Section 3: A GUIDE TO WRITING 2.672 ANALYTICAL REPORTS

CONTENTS

I. PURPOSE OF THESE GUIDELINES

This document is intended to highlight what should be contained in your lab reports for this course. It does not substitute for understanding specific directions your lab instructor gives you, nor is it a complete compendium of all aspects of lab report writing.

This document assumes you are familiar with writing lab reports from course 2.671. It builds on that knowledge while pointing to some key differences. In particular, the focus of 2.672 reports is on the theoretical model you develop, not on the experiments you do to test it. Thus the sequence of elements of your paper is different from the sequence for 2.671 papers. (One way to think of the difference between 2.671 reports and 2.672 reports is that the former are written from the POV of technicians, while the latter are written from the POV of engineers.)

The reports you write for this course are similar to “white papers” or longer reports suitable for publication. They are typically 12-20 pages in length.

- *It is especially important that you focus on your contributions to the understanding and solution of your problem in this report, rather than the errors you made*. You developed a model to characterize an engineering problem; it is a remarkable achievement. Although your model may not be perfect, it is nonetheless an important tool for understanding essential physical processes. Write your report to help readers understand and solve real-world engineering problems.

- While you may share ideas, data and results with your group members, *you are the sole author of this report*. The lab work was a team effort. Writing the report is an individual effort.

II. ELEMENTS OF A 2.672 ANALYTICAL REPORT in the order desired

Title page

- In addition to title, include:
  - Author’s name
  - Project supervisor
  - Names of group members
  - Course and section number
  - Date
- NOTE: The more specific you can make your title, the better: “Silicon Wafers” and “Heating Silicon Wafers” are weak titles—they don’t say anything about your approach to the topic. A good title usually highlights either a specific problem, a specific method, or a solution. Thus “Reducing Heating Time for

Silicon Wafers" is better, and "Reducing Heating Time for Silicon Wafers by [fill in your solution]" is best. (See additional examples in *Mayfield Handbook.*)

Abstract

- An Abstract is a brief summary of a report. It appears as a single paragraph. The Abstract for a 2.672 report includes the following key elements:
  - Succinct problem statement, 1-2 sentences
  - What was done
  - How it was done
  - Significant results (quantified where possible)
  - Conclusion, including brief evaluation and/or recommendation
- NOTE: An Abstract does not describe the background of the problem—why your study was undertaken. That belongs to the Introduction. An Abstract is a complete entity in itself: it is not part of the body of your report; it is not part of the Introduction.
- Just as the experiment is not the main point of your paper, it should not appear to be the main point of your abstract. The focus should be on the model you develop. <u>You should succinctly note the theoretical principles you use and what the theory does.</u>
- Length: approximately 150-250 words, or 1/3 to ½ page single-spaced.

Table of Contents

Please see the *Mayfield Handbook* for a sample format for Contents page. NOTE, however, that unlike the example in the handbook, <u>the heading on the Contents page is not the title of your paper but, rather, Table of Contents</u>.

- Notice how pages are numbered: Title page is never numbered; all pages before Introduction (the body of your paper) are numbered in lower case Roman numerals.
- For longer papers, you may wish to include a List (or Table) of Figures and a List of Tables. These usually appear on their own separate pages, but you may combine them on one page.
- For 2.672 papers, you may wish to include a List of Symbols. This list can simplify your task of explaining terms in equations in your Theory section.

1.0 Introduction

In this section:

  - State the context and/or background of your study.
  - Explain the need for the study.
  - Clearly define the problem you are investigating.
  - Outline the overall approach you are taking (this means not just the experiment, but also and more importantly, your theoretical model).
  - End with a brief roadmap of the rest of your document.
- Assume a reader who is familiar with concepts of mechanical engineering, but is not in your class—i.e., <u>don't assume your only reader is your lab instructor.</u>
- Do not copy language from lab manual—translate the problem you've been given into your own words. Cite your lab manual where necessary (see References, below).

- Length: The length of an Introduction is usually proportional to the length of a report, chapter or book. For a 10-15 page paper, the Introduction is typically ½ to 2/3 of a page—two or three succinct paragraphs.

