Guide to Writing Laboratory Reports

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The presentation of laboratory data should be concise and well–organized. This document provides guidance for the preparation of formal laboratory reports for some Civil and Mechanical Engineering courses.

Motivation

The motivation for the preparation of a technical report is the presentation of technical information along with the authors' interpretation of this information. To be persuasive, the report must present a sufficient amount of information (in ways that are easily understood by the audience of the report) in a logical and organized fashion. The presentation should be organized so that the data speaks for itself – that is, the voice of the author is that of a narrator communicating the data transparently to the reader. Only in the interpretation of the data and in the drawing of conclusions do the author's analysis and opinion get expressed.

Format and Style

This document provides a concise summary of good practices to follow in the preparation of technical reports. Format concerns the organization and appearance of the document. While various formats are in use, some conventions are widely accepted and should be followed. Style comprises the structure, language, and use of illustrations. Style is addressed more generally by other references; some points of style as they pertain to the presentation of technical data are addressed herein.

Organization

The basic standard for technical writing is that sufficient information must be presented to allow a competent person to reproduce the experiments and analyses described and to understand any assumptions and assertions that were made. This requires that any assumptions made in the conduct of the work be stated explicitly. A general scheme for organizing a laboratory report is as follows: Title, Abstract, Introduction, Experimental Procedures, Results, Discussion, Conclusions, Acknowledgments, References, and Appendices. In general, your reports should be structured in the fashion detailed below. The actual length of individual sections will vary depending on the particular experiment.

Title

The title concisely conveys the subject of the report. It should include key words relevant to the experiment. If the experiment involves a particular material, the material should be referenced in the title. Do not use symbols or abbreviations. The title should be no more than approximately fifteen words. Include your name, the course name, date, and the names of the other members of your lab group.

Abstract

The abstract provides a brief synopsis of the background, objective, observed behavior, and conclusions reached. Provide key quantitative data when available. Do not use references or refer to figures; include only information provided elsewhere in the report. Avoid abbreviations. The abstract should be less than 250 words. Chronologically, the abstract is typically written last.

Introduction

The introduction identifies the topic of the report, the motivation for doing the work, the specific objectives of the study, and the scope of the study. Relevant background material needed to understand the work should be presented in this section, unless it is so voluminous as to merit its presentation in a separate section that follows the introduction. The background may include theoretical predictions of anticipated results and a summary of previously published papers on the topic (a highly focused literature review). The introduction should not be a restatement of the lab handout, and the lab handout should not be cited as a reference. The introduction is typically one to two pages in length, but the actual length will vary depending on the particular experiment.

Experimental Procedures

The experimental procedures section describes the materials examined, any processing of the materials, how the experiments were performed, the equipment used, and how the data was analyzed. The narrative description may refer to standard test procedures (e.g. a specific ASTM test procedure) or should describe the main steps, noting any deviations from standard procedures or any special or unusual steps in detail, so that the reader has sufficient information to replicate the experiment. Do not use excessive detail here; for example, do not write “Safety glasses were worn” or “Data was acquired with a computer.” Write the procedures section in the past tense and in paragraph form. Do not number the steps of the procedure. Do not say “next” or “then.”

Results

In this section, describe in detail the results of the study including the equations used to calculate the results. The results usually include figures and/or tables. Figures may present graphs, photographs, and drawings. The text of this section and the figures and tables should complement each other, but must contain enough information to stand independently. Text for this section must be in paragraph form; captions alone are not sufficient. Discussion of the results may be interwoven with the results or may be made in a section following the results, depending on whether the discussion of one result is needed to understand a subsequent result or if the results can be discussed as a whole after their presentation. The results section must portray the actual results with a minimum of judgment or interpretation; let the facts speak for themselves. Any surprising results should be identified here or explained in a discussion section.

To organize the presentation of results, first decide upon a logical flow for presenting the information. Once this is determined, decide how the information will best be presented using tables and figures. The requisite tables and figures with their associated captions can then be created. As a last step, write the text that refers to these

tables and figures. Well–designed tables and figures will convey the essence of the report; the text should provide the narrative that explains what is contained in the tables and figures and their significance. To reiterate this critical point, every figure and table should be sufficient to stand alone (be fully understood from the caption and data), but every figure and table must also be explained in the text of the report. When referring to the figures in the text of the report, refer to the figures by number, e.g., Figure 1.

