EGME 308 Group Project
Design of a telescopic radio antenna

Checkpoint #1:
Design for stress under static conditions

California State University, Fullerton

Fall 2021

Due: Wednesday, October 13, 2021

Project overview

An electronics manufacturer is developing a custom portable AM/FM radio for one of its clients. Your team is one of several teams working on the telescopic antenna, which will serve as the FM signal receiver. Figure 1 shows a schematic diagram of the antenna, as well as an enlarged view of the cross-section. The antenna is a quarter-wave whip, which consists of several interconnected metal segments. The segments are hollow circular tubes that fit inside each other when the antenna is fully retracted. In general, let the length of the antenna be L when fully extended, let N be the number of segments (Figure 1 shows $N = 4$ segments, but N can in principle be any positive integer), and let the tube wall thickness of each segment be h. For the sake of simplicity, let us agree that each segment will have the same length (L/N) and the same thickness h, and that the segments will fit together snugly, as shown in Figure 1. We will ignore the hollow part of the very last segment, which is negligible.

Competition

Your supervisor wants each team to work independently and generate a different design. The team that delivers the best final design (the lightest and least expensive design satisfying the design requirements) will receive a substantial raise, and their design will be used. To simulate this, at the end of the semester, all teams will pitch their designs during the Group Presentation, after the Final Report is due. The one team out of the entire class that delivers the single best final design (again, the lightest and least expensive design satisfying the design requirements) will receive a +10 point bonus on top of their final score in the course.

NOTE: The likelihood of two teams independently submitting identical designs is nil. It is in your team's best interest to keep your work confidential. You do NOT want another team to steal your design, improve on it, and get the bonus instead of you!

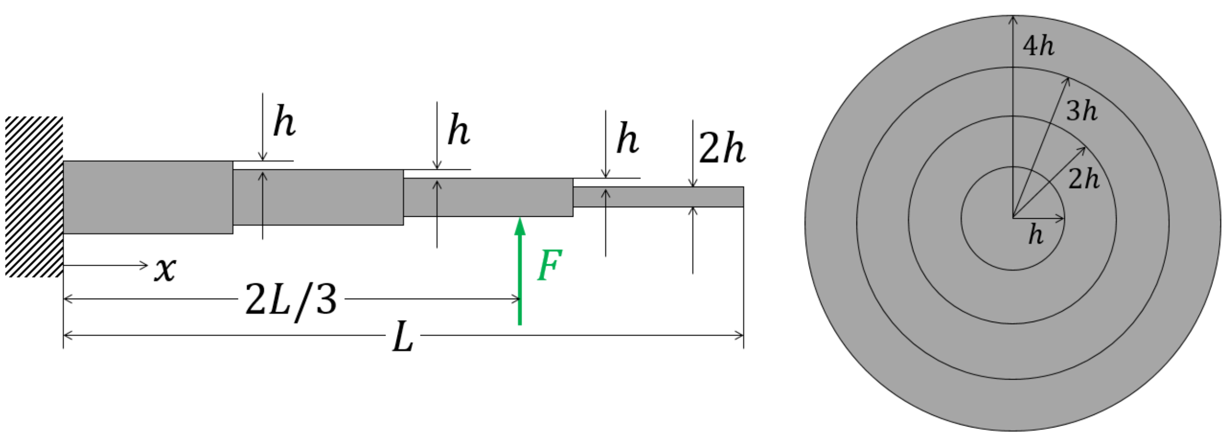

Figure 1: Schematic diagram of the antenna.