2.0 Theoretical analysis

This section includes your assumptions, your model, and your justification for the model (i.e., why *this* model?). It is the heart of your report, along with your Discussion. In this section, you translate the problem you've been given into math and diagrams. Because this section contains a lot of important material, you will want to guide your reader through it by organizing material into a few sub-sections:

- Develop governing equations
    - State your assumptions explicitly and support them quantitatively: e.g., assume laminar flow and give Reynolds number. Make sure to explain why these are your assumptions, and to note their limitations.
    - Describe the model development; give the major equations, but leave detailed algebra to the Appendix. NOTE : this section is not simply a list of equations but is a narrative of your process of analyzing the problem and creating a model. Thus you must link equations with narrative.
    - Equations are sensitive to conditions, so tell readers what your equations mean in the context of your model.
    - Use figures (diagrams) to show relationships among the parts of your model, to illustrate, for example, forces or control volume.
- Explain computer simulation
    - Describe the algorithm for getting your answers from your equations first, and then the numerical scheme used.
    - Discuss numerical parameters: e.g., step size in integrating differential equations.
    - Specify boundary conditions.
    - Leave program listing for an Appendix

3.0 Validating the model

In this section, you describe the experiment(s) you did to test your model. Note: it is never acceptable to "stack" headings. You must always provide at least a "mini" introduction to the sub-sections that follow.

3.1 Experimental methods (i.e., apparatus & procedures)

In this section, you:

- Explain the overall operation and provide a schematic diagram. You may also wish to provide a photo of the set-up (see "Figures and Tables" below).
- Give dimensions of the apparatus; point out the relationship between the lab device and the actual device
- State what is being measured. Give detailed information regarding transducers and measurement systems *only if they are uncommon devices*.

- State accuracy and frequency response of transducers. If you use and A/D system, also give sampling rate and total sampling duration.
- Explain calibration procedure. (Not a lot of detail here! If you feel you must provide a more comprehensive explanation of calibration, put it in an Appendix).
- Describe how you conducted the experiment.
- List sets of experiments done, along with the range of parameters you have varied.

3.2 Experimental results

In this section you present your results but do not interpret them. Present results by referring to figures.

- Describe the direct observation first—e.g., pressure as a function of time. Point out and explain the features you observed in terms of physical laws.
- Describe how the results change when you vary the parameters of the experiment:
  - Magnitude of change (goes up/down, by how much)
  - Scaling (e.g., peak pressure proportional to the driving pressure)
- Describe how experimental results differed from what your model led you to expect.
  - See if theoretical results produce the same features as the direct observations of the experiment (e.g., pressure vs. time curve).
  - Compare qualitatively and/or quantitatively (as appropriate) the theoretical predictions and the experimental values when the experimental parameters are changed.
  - Plot theoretical curve on same graph as experimental points.
  - Account for and explain discrepancies.

• NOTE: If you report a temperature of 100.002C, it suggests that the temperature error is less than 0.001C. *Always present results with the number of decimal places ("significant digits") that accurately represents the level of precision of your model simulations and experiments.*

4.0 Discussion

This is where you show your understanding of the model you've developed, and interpret it for the reader—e.g., what are its consequences? What is it good for? Take your time with this section; along with your Theoretical Analysis, it is the heart of your report. In this section you:

- Discuss assumptions and/or idealizations used in the development of the model and how they affect the theoretical predictions—e.g., do they result in an overestimate? an underestimate?
- DON'T just refer to your graph(s): explain what they mean.
- DON'T blame discrepancies on instrumentation; such blame is not useful to those who would understand how good your model is. (If you knew instrumentation was inadequate, you should not have wasted your time in making the measurement in the first place.)
- When discussing sources of error in experimental measurement, be quantitative: estimate or calculate percentage of error explained by measurement.
- DO focus on your contributions to the understanding and solution of your project problem.
- State whether your model might usefully be applied at full-scale on "real-world" operations.

• *NOTE: The point of your discussion is not to compare the "fit" of your model to your experiment but to explain what problem you've solved. Make sure to explicitly relate your results back to your original problem.*

5.0 Conclusion

In this section, you:

- Briefly recap of the problem, your approach and results (approx. 1 paragraph).
- Evaluate your model
  - What are the key parameters in the experiment?
  - How good is your model?
  - Does it give the upper/lower bound of the results?
- State the implications of your final evaluation: how would your results apply to your original objective?
- Suggest how the model might be improved; make recommendations for further work.

Acknowledgements

If you want to credit a lab partner, instructor, TA, etc., for an insight on a particular problem, do so here.

References

Even if your only sources are lab handouts, your textbook, and/or manufacturer's websites, cite sources where it is appropriate to do so for both text and illustrations. By doing so you demonstrate intellectual honesty. You also give readers useful clues for obtaining additional information about your topic. Use ASME style for in-text citations and References at the end of your paper. See a brief version of ASME style at end of this document.