Decide whether a particular dataset is best presented in a table or plotted as a graph. Plots are useful for identifying trends and comparing the performance of different specimens. Tables are useful for concisely presenting numerical data, which if presented in paragraph form would be difficult to follow. The details of the formatting and presentation of tables and figures are discussed in the Appendices.

Discussion

The interpretation and significance of the results is developed in this section. In the effort to understand the data, further analysis of the results is presented and speculative and subjective statements may be made. The discussion may be organized topically. The success or failure of the experiment should be evaluated with regard to the objectives. In this section, suggestions for modifications to improve the experiment in the future should be made, and questions specifically asked in the lab handout should be addressed. Unexpected behavior should be discussed, particularly in the context of other published data. Potential sources of error may be identified if appropriate. Note that sources of error do not include "operator error" or "faulty equipment." In order for this type of scientific data to be publicly presented, the author must be confident that the experiments were performed competently. An example of a source of error that might be pertinent in some circumstances is drift of electronics due to temperature fluctuations.

Conclusions

The conclusions section briefly summarizes the basic results and conclusions of the study in about one–half page. Each conclusion stated in this section must be supported by the data, analysis, and discussion of the preceding sections. No new information should be presented in the conclusions. Do not refer to specific figures or tables in the conclusions.

Acknowledgments

Credit should be given to the people and institutions that contributed to the success of the work, but are not listed as authors. This could include, but not be limited to, individuals and organizations that provided funding, materials, special support services, and/or professional expertise. For example, W.J. Wright acknowledges J.C. Doan for assistance in formulating an early version of her contributions to this document.

References

References should be made in the text to external sources of information or ideas. Doing so demonstrates your awareness of the contributions of others to the scholarly community of which you are a member. Additionally, provide the citation in the main body of the text immediately after the reference information is presented or an observation or conclusion attributed to others is quoted or paraphrased. Reference citations in the main body of the report should follow these guidelines:

Number of Authors	In–text Citation Format
1	(Smith, 1998)
2	(Smith and Jones, 2003)
3 or more	(Smith, *et al.*, 2002)

This parenthetical citation information should appear within the sentence in which the external information is presented. If there are two or more references with the same set of authors and these references were all published during the same year, the individual references should be distinguished by an alphabetical suffix (i.e., Smith and Jones, 2002a; Smith and Jones, 2002b; etc.) All references made in the main body of the text must also be listed in the References section presented in alphabetical order by the last names of the first author.

You must list the references you have used, including the author, title, journal, volume, number, page numbers (if appropriate), and year. Plagiarism is never tolerated. Avoid using references to web pages. If such a reference is critical, be sure the source is reputable. References to Wikipedia are not acceptable. A highly recommended search engine for locating references is Web of Science (http://www.isiknowledge.com). Many good sources of information on technical writing are available and were used to prepare this document (Alley, 1996).

Appendices

Material that is useful but not required for the presentation and interpretation of the data may be put in one or more appendices. The appendices allow the main body of the report to be concise. Examples include lengthy derivations, elaborations of concepts of secondary importance, and information included for archival purposes. Do not weigh the report down unnecessarily with appendices; do not submit all sheets of paper prepared by lab team members or lengthy printouts of EXCEL spreadsheets containing all of the data. Rather, provide only material that gives special insight, but which is not provided in the main body of the report. Any material provided in an appendix should be referred to in the main body of the report. Additional guidelines for formatting, figures and tables, number use and precision, style, and reference formatting are provided in Appendices 1–5 of this document, respectively.

Appendix 1: Some Additional Guidelines for Formatting

1. The report should be formatted in one column and a 12–point font with 1.5 line spacing and 1 inch margins on all sides.
2. If using a monospaced font such as Courier, there should be two blank spaces after a period at the end of a sentence; otherwise, use a single black space after a period at the end of a sentence.
3. Label each section accordingly (except for the title page).
4. Number the pages.
5. Whenever possible, make sizes, formatting, and fonts of figures consistent.
6. Number figures and tables separately.
7. Incorporate your figures and tables into the text. Do not simply attach them to the end of your report.
8. When referring to the figures in the text of the report, refer to the figures by number, e.g., Figure 1.
9. The report may need to include equations to adequately describe pertinent theory (in the Introduction) or techniques used in data processing or data analysis (in the Results or Discussion). Place equations on lines separated from the text, and number equations separately in parentheses at the right margin. Equations, such as Equation 1 below, can be produced in Microsoft WORD using the Insert → Object → Microsoft Equation command sequence. Note that this requires that Microsoft EQUATION be selected as an option when the program is installed. As an example, the engineering strain e may be defined as

