No matter what professional path you take in life, the ability to clearly communicate your thoughts through both written and spoken language will be critical to your success. Lab reports offer an opportunity to develop your technical writing skills, which for those of you continuing on in engineering will be the primary type of written communication that you do.

Almost as important as your technical writing capabilities is the professional style of your report. Organization, consistent line spacing, headings, professional-looking graphs and figures, etc. are all important parts of written communication. A disorganized report is distracting to the reader and may not be taken seriously, no matter how well it is written.¹

Each lab report for this course will be worth 150 points. The content of the report will be worth 100 points, and the presentation/style/format/appearance of the report will be worth 50 points.

**Lab Report Content**

Lab reports should be organized into the following sections (with appropriate headings):

- Title Page
- Background and Objectives
- Experimental Methods and Analysis
- Results
- Discussion
- Conclusions
- Appendix (optional)

A brief description of the required content of each section follows.

**Title Page** – 5 points

The Title Page must include:

- Your name
- The course number and name
- The lab number and name
- The date you conducted the experiments
- The first and last names of your lab partners (i.e. all of the people who performed the lab with you)

The above information should be centered horizontally and vertically on the first page. Nothing else should be included on this page.

¹ Thanks to Prof. Sangree in Civil Engineering for these first two paragraphs.
Background and Objectives – 5 points
Start with a few sentences explaining why the technologies and engineering principles introduced in the lab are important. Next, state the objectives of the lab in a couple of sentences. Finish this section by briefly stating (no details yet) how you went about achieving the objectives.

Experimental Methods and Analysis – 25 points
Here, you should explain how you performed the experiments. Start by mentioning the equipment you used. You can assume the reader has some familiarity with the general engineering technologies and concepts, but is unfamiliar with the specific equipment you used. You do not have to explain in detail how the equipment works, but rather how the equipment was used to perform the experiments.

Next, describe the experiments you performed. What was controlled (motor rpm, temperature, voltage, etc.)? What was measured? You want the reader to gain enough of an understanding of your work to be able to replicate your experiments (but not your specific actions). As you write this section, be sure to explain why you did what you did. Why did you bother to record the temperature? Why did you wait for 10 minutes before taking your measurements? Why did you change the flow rate? Make it clear how the experiments you performed relate to your objectives.

After you have explained what data you collected, why you collected it, and how you collected it, then explain how you processed it to get your final results. What equations did you use, and where did they come from? Include references if necessary.

Results – 25 points
All sections, including the Results, should be written in complete sentences. Do not dump a bunch of calculations in this section. In fact, do not put calculations in the report at all. If you provide the equations you used (in the previous section) and the input data, the reader will assume you did the math correctly.

Tables and figures (e.g. graphs) should be included in this section with the text. Each table and figure should include a reference number (e.g. "Table 1", "Figure 1") and a caption (see Lab Report Presentation section later in this document). Every figure and table you include must be mentioned and described in the body of the report. You must also include a comment (in the body of the report) for each plot indicating the most important information revealed by the plot.

A well-formatted table, or possibly multiple tables containing your relevant raw measurements should be included in every report. These tables may be placed in an Appendix at the end of the report.

In general, there is no limit on the number of tables and figures you may include (unless this is specified in the handout), but you must be as clear and concise as possible with the presentation of your data and results. When considering how to present your results, first make a list of everything that you think is important to show. (Be sure to include your raw measurements.) Then think about how to present the information in as clear and concise a way as possible. Can multiple plots be combined into one? Should the measurements be included in a single table, or would that be too disorganized and confusing? Keep asking yourself if the information can be presented in a simpler and/or clearer way.
Discussion – 30 points
Here is where you discuss the results you just presented. In general, you are to address these questions in every report:

- What do the results mean? What did you learn from the results?
- Were you expecting these results? If so, why? If not, was there something wrong with your expectations or with the experiment? It is sometimes ok if you did not know precisely what to expect, but you should have had at least some idea as to what kinds of results would be reasonable.
- Why do you think the results came out as they did? Can you explain them from an engineering standpoint?
- Did anything go wrong with the experiment that makes you question the validity of your results?
- What sources of error/uncertainty were present in the experiments? How much of an effect did these have on the results? Do not just state the sources of error and uncertainty - also mention the significance of these on the quality of the results.
- Is the data overly noisy? Are there any outliers in the data? If yes, provide a possible explanation.
- How well did you meet your objectives?
- How could the experiments be improved?

