**Laboratory #1: Heat Engine**

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**Abstract** *(typically around 200 words)*

**These instructions give you guidelines for preparing papers for AIAA Technical Journals. Use this document as a template if you are using Microsoft Word 2001 or later for Windows, or Word X or later for Mac OS X. Otherwise, use this document as an instruction set. Either way, you are required to adhere to these formatting standards. This first paragraph is formatted in the “Style Abstract” style (under the “Home” ribbon tab). In general, if you expand the “Styles” box, you can identify the style that you are to use by placing your cursor in the area of the template with the appropriate formatting. In this section, give a brief summary of the purpose or objectives of the lab and a very high-level description of the methods used to obtain the results that will be presented. Also present the most important results. The purpose of this section, generally, is to provide a synopsis of the paper that someone could use to determine whether they want to read the report.**

**Nomenclature**

Papers with many symbols may benefit from a nomenclature list that defines all symbols with units, inserted between the abstract and the introduction. If one is used, it must contain all the symbology used in the manuscript, and the definitions should not be repeated in the text. In all cases, identify the symbols used if they are not widely recognized in the profession. Define acronyms in the text, not in the nomenclature.

*Cp*= pressure coefficient

*Cx* = force coefficient in the *x* direction

*Cy* = force coefficient in the *y* direction

c = chord, *cm*

d*t* = time step, *s*

*Fx* = *X* component of the resultant pressure force acting on the vehicle, *N*

*Fy* = *Y* component of the resultant pressure force acting on the vehicle, *N*

* =* angle of attack, *deg*

*Θ =* boundary-layer momentum thickness

*ρ* =density, g/cm3

*Subscripts*

(You may use common subscripts on multiple variables. If you do so, include this section.)

cg = center of gravity

*G* = generator body

iso = waypoint index

T

**Introduction**

HE Ericsson cycle is an ideal, reversible, thermodynamic cycle. It was invented by John Ericsson in the late 1800s. Like a double-acting Stirling cycle or a Carnot cycle, the Ericsson cycle achieves the maximum theoretical efficiency in the ideal limit. Analyzing and quantifying heat engine cycles is important because it identifies areas for future development in heat engines. If a more efficient heat engine cycle could be developed and utilized widely, cars would be more efficient, ships would pollute less, and humanity would have a cheaper and better source of energy.

There are four processes in the ideal Ericsson cycle. The first is an isothermal compression from a cold uncompressed state to a cold compressed state. The second is isobaric heat addition, where the gas is maintained in a compressed state and heated to the hot compressed state. The third is an isothermal expansion, where the gas expands to the hot uncompressed state. The final process is an isobaric heat rejection, where the gas is cooled so it returns to the original cold uncompressed state. In this context, the terms ‘hot’ and ‘cold’ refer to the high and low temperature reservoirs or heat sources.

In the ideal limit, the Ericsson cycle operates with isothermal expansion and compression. This is the most efficient way to transfer heat. In addition, the Ericsson cycle uses regeneration. The heat is recycled between the hot and cold cycles, which minimizes energy loss.

However, the ideal limit is impossible to attain in a real Ericsson engine. True isothermal expansion and compression require infinite time. In addition, real heat exchangers are not perfectly efficient, so the regeneration is not perfectly efficient. Therefore, it is impossible to build an ideal Ericsson engine, and unrealistic to build an efficient one.

To quantify the error between an ideal and practical Ericsson cycle, this laboratory experiment compares the ideal Ericsson cycle with an experimental version of the cycle performed in the laboratory. A simple piston-cylinder setup is used. The system undergoes isobaric compression by placing a fixed mass on top of the cylinder. Next, it undergoes a quasi-isothermal expansion by heating the air in the cylinder. The mass is removed and the system undergoes isobaric expansion. Finally, a quasi-isothermal compression cools the gas to the starting temperature.

Based on collected pressure and temperature measurements, the efficiency of the laboratory Ericsson cycle is calculated. This is compared with the calculated efficiency for an ideal Ericsson cycle.

A simple uncertainty analysis is performed. Sources of uncertainty and error are identified and quantified. Conclusions are drawn about the performance of the experimental Ericsson cycle, and suggestions are made for improvements on accuracy in future experiments.

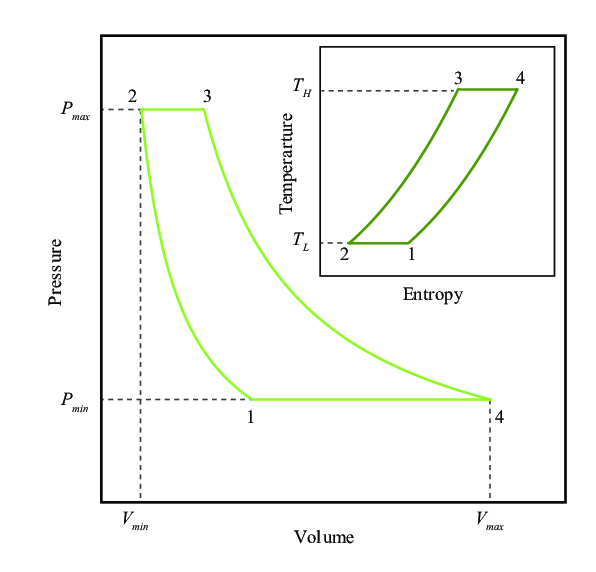
**Methods**

**Theory of the Ericsson Cycle**

As described in the Introduction, the Ericsson cycle consists of 4 steps:

1. Isothermal Compression
2. Isobaric Heat Addition
3. Isothermal Expansion
4. Isobaric Heat Rejection

Pressure-Volume and Temperature-Entropy diagrams help to characterize these cycles. The P-V and T-S diagrams for the Ericsson cycles are provided below:



**Figure 1: P-V, T-S diagram of Ericsson cycle [1]**

**I**n theory, all the heat absorbed from the high-temperature heat source is converted into work, and there are no viscous losses or internal or external efficiencies. This is clearly physically unrealistic, but .