$$e = \frac{\Delta}{L}, \tag{1}$$

where Δ is the displacement and L is the length of the specimen. Note that the definition of each symbol is made in a sentence, not as a list. Equations should be numbered, and all terms used in the equation must be explicitly defined as illustrated by the previous sentence. Greek symbols can be produced using the Symbol font. Variables are typically denoted by italics. Punctuate an equation as part of the sentence in which it is presented. For example, if the equation ends a sentence, place a period immediately following the equation.
10. Do not report the magnification of images since magnification is easily altered during imaging processing. Use calibrated scale markers instead.

Appendix 2: Some Additional Guidelines for Figures and Tables

1. Each figure and table requires a caption. The caption for a figure appears below the figure. The caption for a table appears above the table. Give complete descriptions in the captions. For example, "True stress versus true strain for cartridge brass as a function of annealing temperature" is a good caption. "Stress vs. Strain" is insufficient.
2. Remember every figure and table should be sufficient to stand alone (be fully understood from the caption and data), but every figure and table must also be explained in the text of the report.
3. Figures and tables should be referred to in the text before they first appear.
4. Tables are numbered consecutively and should appear with a caption above the table. Table 1 illustrates this. Table 1 is clearly organized, has clear labels (with units where appropriate), and is easily understood. Tables can be produced in Microsoft WORD using the Table ⟶ Insert command sequence. Tables and their captions should be centered horizontally on the page. While the caption should be centered on the page, it should also be left justified if it consists of multiple lines of text. Place a period at the end of each caption.

Table 1: The ultimate tensile strengths of five samples of as–rolled 1020 steel tested to failure.

Sample	Ultimate Tensile Strength (MPa)
1	410
2	422
3	417
Mean	**416**
Standard Deviation	**6.0**

5. Figures are numbered sequentially and may present photographs, drawings, and plots. Figures and their captions should be centered horizontally on the page. For example, Figure 1 (shown on page 7) is a plot of true stress versus true strain for uniaxial compression of Ti–6Al–4V and pure aluminum. The titanium alloy has a much higher yield stress and a larger strain to failure. Descriptive, summary statements such as the last one are necessary to ensure that the reader understands the plots correctly. Other noteworthy features of the plot in Figure 1 are outlined below.

- The abscissa (horizontal axis) and ordinate (vertical axis) both have titles, with appropriate units indicated. Always provide the units on the axes labels in parentheses and be consistent (note that strain is unitless). Use the most relevant unit of measure. For example, if you measure stresses up to 200×10^6 Pa, label the axes in MPa.
- A legend should be provided to allow multiple data series to be identified. If only one data series is plotted, a legend should not be used; the caption is sufficient. In EXCEL, specifically name each data series. The default "Series 1," "Series 2" labels are not adequate descriptors.

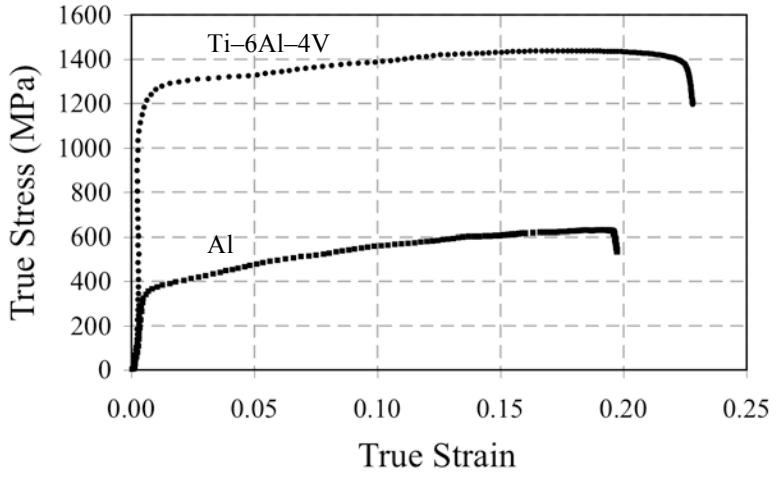

Figure 1. True stress versus true strain for Ti–6Al–4V and pure aluminum in uniaxial compression.