Also, be sure to answer every question asked in the handout.

Conclusions – 10 points
Now take the most important parts of the previous sections and put them together. Restate the objectives. Summarize in a few sentences the experiments that were conducted. Summarize in a few sentences the (important) results of the experiments. Restate any problems you had with the lab and what you think about the validity of the results. Restate (briefly) what the results mean, particularly with respect to the objectives.

Appendix
An appendix may be included in your report if necessary. Raw measurements, equations, and other supplemental information may be located here. Appendices will not contribute toward the total page count of your reports.
General Pointers Regarding Content

- **Start by writing an outline for your report.** This will help you to:
  - Figure out what you still need to do with the data
  - Figure out what plots and tables you will need to create
  - Figure out what specific questions must be addressed
  Do this as soon as possible after you have completed the lab.

- Assume your audience is a fellow student at a different university who has the same level of knowledge as you.

- Your lab report should be a stand-alone document, meaning all of the information the reader needs to know should either be included or referenced in the report.

- The lab handout is not a source document. It is written to help you better understand and perform the lab. Information and figures should not be copied from the handout and pasted into your report.

- Assume the reader has not seen the lab handout and **do not refer to the lab handout at all.**

- Use the *past* tense when writing about work that has already been performed.
  Examples: Pressure was measured using a slant-tube manometer.
  The air velocity was computed from the dynamic pressure.

  Use the *present* tense when writing about things that still exist.
  Examples: The PRT resistance measurements agree with published values.
  The transient response model provides a good fit to the experimental data.

- Include references when necessary, and use proper citations and reputable sources (not Wikipedia).

- Before you hand in your report, read it out loud to yourself (this will help you catch mistakes).
Lab Report Presentation

The presentation of the lab report will count for 50 points. Points will be deducted for not following the specifications presented below.

Five (5) points will be deducted if your lab report exceeds the specified page limit (page limits will vary with labs and will be specified in the lab handouts). All other instances of non-compliance will result in a one (1) point deduction for each initial occurrence. Points will not be deducted for subsequent instances of non-compliance to the same specification.

General formatting

- The written text shall not exceed the specified page limit.
- Paper sheets shall not be double-sided (i.e. only print on one side of each sheet of paper).
- No text shall be hand-written.
- Pages shall have one (1) inch margins at the top, bottom and sides.
- Text shall be double-spaced.
- Text shall have a font size no smaller than 11 point.
- Page numbers shall be included at the bottom right corner of every page, starting on page 2. The title page will be page 1, but do not include a page number on it.
- A reference number and a short, descriptive caption shall be included below every figure, including plots.

Composition

- Sentences shall be written clearly and properly according to the rules of English grammar.
- Words shall not be misspelled.
- Contractions (e.g. "don't", "wasn't") shall not be used.
- A sentence shall not start with "And" or "But", nor shall they begin with a numeral.
- An abbreviation shall not be used until it has been clearly defined.
- Proper units shall be used throughout the report.
- Proper use of significant digits shall be used throughout the report.
- Zeros shall be placed before the decimal point in numbers less than one.
- A multiplication sign (\( \times \)) and exponent shall be used when expressing scientific notation (e.g. \( 4.5 \times 10^6 \) psi, not 4.5E6 psi)
- References shall be properly cited.

