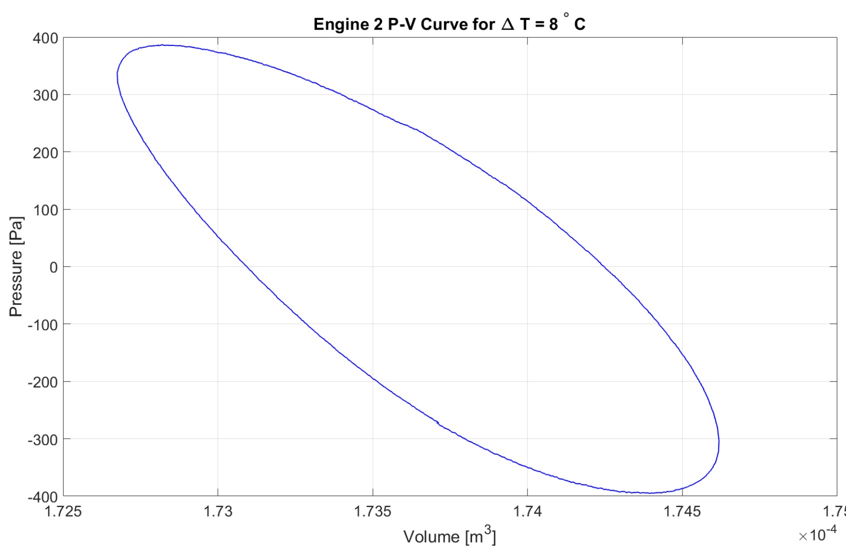
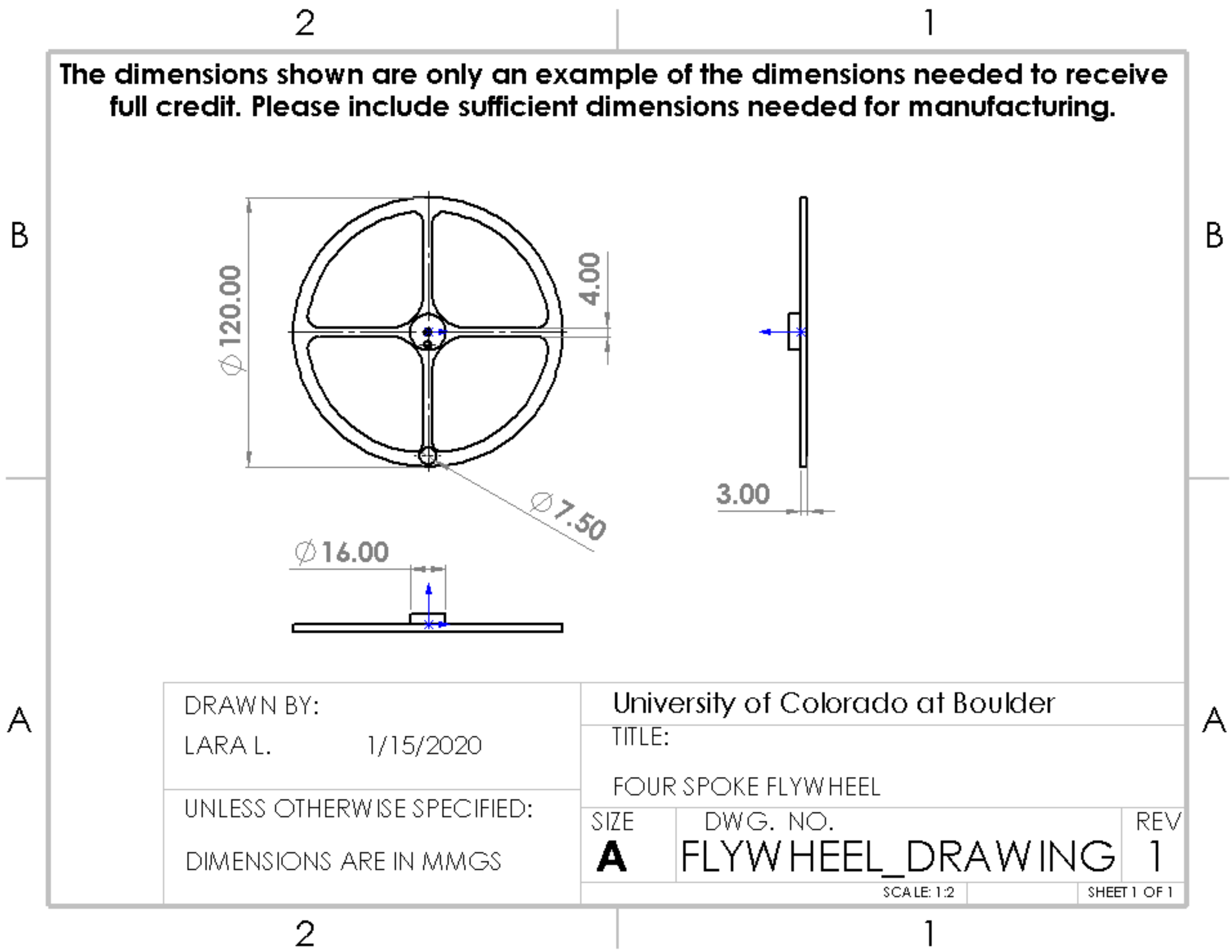