- At times, it may be appropriate to label the data series rather than use a legend. This point is illustrated in Figure 1. The two data series are labeled with text boxes rather than using a legend. This is particularly helpful when it may be difficult to distinguish between data sets according to the symbol data markers (e.g. circle versus square markers in Figure 1.)
- The typical EXCEL plot to be used is an XY Scatter Plot, rather than some other type such as a Line Plot (which plots Y values at regular intervals on the abscissa).
- Within EXCEL, to allow the data to be seen clearly and to eliminate distractions, format the plot as follows:
    - Turn on gridlines for both axes, and set the line type for the grid to a dashed line that is 50% gray, not black.
    - Format the plot area to have no color, instead of the default gray.
    - Format the chart area to have no border.
    - Have the abscissa and ordinate lines (and labels) located at the bottom and left edges of the plot, respectively, rather than having them run through the data. Pick suitable limits and intervals for each axis scale. This will often require manually selecting the plotting range in EXCEL. The plotting range in all coordinate directions should exceed the maximum plotted data values by approximately 10 to 20 percent. Also avoid the temptation to truncate the vertical axis unless you clearly specify that you have done so in the figure caption. Shifting the origin from zero along the ordinate axis causes trends to appear more dramatic than they actually are.
    - If EXCEL is used to plot data, to avoid having large file sizes, copy the plot from EXCEL using the Edit $\rightarrow$ Paste Special $\rightarrow$ Picture command sequence.
- If Microsoft WORD is used to produce the report, a convenient trick to place figures in the report is to insert a new table (1 column by 2 rows), change the borders to not print, and use the preceding command sequence to paste the plot into the first row of the table. The caption for the figure is written in the second row of the table. An alternative is to display the plot on the screen, hit the “Print Screen” key, then place the cursor in the

document where you wish the image to appear, and insert using Ctrl–V. Using this approach requires that the image be cropped on all four sides using the "Format Object" command, available by right clicking the inserted image.

6. Make the figures in documents and reports physically large enough to show sufficient resolution for readers to see and understand the data being presented but not excessively large so as to just help meet some specified document length requirement.
7. You should only use a curve fit that is based on known behavior. For example, use a linear fit to calculate the elastic modulus of a material based on a stress–strain curve. Do not use a spline fit to simply draw a curve through all of the data points. Such a fit does not have a scientific basis and should not be used.
8. Curve fits are always shown as solid lines. Data is shown as discrete points. Sometimes when large amounts of data have been acquired, the data appears as a solid line even though the points are actually discrete. This is acceptable. The size of the symbols may be reduced to improve clarity.
9. When curve fits have been made, display the equation on the graph in the appropriate form. The last two points regarding curve fits are illustrated in Figure 2. Notice that the curve fit equation has been modified to use "τ" and "γ" not "*x*" and "*y*."

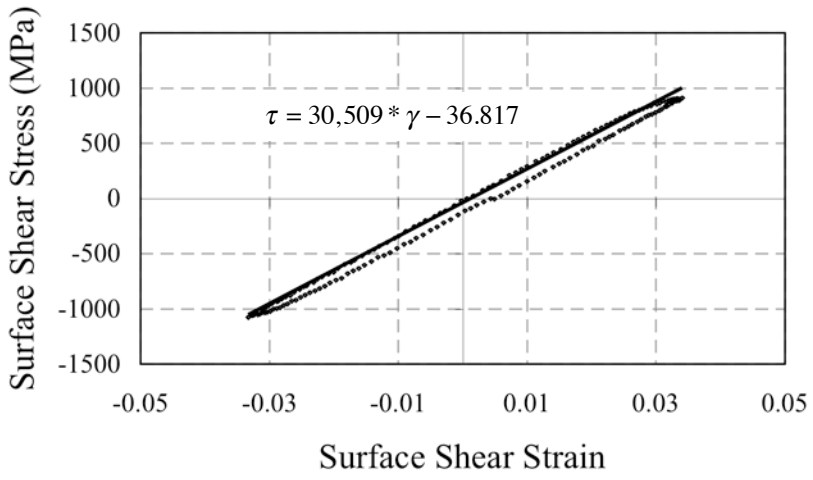

Figure 2. Surface shear stress versus surface shear strain for a Zr alloy tested in shear while subjected to a tensile stress of 920 MPa. The slope of the linear fit is the shear modulus of the material, which is calculated to be 30.5 GPa.