Checkpoint #1: Design for stress under static conditions

The first step in the process—and your goal for Checkpoint #1—is to design the material and geometry of the antenna (specifically, L, N, and h) to ensure functionality without material failure under given conditions. In particular, the antenna must satisfy the following design requirements:

- When fully extended, the antenna must be long enough to pick up FM radio signals.
- When completely retracted, the length of the antenna must not exceed 15 cm.
- The maximum diameter of the antenna must not exceed 1 cm.
- When fully extended, the antenna must be able to withstand a static, concentrated test force F, equal to 10 times the antenna's weight, applied transversely at a distance of two-thirds the fully extended length ($2L/3$) from the fixed base, as shown in Figure 1. Under said loading conditions, the following requirement(s) apply:
  - The maximum normal stress within the segments must not exceed the yield stress of the material, with a safety factor of at least 1.2.
- The antenna should be as light and inexpensive as possible, while meeting all of the above requirements.

Tasks

The following tasks are required for Checkpoint #1:

(a) Radio waves, like visible light, are a form of electromagnetic radiation, which is characterized by its frequency. Research the frequency range for FM radio signals. Be sure to use only reputable sources, such as peer-reviewed scientific journal articles and professional society standards. Note that websites are generally *not* considered reputable sources, because they are not peer-reviewed (the only exception to this rule would be commercial websites used for pricing purposes).

(b) The wavelength λ and frequency f of an electromagnetic wave are related by the following equation:

$$\lambda f = v, \tag{1}$$

where v is the speed of light in a vacuum. Based on the frequency range you found in part (a), determine a range for the wavelength of an FM radio signal.

(c) This is a quarter-wave antenna, so the length of the fully extended antenna needs to be about one-quarter the wavelength of the signal it is trying to pick up. Based on the wavelength range you found in part (b), determine an admissible range for the length L of the antenna. Even though you have now determined a range for L, do not select a particular value yet. Until further notice, work in terms of an arbitrary length L.

(d) Mechanically, we will model the antenna as a cantilever beam (one end fixed/clamped, the other end free) under transverse loading. Sketch the free-body, shear-force, and bending-moment diagrams for the antenna under the loading conditions shown in Figure 1. Recall that the applied force F is a concentrated force. (Note that these diagrams do not depend on the number of segments N in the antenna.)

(e) Derive a symbolic formula for the bending moment $M(x)$ by solving the following equation,

$$M''(x) = w(x), \tag{2}$$

subject to appropriate boundary conditions, using the Laplace transform technique. Here $w(x)$ is the transverse force per unit length applied to the antenna as a function of x (the applied force F is a concentrated force, so model $w(x)$ accordingly). For the purposes of this assignment, you may take this equation as given.[1] However, you must show the details of your solution for $M(x)$—you may not simply look up the solution in a reference book. Express your solution for $M(x)$ symbolically in terms of L, F, and any special functions (like Heaviside or Dirac) required. Sketch your solution for $M(x)$ versus x. Does your symbolic solution agree with the bending moment diagram you sketched earlier in part (d)?

(f) The maximum normal stress at any point x along the length of the antenna is given by

$$\sigma(x) = \frac{|M(x)|c(x)}{I(x)}, \tag{3}$$

where $|M(x)|$ is the absolute bending moment at that point, $c(x)$ is the maximum vertical distance from the neutral surface within the cross-section at that point, and $I(x)$ is the second moment of area of the cross-section at that point.[2] For an annular cross-section of inner radius r_i and outer radius r_o, as shown in Figure 2, I is given by

$$I = \frac{\pi}{4}(r_o^4 - r_i^4), \tag{4}$$

and c is given by

$$c = r_o. \tag{5}$$

A solid circular cross-section can be considered an annulus of inner radius zero.

Note that because the cross-section varies along the length of the antenna, so do c and I. Sketch what $c(x)$ versus x and $I(x)$ versus x would look like for arbitrary L, N, and h. Express $c(x)$ and $I(x)$ symbolically in terms of the Heaviside step function for arbitrary L, N, and h.

(g) Write a Matlab code or an Excel spreadsheet that plots the relevant graphs (i.e., shear-force and bending moment diagrams, $c(x)$ versus x, $I(x)$ versus x, and $\sigma(x)$ versus x) for arbitrary system parameters. You will need to include a computation of the total

[1] If you are curious, you can find the derivation of this equation in any statics or strength-of-materials textbook. You are not required to include the derivation of this equation in this assignment.