Figure 4: PV Plot One Rotation. Note: Pressure is plotted as a gague pressure

Appendix B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University of Colorado at Boulder
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SHEET 1 OF 1

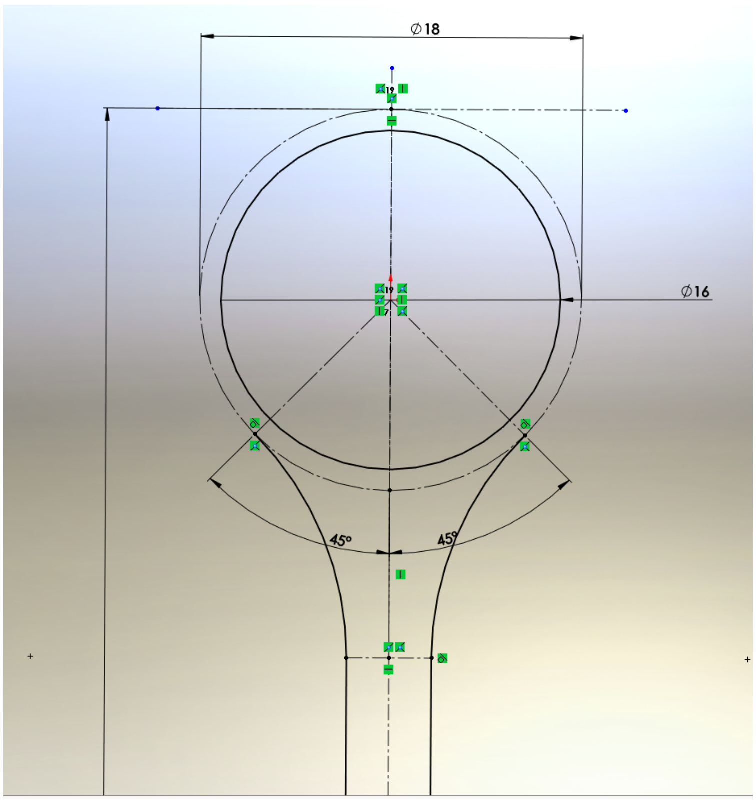
Appendix C:
SolidWorks Flywheel Supporting Documentation

1. Copy the "Flywheel" part from the directory "courses Z:\AES\lab-documents\ASEN 3113\Lab1 Stirling Engine\SolidWorks model". The file are also available on Canvas for those working remotely.

   Open the "Flywheel" file, and begin by editing the sketch on "Boss-Extrude 1". Display the drop down arrow for ""Boss-Extrude 1", highlight *Sketch 1* and select sketch in the top left corner.

2. With the circumferential encoder hole on the bottom, remove the top two spokes entirely, but leave the spoke adjacent to the encoder hole intact. Remove all curves and construction lines near the center. Create a **construction** circle in the middle with a 9mm radius. Draw two more lines for **construction** that are 45°off of the center line. To do this use the smart dimension tool by clicking on both lines to set the angle between them.

3. Using two three point arcs, create fillet between the vertical lines of the spoke and the construction circle that you just made. Constrain the fillets to be tangent to the vertical lines and the construction circle. Do this by selecting both the arc and the construction circle and select a tangent relation. Repeat for vertical lines of spoke. You may need to add another relation to intersect your fillets with your construction lines. Make sure (using dimensions, construction lines, or another technique) that the tangent points on the construction circle are symmetric about the spoke and take up 90°of the construction circle:



4. Revolve the spokes by using "Circular Pattern" feature found under Tools ⟩ Sketch Tools. Click on each line you would like to rotate.

5. Exit the sketch.

6. **Create the Part Drawing:** Click File: Make drawing from model. Add views consistent with Appendix B. Hint: Uncheck "Only show standard formats" and use "A (ANSI) Landscape".

7. Annotate the part drawings with the necessary dimensions using Smart Dimension. Also indicate tolerances as shown on the drawing in Appendix B.

8. Save any necessary changes/files.