10. Photographs of experimental systems and test specimens may also be used to provide needed detail and documentation. Photographs taken with digital cameras should be modified as needed to include in–photo captions (text boxes) to identify particularly relevant system elements and characteristics.

Appendix 3: Some Additional Guidelines for Number Use and Precision

1. The numbers presented in the text or tables cannot have more precision than the precision of the instrument used to acquire the data. For example, consider three temperature measurements taken over a period of 1 hour using a thermocouple with a digital indicator that reports the temperature to a tenth of a degree: 350.3 K, 354.1 K, and 352.6 K. The average temperature during the one hour period is 352.333 K, but this number should be reported as 352.3 K since the temperature is not known precisely to the one–thousandth of a degree. The standard deviation should be reported with the same precision as the measurement. In this example, the standard deviation is 1.6 K. Note that the standard deviation has the same units as the measurement of interest. In some instances, it may be appropriate to report the uncertainty in the measurement or the accuracy of the instrument when measured against a calibration standard, but, in general, these values are not required in this course.
2. Consider another example. If you are determining grain size using measurements from optical microscopy, you might report an average grain diameter of 5.1 μm, because " 5.145 μm" would imply more precision than can be justified due to the resolution of the instrument, i.e. an optical microscope cannot measure 0.001 μm (or 1 nm) features.
3. Note that when data is acquired digitally, the digital format may have more precision than the instrument that was used to acquire it. The precision should be reduced to match that of the instrument when reported in tables or the text of the report. Ask your lab instructor to specify the precision of each instrument that you use.
4. When converting between units, use all of the significant figures available for the data and the conversion factor. For the purposes of reporting values in tables or in the text of the report, the precision should then be reduced as outlined above.
5. Even if the precision of a value is appropriate, consider whether all of the significant figures carry pertinent information. For example, it is likely that a stress measurement can be made with a precision of 0.1 MPa; however, it is common practice to report measurements rounded to the nearest MPa (61 MPa rather than 61.3 MPa).
6. If a number is less than one and written in decimal form, use a zero before the decimal point, e.g., 0.25 kg, not .25 kg.
7. The sample standard deviation σ is a measure of the variation of a set of values from the mean. It is calculated according to

$$\sigma = \sqrt{\frac{\sum_{n=1}^{N} \left(x_i - \bar{x}\right)^2}{N}}, \tag{A1}$$

   where x_i represents each individual data point numbered from *i* to *N* and $\bar{x}$ is the mean of the data points.
8. Do not start a sentence with a number written in numerical form. In general, write all numbers that precede units as numerals.
9. Use SI prefixes or scientific notation to eliminate unnecessary zeros. Be aware of the appropriate number of significant figures to use when using scientific notation (see 1 above).

10. Where possible, exponents should be shown as superscripted characters (e.g. use 10^3 and not 10^3).
11. There should always be a space between a number and its unit, e.g. 150 mL. The number should not be separated from its unit at the end of a line; this can be ensured in Microsoft WORD by pressing "Option + Space" simultaneously, to produce a space that will keep the words before and after the space together on a single line.
12. Use the most relevant unit of measure and conventional units, e.g. use MPa when reporting stress values and GPa when reporting elastic modulus values.