[2] If you are curious, you can find the derivation of this formula in any strength-of-materials textbook. You are not required to include the derivation of this equation in this assignment.

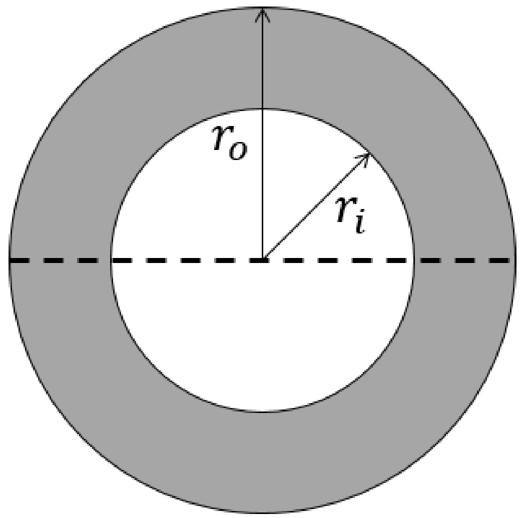

Figure 2: A circular annulus of inner radius r_i and outer radius r_o.

mass of the antenna. This determines the total weight of the antenna, and therefore the magnitude of the test force F (which is 10 times the weight). The code may seem like a lot of work at first, but it will actually save you substantial time in the long run when you need to modify your design at will.

(h) Choose a specific material and specific geometry (L, N, h) for the antenna that satisfy the design requirements.

(i) From your plot of $\sigma(x)$ versus x, identify the single greatest normal stress $|\sigma|_{\max}$ along the entire length of the antenna, and the point at which that stress occurs.

(j) The factor of safety (aka safety factor) is given by

$$SF = \frac{\sigma_Y}{|\sigma|_{\max}}, \tag{6}$$

where σ_Y is the yield strength of the material. Add code to compute the associated safety factor for your design. Does the safety factor exceed the value specified in the design requirements?

(k) If necessary, modify your design until it satisfies all of the design requirements. This may require many iterations, which is why it is better to perform your analysis and write your code for arbitrary system parameters rather than specific parameter values. If you have written the code well, modifying your design should be as simple as changing the parameter values at the very beginning of the code and running it again.

(l) Once you have arrived at a final design that satisfies all of the requirements, estimate the cost of the raw material required to construct your antenna.

(m) Complete the Design Specifications Form (located on Canvas in Word format).

(n) After you write the report (see below), complete the Authorship Declaration Form (located on Canvas in Word format).

(o) Each member of your group must complete a Peer Evaluation Form (located on Canvas in Word format). You will submit the Peer Evaluation Forms individually and confidentially, separate from the report. Missing Peer Evaluation Forms will be treated as reporting the lowest amount of participation across the board, for all team members.

(p) Document your work in a formal, typeset (not handwritten) report with the following sections:

1. *Title page* A title page with the title of your report, your team number, and a list of all team members in alphabetical order by last name.
2. *Abstract* A concise summary of the entire report in a single paragraph, written for a layperson (non-engineer). A layperson should be able to read the Abstract and glean all of the important information from the report without any technical details. Important information includes everything on the Design Specifications Form. You should not start writing the Abstract until all of the other sections have been written. The Abstract will seem redundant—it is supposed to be.
3. *Introduction* A discussion of the problem, and a review of the relevant background required for subsequent sections. Include a discussion of the frequency/wavelength range for FM radio signals, citing the (reputable) sources you found.
4. *Design* A detailed description of your design. This section should contain all the information needed for the manufacturing company to create your antenna, including all of the geometric and material parameters listed on the Design Specifications Form. Also include a detailed CAD drawing of your antenna, with all dimensions labeled.
5. *Static stress analysis* A step-by-step derivation of your stress analysis, presented in a logical and coherent manner. Include exact free-body, shear-force, and bending-moment diagrams for your antenna, your symbolic derivation of $M(x)$ using the Laplace transform technique, exact plots of $c(x)$, $I(x)$, and $\sigma(x)$ versus x, and exact numerical values for the maximum normal stress and the associated safety factor for your antenna. While this section will include plenty of equations, it is NOT simply a sequence of equations: you must incorporate the equations into a narrative. A good rule of thumb is to write as if the reader were not familiar with the material, but you should also avoid being pedantic with the reader.
6. *Cost* An estimate of the cost of the raw material required to construct the antenna. This should include the exact value of the total mass of the antenna.
7. *Conclusion* A concise summary of the report, highlighting the bottom line: your design, its performance, and its cost. Include all information contained in the Design Specifications Form. Also include a discussion of the merits of your design, as well as possible problems, issues, and areas for improvement (consider the inherent assumptions in your analysis and in choosing your design). The Conclusion is different from the Abstract in that the Conclusion is written for someone who has