Equations

- All equations shall be created using an equation editor.
- Equations shall not be pasted as images into the report.
- All equations shall be written in Times New Roman, or a similar serif, font.
- All scalar variables shall be written in italics, and all vector and tensor variables shall be written in bold.
- All equations shall be written on a separate line.
- All equations shall be identified with a sequential number located along the right margin.
- All new variables introduced in an equation shall be defined immediately before or after it.
Example of how equations should be presented in the text:

Newton's second law is often written as

\[ F = ma \] (1)

where \( F \) is the force vector, \( m \) is the mass, and \( a \) is the acceleration vector. The acceleration is obtained from the second derivative of the position vector, \( \mathbf{x} \):

\[ \mathbf{a} = \frac{d^2 \mathbf{x}}{dt^2}. \] (2)

Equations may be included in an appendix at the end of the report. All of the specifications above regarding the presentation of equations apply to the appendix, plus:

- The appendix must be acknowledged in the main body of the report (e.g. “The equations used to process the data are presented in the Appendix.”).
- A subtitle must be included in the appendix describing the purpose of the equations (e.g. “Derivation of the Average Heat Transfer Coefficient for Convection Around a Horizontal Cylinder”).
- Equations in the appendix shall be identified with the letter “A” followed by a sequential number, located along the right margin.
- The main equations must also be identified in the body of the report (e.g. “The Grashof number for free convection was calculated using equation A5.”).
- The appendix must be written in sentences, with the equations presented in a clear manner.

For example:

Appendix

Table 1 – Raw pressure, temperature, and flow rate measurements

[TABLE OF RAW MEASUREMENTS]

Calculating the Coefficient of Performance

The coefficient of performance, \( \beta \), is defined as:

\[ \beta = \frac{\dot{Q}_L}{\dot{W}_C} \] (A1)

where \( \dot{Q}_L \) is the heat flux into the refrigerant during the evaporation process, and \( \dot{W}_C \) is the work into the refrigerant from the compressor. The heat flux into the refrigerant during the evaporation process is determined from the refrigerant mass flow rate, \( \dot{m}_{\text{refrigerant}} \), and from the change in specific enthalpy, \( h \), of the refrigerant across the evaporator:

\[ \dot{Q}_L = \dot{m}_{\text{refrigerant}} (h_{\text{evaporator output}} - h_{\text{evaporator input}}). \] (A2)

The work put into the refrigerant from the compressor is determined from the refrigerant mass flow rate and from the change in specific enthalpy of the refrigerant across the compressor:

\[ \dot{W}_C = \dot{m}_{\text{refrigerant}} (h_{\text{compressor outlet}} - h_{\text{compressor inlet}}). \] (A3)
Plots

- Plot shall be presented in grayscale – color shall not be used.
- Plot axes shall be labeled clearly.
- Proper units shall be included in the axis labels.
- Y-axis labels shall be parallel to the y-axis (i.e. rotated 90° counter-clockwise with respect to the bottom of the page).
- Plot axes shall be scaled appropriately and the range of each axis shall be set appropriately to convey the important information without misleading the reader.
- An appropriate legend shall be included in each plot as necessary.
- Plot fonts shall be sized appropriately to facilitate easy reading.
- Gridlines shall not be included.
- Plot titles shall not be included.
- Individual data points shall be included in each plot.
- Error bars shall be included in every plot.
- Data points shall not be connected with smoothed lines.
- Data points shall be connected with straight lines *only if needed* to assist the reader in “tracking” different sets of data on the same plot.
- Non-linear curves shall not be included on plots unless specified in the lab handout.
- A reference number and a short, descriptive caption shall be included below every plot.
- Efficiency values shall be reported as percentages, and the “%” symbol shall be included in the proper axis label to ensure that this is clear to the reader. *(New for 2018!)*

Examples of correct and incorrect plots are shown below. Note that each plot should have an appropriate caption under it.

**INCORRECT** – Do not connect data points unless it is necessary
INCORRECT – Do not include gridlines

INCORRECT – Units are missing from axis labels
INCORRECT – Error bars are missing

INCORRECT – Do not include a title
CORRECT

INCORRECT – Do not connect data points unless it is necessary
CORRECT – Do not connect data points with smoothed lines

INCORRECT – Do not connect data points with smoothed lines
**INCORRECT** – Data points are missing

**CORRECT**
Tables

- Gridlines shall not be included in tables.
- Font size shall be no smaller than 11 point.
- Proper units shall be included.
- Symbols and abbreviations shall not be used unless they are defined in the table or caption.
- Scientific notation shall be expressed properly (e.g. $4.3 \times 10^2$, not $4.3E2$).
- A reference number and a short, descriptive caption shall be included above every table.