Appendices

Put details readers may need to replicate your work, but which are not required to understand your work, in an Appendix. *Essential derivations, governing equations, key assumptions and definitions belong in the body (main text) of your report.* Details of calibrations and procedures (e.g., tables of raw data used to plot curves) belong in Appendices.

- Appendices are numbered A,B,C, etc. Figures or Tables in Appendices are numbered A1, A2, B1, etc.
- Appendices are not meant to be "dumping grounds" for raw data. They require textual explanation, if only a detailed caption.
- Present Appendices in the order in which they appear in your text—i.e., readers expect you to refer first to Appendix A, then Appendix B, etc.
- NOTE: it's always a good idea to clarify with your instructor what s/he wants, if anything, in appendices. Preferences vary.

III. ILLUSTRATIONS

Use figures to explain theory, procedures and results. The physical apparatus for the experiment should be drawn as a schematic, not a three-dimensional drawing.

- Refer to every figure or table in your text, before it appears. This does not mean, however, that figures must appear immediately below text that mentions them—i.e., do not break off text mid-sentence to present an illustration. As a rule, illustrations should appear on the same page or the page following your first reference to them.
- Figures and Tables are numbered separately. Each should be captioned and labeled well enough to allow it to stand alone. (This does not take the place of explanation within your text; it is a courtesy to readers who may be skimming or reviewing your report.)
- Each caption includes a number, an informative label, and additional relevant information. For example:

  Figure 6. Experimental data for 138g of water. Note that . . . . (draw the reader's attention to a key point).

- Captions appear below Figures and above Tables.
- Note that you need a period after the figure number and at the end of the caption, even if it is not a complete sentence. You do not need headings (titles) on figures that have complete captions. Because captions are not headings, there is no need to capitalize words in captions.
- If your instructor wants you to include a photo of your experimental set-up in addition to a schematic, make sure the key elements are clearly visible and that labeling is neat and legible. (Note: Some instructors prefer schematic drawings because they make it easier for the reader to see what matters.)
- Results should be presented as graphs whenever possible. Graph data in a form that relates to your analysis. Don't curve fit results just because Excel can make them fit!
- Use lines for theoretical predictions and symbols for data points. If you insert a line to show the trend of the experimental data points, it must be clearly distinguished from the theoretical line and it should not obscure the data

points. Grid marks that are light and unobtrusive, but not too crowded, can make results easier to read. Tick marks and scales should be well spaced—typically, 3-6 marks on the ordinate (y) and 5-10 on the abcissa (x). Make sure tick mark labels accurately represent the level of precision of your work—don't add more decimal places than you can justify.

- Axis labels should be simple and descriptive. For quantities with dimensions, graphs must have units of measurement, and they must be consistent—i.e., don't switch from cm to mm or from cm to in. Units *must* be given on the figure, not in the caption. (Remember to refer to units in your Discussion, too.)
- Beware of printing in faint colors or colors that are too similar to be easily distinguished. Do not refer to the "blue" curve if you are printing in black and white.

IV. WRITING STYLE

The following are just a few notes on common questions and errors. In addition to using a manual on technical writing such as the *Mayfield Handbook,* it is a good idea to own a general writing style manual that you find clear and easy to use, such as Strunk and White's classic *Elements of Style* or Patricia O'Connor's *Woe Is I,* and to develop the habit of consulting it when you have questions.

- Can I use "I" in my report? As a rule, 1st-person pronouns are not used in technical writing. The rationale is that you want to spotlight the work, not yourself. Sometimes, however, it makes sense to use "I" or "we" (if you are reporting on a team effort) in your discussion section, where you are explaining your line of thinking, why you did things certain ways, etc. When in doubt, check with your instructor.
- NOTE: Avoiding "I" does NOT mean "use passive voice." It is always preferable, and usually possible, to phrase ideas in the active voice. E.g., instead of "I developed an engineering model to predict wafer temperatures during hot-plate photoresist processing" you can say "This project developed an engineering model . . ." Instead of "My system comprises three major parts," you can say "The experimental system comprises three . . ."
- Keep verb tenses logical and consistent.
- Avoid vague "this"es as subjects. When "this"es start to pile up, the reader loses sight of what you're talking about.
- Are your modifiers dangling? Danglers are tough to weed out but, like vague words, they make it harder for your readers to see what you are really talking about—e.g., "Using the HP software, the plot shows the relationship between predicted and actual force." The *plot* isn't *using* anything—you are! Syntax is a form of logic; words need to relate logically to other words in your sentences.
- Eliminate unnecessary words; cluttered writing gives an impression of cluttered thinking. E.g., why say "Due to the fact that" when you can say "because"? Why say "is dependent upon" when "depends on" is not only more concise, but also uses a much stronger verb?
- Diction: When you proofread your report, look for and eliminate casual speech such as "plugged in" or "Sticking this in" –you want your report to sound professional.