Appendix 4: Some Additional Guidelines for Style

1. The report should be formal and written in the third person. Do not use "I" or "we."
2. Write the report from the point of view of a professional scientist; i.e., do not refer to "the student," "this lab," or "the instructor."
3. As a general rule of thumb for appropriate verb tense for various sections of the report, use past tense for the procedures section and present tense for other sections. (The procedures were performed in the past; the results and findings continue to exist in the present.)
4. Acronyms should normally only be used after they are spelled out completely the first time they appear in a document. The following sentence is provided as an example of the proper format. "American Society for Testing and Materials (ASTM) procedure D1894–06 was used to determine the static and kinetic friction coefficients for the surface." If many acronyms and abbreviations will be used within a long report, a summary table of such information can be included after the abstract to provide readers with a single, easily locatable reference.
5. The names of elements are not capitalized. The chemical symbols for elements are capitalized. A chemical symbol is not an acronym; therefore, it is not necessary to explain the meaning of a chemical symbol.
6. Use the SI system of units (m, kg, s, N, Pa) unless instructed otherwise. These conventional unit abbreviations do not need to be spelled out the first time they are used.
7. Refer to the figures and tables by number, i.e., do not refer to "the figure below," "the following figure," etc.
8. Aim for brevity; eliminating unneeded words aids the reader.
9. Use words correctly, and once their usage is established, do not substitute other words for the same term.
10. Do not use contractions or slang.
11. Avoid subjective statements (e.g., whether a result is "good" or "bad" depends on the context and perspective of the observer and such language should not be used).
12. Do not refer to the "*y*–axis" or "*x*–axis." Refer to the "ordinate" or "abscissa."
13. A variety of Greek symbols and other special characters can easily be added to a Microsoft WORD document using the Insert $\rightarrow$ Symbols command sequence. These symbols should not be added manually by hand.
14. Do not start sentences with "However."
15. Refer to "materials properties" not "material properties" when addressing the properties of multiple materials.
16. Run–on sentences are serious grammatical errors in formal writing. Run–on sentences are two or more complete clauses that are not separated within a single sentence by a semicolon or a comma and a conjunction. A single comma between two complete clauses is not sufficient to rectify a run–on sentence.
17. The word "affect" is a verb. The word "effect" is almost always a noun.
18. To "lose" is to suffer a loss. To "loose" is a form of "loosen," which is to make less tight.
19. The titles of books and journals should be italicized, not underlined. Underlining is a relic from the use of typewriters.
20. If a descriptive clause in a sentence is critical, use "that" instead of "which." A comma does not precede "that." If a descriptive clause is not critical, use "which." A comma precedes the use of "which."

Appendix 5: Reference Formatting Examples Using the Guidelines Provided by the American Society of Civil Engineers

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Report Checklist

This checklist contains some of the most important guidelines provided in this document for writing technical reports for Civil and Mechanical Engineering courses. After writing your report, you should compare it against this checklist to ensure compliance with the guidelines. (Based on a grading checklist provided by Dr. Fabris)

Overall

a. Written in the third person _____
b. Professional (e.g. no references to "this lab" or "the instructor") _____
c. Logical and clear overall organization of the report _____
d. Logical and clear organization of individual sections _____
e. Logical and coherent presentation of arguments _____
f. Mechanics: grammar, syntax, and punctuation _____
g. Spell check performed _____
h. Clarity of figures and tables _____
i. Completeness in terms of required report components as provided in the lab description _____

Title Page

a. Appropriate title _____
b. Name, course name, group member names, date included _____
c. No more than approximately 15 words _____
d. References a specific material if appropriate _____

Abstract

a. 250 words or less _____
b. States the purpose of the experiment _____
c. States the experimental methods used _____
d. States the primary results *quantitatively* if appropriate _____
e. States the conclusions succinctly _____
f. Stands alone _____
g. No abbreviations used _____

Introduction

a. States the goals of the experiment _____
b. Concise presentation of key scientific concepts _____
c. References literature _____
d. Does not reference the lab handout _____

Experimental Procedures

a. Accurate and complete description of experimental method _____
b. Written in paragraph form and not as a list of instructions _____
c. Appropriate level of detail in description of experimental method _____
d. Past verb tense is used for this section _____

Experimental Results

a. Required figures and tables presented _____
b. Text in paragraph form (in addition to captions for figures and tables) describes the results _____
c. Text and figures contain enough information to stand independently _____
d. Captions are detailed _____
e. Appropriate precision for the results _____
f. Figures appropriately formatted (no gray background, axes labeled with units, legend or labels for multiple data series) _____

Discussion

a. Detailed data analysis _____
b. Evaluation of error sources if appropriate _____
c. Draws key technical conclusions _____
d. Questions asked in the lab handout are answered _____

Conclusions

a. Precise and concise _____
b. Consistent with prior sections _____
c. No new information is presented _____
d. Tables and figures are not referenced _____

Acknowledgements

a. Appropriate credit given to others _____

References

a. Appropriate use of references _____
b. Thorough use of references _____
c. Consistent formatting of references _____
d. Use of reputable sources (no Wikipedia citations) _____

Appendices

a. Appendices are referred to in the main body of the report _____
b. Appendices provide pertinent information that gives special insight _____

Formatting and Style Details

a. One column in 12–point font with 1.5 inch line spacing and 1 inch margins _____
b. Pages are numbered _____
c. Figures and tables are numbered separately _____
d. Figures and tables are incorporated into the text _____
e. All symbols are defined _____
f. Equations are numbered _____
g. Each figure and table has a caption _____
h. SI units used _____