<table>
<thead>
<tr>
<th>Water Bath</th>
<th>PRT Temperature (°C)</th>
<th>PRT Resistance (Ω)</th>
<th>Thermistor Resistance (Ω)</th>
<th>$V_{O,amplified} \text{ (V)}$</th>
<th>$V_{O,actual} \text{ (V)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Water</td>
<td>0.7</td>
<td>100.3</td>
<td>5600</td>
<td>8.7E-03</td>
<td>2.18E-04</td>
</tr>
<tr>
<td>Boiling Water</td>
<td>99.5</td>
<td>138.2</td>
<td>184</td>
<td>1.40E-01</td>
<td>3.51E-03</td>
</tr>
<tr>
<td>Elevated Temperature</td>
<td>74.3</td>
<td>XXX</td>
<td>395</td>
<td>8.94E-02</td>
<td>2.24E-03</td>
</tr>
<tr>
<td>Room Temperature</td>
<td>26.3</td>
<td>XXX</td>
<td>1913</td>
<td>3.11E-02</td>
<td>7.78E-04</td>
</tr>
</tbody>
</table>

**INCORRECT**

**CORRECT**
<table>
<thead>
<tr>
<th>Cooling Water Flow Rate (gpm)</th>
<th>0.5</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Speed Setting</td>
<td>60</td>
<td>75</td>
</tr>
<tr>
<td>Refrigerant Flow Rate (g/s)</td>
<td>0.00287</td>
<td>0.00363</td>
</tr>
<tr>
<td>Specific Enthalpy (kJ/kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle State</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1- Compressor inlet</td>
<td>2650000</td>
<td>2670000</td>
</tr>
<tr>
<td>2- Compressor outlet</td>
<td>2770000</td>
<td>2930000</td>
</tr>
<tr>
<td>3- Condenser inlet</td>
<td>2770000</td>
<td>2810000</td>
</tr>
<tr>
<td>4- Condenser outlet</td>
<td>2700000</td>
<td>2700000</td>
</tr>
<tr>
<td>5- Expansion Valve inlet</td>
<td>2670000</td>
<td>2670000</td>
</tr>
<tr>
<td>7- Evaporator inlet</td>
<td>2530000</td>
<td>2510000</td>
</tr>
<tr>
<td>8- Evaporator outlet</td>
<td>2600000</td>
<td>2600000</td>
</tr>
<tr>
<td>Condenser water inlet</td>
<td>972000</td>
<td>955000</td>
</tr>
<tr>
<td>Condenser water outlet</td>
<td>121300</td>
<td>124100</td>
</tr>
<tr>
<td>Power and Heat Flux (J/s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power input into compressor, $\dot{W}_c$</td>
<td>33.3</td>
<td>92.9</td>
</tr>
<tr>
<td>Heat Flux out of refrigerant during condensation, $\dot{Q}_H$</td>
<td>-20.0</td>
<td>-42.2</td>
</tr>
<tr>
<td>Heat Flux into tap water during condensation, $\dot{Q}_{water}$</td>
<td>760.0</td>
<td>899.0</td>
</tr>
<tr>
<td>Heat Flux into refrigerant during evaporation, $\dot{Q}_L$</td>
<td>20.0</td>
<td>33.8</td>
</tr>
<tr>
<td>Coefficient of performance, $\beta$</td>
<td>0.600</td>
<td>0.364</td>
</tr>
</tbody>
</table>

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<td>3- Condenser inlet</td>
</tr>
<tr>
<td>4- Condenser outlet</td>
</tr>
<tr>
<td>5- Expansion Valve inlet</td>
</tr>
<tr>
<td>7- Evaporator inlet</td>
</tr>
<tr>
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