The air in the Ericsson cycle is assumed to be ideal and calorically perfect. These assumptions hold for pressures and temperatures orders of magnitude on either side of room temperature and pressure (298K, 1atm). Therefore, the ideal gas law is used for analysis:

Under the assumption that air is not transferred into or out of the system, *n* is constant. *R* is a gas property, so for a cycle where air is not transferred in or out of the system:

Given these equations, an analysis is performed based on the ideal Ericsson cycle, as shown in Fig. 1.

**Laboratory piston-cylinder system**

The Methods section also presents all relevant equations that model the problem. Don’t just drop a very complicated and problem-specific equation. Instead, show how an equation is derived from standard equations (such as the ideal gas law). After providing equations that model your problem, the limitations and assumptions of this model (if any) should be discussed.

*Pressure Transducer*

*Water Baths*

*Piston*

*Submerged Cylinder*

**Experimental procedure**

The Methods section also presents all relevant equations that model the problem. Don’t just drop a very complicated and problem-specific equation. Instead, show how an equation is derived from standard equations (such as the ideal gas law). After providing equations that model your problem, the limitations and assumptions of this model (if any) should be discussed.

**Results**

This section describes the obtained results. You need to show that you obtained these results using the methods and equations presented in the previous section. So don’t just drop a final number. Instead, present your raw data, then refer to the equations from the Methods section that you apply to this raw data, and finally present the calculated results. All calculated results (as well as relevant raw data) in this section require uncertainty values. The calculation of uncertainties should be presented in the next section. Results need to be interpreted and discussed in this section. If results are different from expected, this should be adequately discussed. If they are as expected, this should be mentioned as well. Don’t ascribe variances to “human error” in your report. If human error was a significant source of error, you need to go back and redo the lab.

Present all plots and relevant numerical calculations here. Be sure to follow proper format for figures, including scales, axis units, and figure labels. Determine likely sources of precision and bias error and estimate their magnitudes based upon what you have learned in class and homework. Identify, for all labs, the greatest source of uncertainty, making sure to justify your assertion.

A graph of a function

AI-generated content may be incorrect.

**Fig. 1 Magnetization as a function of applied fields.**

Line drawings must be clear and sharp. The must be large enough to be legible. *Use of colors to highlight details is encouraged.* Make sure that all lines and graph points are dark and distinct and that lettering is legible; 8- to 10-point type is suitable for artwork that is sized to fit the column width (3 ¼ in.). Keep the lettering size and style uniform both within each figure and throughout all of your illustrations. Place figure captions below each figure, and limit caption length to 20-25 words. If your figure has multiple parts, include the labels “a),” “b),” etc., below and to the left of each part, above the figure caption. Please verify that the figures and tables you mention in the text actually exist. When citing a figure in the text, use the abbreviation “Fig.” except at the beginning of a sentence.

Figures should have no background, borders, or outlines. In the electronic template, use the “Figure” style from the pull-down formatting menu to type caption text. You may also insert the caption by going to the Insert menu and choosing Caption. Make sure the label is “Fig.,” and type your caption text in the box provided. Captions are bold with a single tab (no hyphen or other character) between the figure number and figure description.

Use the Table drop-down menu to create your tables; See the Table 1 example for table style and column alignment. If you wish to center tables that do not fill the width of the page, simply highlight and “grab” the entire table to move it into proper position.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Table 1 Transitions selected for thermometry** | | | | | | |
|  | Transition | | |  |  | |
| Line | ν″ |  | *J*″ | Frequency, cm-1 | *FJ*, cm-1 | *G*ν, cm-1 |
| a | 0 | P12 | 2.5 | 44069.416 | 73.58 | 948.66 |
| b | 1 | R2 | 2.5 | 42229.348 | 73.41 | 2824.76 |
| c | 2 | R21 | 805 | 40562.179 | 71.37 | 4672.68 |
| d | 0 | R2 | 23.5 | 42516.527 | 1045.85 | 948.76 |

**Uncertainty calculations**

This section should make it clear how the final uncertainty values (presented in the previous section) are determined. This includes mentioning and discussing the uncertainties chosen for the raw data as well as showing how you calculated the uncertainty propagation. If uncertainty values are much larger or smaller than you would reasonably expect, they should be discussed here.

**Conclusion**

Although a conclusion may review the main points of the paper, it must not replicate the abstract. A conclusion might elaborate on the importance of the work or suggest applications and extensions. The conclusion should emphasize the most important results and answer/address the problems/questions stated in the introduction. Do not cite references in the conclusion. Note that the conclusion section is the last section of the paper to be numbered. The appendix (if present), funding information, other acknowledgments, and references are listed without numbers.

**Appendix**

An Appendix, if needed, appears at the end of the paper, but before the References. Include any required source code in the appendix.

**References**

Almost every report requires references. If you use any of the images from the Canvas site, refer to it. If you use an online calculator, refer to that, if you use uncertainty/calibration information for measurement instruments, refer either to the Canvas site or to the manufacturer website where you found that information. References should be presented as a numbered list which can be referred to in the text [1].

[1] Example of how to use reference in the text

[2] Second entry in the references list

[3] Lab description on MAE4400 Canvas site

[4] Manufacturer website, [www.example.com](http://www.example.com), visited on 1/10/2023

1. Insert Academic Level, Department Name, and A number. [↑](#footnote-ref-1)