Finally, although you usually write lab reports in bits and pieces, and rarely write them in order, your finished report should read as a coherent document. Remember that in a 2.672 report you are making an argument for the model you developed. To give readers the impression that you are making an argument, make sure:

- material is logically organized;
- topic sentences are focused on ideas (not just “I did this . . .Then I did that . . . Fig. 3 shows . . . Fig. 4 shows . . .”); and
- transitions between sections and paragraphs clearly link the parts of your work.

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APPENDIX: ASME CITATION STYLE

Here is an abbreviated version of ASME (American Society of Mechanical Engineers) citation style. It is taken from the following weblink from the ASME home page:

http://www.asme.org/pubs/authors/MS4.html#Description

References

Text Citation. Within the text, references should be cited in numerical order according to their order of appearance. The numbered reference citation should be enclosed in brackets.

Example: It was shown by Prusa [1] that the width of the plume decreases under these conditions.

In the case of two citations, the numbers should be separated by a comma [1,2]. In the case of more than two references, the numbers should be separated by a dash [5-7].

List of References. References to original sources for cited material should be listed together at the end of the paper; footnotes should not be used for this purpose. References should be arranged in numerical order according to the sequence of citations within the text. Each reference should include the last name of each author followed by his initials.

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(1) Reference to journal articles and papers in serial publications should include:

- last name of each author followed by their initials
- year of publication
- full title of the cited article in quotes, title capitalization
- full name of the publication in which it appears
- volume number (if any) in boldface (Do not include the abbreviation, "Vol.")
- issue number (if any) in parentheses (Do not include the abbreviation, "No.")
- inclusive page numbers of the cited article (include "pp.")

(2) Reference to textbooks and monographs should include:

- last name of each author followed by their initials
- year of publication
- full title of the publication in italics
- publisher
- city of publication
- inclusive page numbers of the work being cited (include "pp.")
- chapter number (if any) at the end of the citation following the abbreviation, "Chap."

3) Reference to individual conference papers, papers in compiled conference proceedings, or any other collection of works by numerous authors should include:

- last name of each author followed by their initials
- year of publication
- full title of the cited paper in quotes, title capitalization

- individual paper number (if any)
- full title of the publication in italics
- initials followed by last name of editors (if any), followed by the abbreviation, "eds."
- publisher
- city of publication
- volume number (if any) in boldface if a single number, include, "Vol." if part of larger identifier (e.g., "PVP-Vol. 254")
- inclusive page numbers of the work being cited (include "pp.")

(4) Reference to theses and technical reports should include:

- last name of each author followed by their initials
- year of publication
- full title in quotes, title capitalization
- report number (if any)
- publisher or institution name, city

Sample References

[1] Ning, X., and Lovell, M. R., 2002, "On the Sliding Friction Characteristics of Unidirectional Continuous FRP Composites," ASME J. Tribol., 124(1), pp. 5-13.
[2] Barnes, M., 2001, "Stresses in Solenoids," J. Appl. Phys., 48(5), pp. 2000–2008.
[3] Jones, J., 2000, Contact Mechanics, Cambridge University Press, Cambridge, UK, Chap. 6.
[4] Lee, Y., Korpela, S. A., and Horne, R. N., 1982, "Structure of Multi-Cellular Natural Convection in a Tall Vertical Annulus," Proc. 7th International Heat Transfer Conference, U. Grigul et al., eds., Hemisphere, Washington, DC, 2, pp. 221–226.
[5] Hashish, M., 2000, "600 MPa Waterjet Technology Development," High Pressure Technology, PVP-Vol. 406, pp. 135-140.
[6] Watson, D. W., 1997, "Thermodynamic Analysis," ASME Paper No. 97-GT-288.
[7] Tung, C. Y., 1982, "Evaporative Heat Transfer in the Contact Line of a Mixture," Ph.D. thesis, Rensselaer Polytechnic Institute, Troy, NY.
[8] Kwon, O. K., and Pletcher, R. H., 1981, "Prediction of the Incompressible Flow Over A Rearward-Facing Step," Technical Report No. HTL-26, CFD-4, Iowa State Univ., Ames, IA.
[9] Smith, R., 2002, "Conformal Lubricated Contact of Cylindrical Surfaces Involved in a Non-Steady Motion," Ph.D. thesis, http://www.cas.phys.unm.edu/rsmith/homepage.html