just read the entire report, while the Abstract is written for someone who does not have the time or expertise to read the entire report.

8. *References* You must cite all external references you consulted during the course of your work, in IEEE format. References should be cited appropriately throughout the text.
9. *Appendix A* Include your Design Specifications Form as Appendix A.
10. *Appendix B* Include your Authorship Declaration Form as Appendix B.
11. *Appendix C* Include the code used to generate results as Appendix C. If there is more than one code, give each code a separate appendix, continuing with Appendix D, Appendix E, etc.

There is no length requirement for the report: it should be as long as it needs to be to convey all of the necessary information, and no longer. Tables and figures should be numbered, captioned, and referenced appropriately (table captions go *above* the corresponding tables, while figure captions go *below* the corresponding figures). Equations should be numbered sequentially, with the labels right-justified in parentheses. See the "Helpful Hints for Technical Writing" guide for more tips. Reports written in LaTeXwill receive a 5% bonus.

Grading

As stated in the course syllabus, your report will be scored on a standards-based grading scale. The standards-based grading scale corresponds to the following levels of competency:

4	A	Mastery of the material needed for subsequent courses and engineering practice.
3	B	Proficiency in the material needed for subsequent courses and engineering practice.
2	C	Bare minimum proficiency needed for subsequent courses.
1	D	Insufficient proficiency for engineering practice.
0	F	Insufficient proficiency for subsequent courses or engineering practice.

Each group will be assigned a baseline score of 0, 1, 2, 3, or 4. Each individual team member will receive the baseline score scaled by a participation factor $0 \leq p \leq 1$, computed from the average of that member's scores on the Peer Evaluation Form.

Example: Suppose your team's baseline score is 4, and you receive the following scores on the Peer Evaluation Forms: 0, 2, 2, 2, and 4 (you gave yourself the 4 rating). Your average Peer Evaluation Score is 2.0/4.0, which translates to a participation factor of $p = 0.50$. Your individual score for this checkpoint would be $0.50 \times 4 = 2.00$ (C-range).

Example: Suppose your team's baseline score is 4, and no one turns in a Peer Evaluation Form. Each missing Peer Evaluation Form is treated as reporting 0 for all team members. Your average Peer Evaluation Score is 0.0/4.0, which translates to a participation factor of $p = 0$. Your individual score for this checkpoint would be $0 \times 4 = 0.00$ (F-range).

Meeting all of the following conditions is sufficient to receive a baseline score of 4:

- A typeset report with all of the requested information in each section.
- All text and figures created using appropriate software; nothing drawn or written by hand.
- A Design Specifications Form with design parameters that do, in fact, satisfy the design requirements.
- All information (including text and figures) is accurate. No false statements, contradictions, logical inconsistencies, logical fallacies, or factual errors anywhere.
- No mathematical or computational errors anywhere.
- No dimensional inconsistencies or naked numbers anywhere.
- No spelling or grammar mistakes anywhere.
- No formatting mistakes anywhere.
- Shear-force and bending-moment diagrams plotted from a symbolic formula using Matlab or Microsoft Excel (no "beam calculators" used).
- Appropriate and reputable references cited for every claim asserted in the report. No websites cited, except possibly for pricing materials.
- No missing information. NOTE: If your report is missing crucial information necessary to assess your work (such as the Design Specifications Form or the Authorship Declaration Form), you will receive a score of 0.
- No academic dishonesty of any kind (including plagiarism, fabrication of results, or any other form of academic dishonesty). NOTE: It is in your team's best interest to monitor each other's work and ensure that no academic dishonesty takes place. If any member of your team commits an act of academic dishonesty, your entire team will receive an automatic F in the course and will be referred to the Office of Student Conduct.

Anything less than the above may result in a baseline score less than 4.

Appendix A: Design Specifications Form

Geometry

Number of segments:		
Length when fully extended:		cm
Length when fully retracted:		cm
Tube wall thickness:		cm
Maximum diameter:		cm

Material

Material name:		
Density:		kg/m^3
Elastic modulus:		GPa
Yield strength:		MPa

Performance

Maximum normal stress under given loading:		MPa
Safety factor under given loading:		

Cost

Mass of antenna:		kg
Cost of raw materials:		USD

Appendix B: Authorship Declaration Form

Section	Contributors	Typeset by	Checked by
Abstract			
Introduction			
Design			
Static stress analysis			
Cost			
Conclusion			
References			

Peer Evaluation Form

Team Number:

Please type the names of all of your group members, including yourself, and rate the degree to which each member fulfilled his or her responsibilities in completing the group project on the following scale:

0	1	2	3	4
Did little or no work				*Did their fair share of work*

These ratings should reflect each individual's level of participation, effort, and sense of responsibility, not their academic ability.

Name	Rating

Comments:

Helpful Hints for Technical Writing

John W. Sanders

Accuracy

In engineering, accuracy is paramount. It can literally make the difference between life and death. Pay attention to the little details. Even things you might consider to be small mistakes or typos, like a single incorrect sign or a misplaced parenthesis, can lead to drastic errors. (A student once came to me exasperated. He had been working on a code for weeks but it wasn't working; the plots and the computations were completely off. We went over his math, and it was all correct. It turned out that the error was not with the math: it was a single misplaced parenthesis in his code. Once he fixed that, the code worked perfectly.) Make sure that you compute everything correctly and accurately. Embrace your inner perfectionist. Even though perfection is unattainable, if you strive for perfection, your work will be of higher quality than if you strive for anything less. If it helps, think of the person you care about most in this world, and imagine that their life depends on the reliability of your design. The same goes for technical writing. Make sure that all information you report is accurate. There should be no false statements, contradictions, logical inconsistencies, logical fallacies, factual errors, mathematical errors, computational errors, dimensional inconsistencies, spelling mistakes, grammar mistakes, formatting mistakes, or typos anywhere. Note that most typesetting software (including Microsoft Word and most LaTeX distributions) has a spelling and grammar check feature.

Dimensions and units

As you know, units are extremely important. Never mix unit systems, like metric (SI) and imperial (US) units. That is what NASA infamously did with the Mars Climate Orbiter and bad things happened (spoiler alert: it crashed). Always choose one system (preferably SI, unless your employer insists on working in imperial units) and work entirely in that system. It is easiest to work in the base units of whatever system you are using, but base units are not always the standard for reporting results (for example, the base unit of stress is the pascal Pa, but most of the time stress is reported in megapascals MPa or gigapascals GPa). In technical writing, put units on every single number that has them. Never, ever leave "naked numbers" (numbers without units). Not only is this the formally correct thing to do, it can also alert you that you have made a mistake if the units of a calculation do not work out. Units should never be italicized or expressed in the form of a fraction. There should always be a space between a number and its units.

NO: $w_0 = \frac{3{,}000}{3} = 1,000$
YES: $w_0 = \frac{3{,}000\ \mathrm{N}}{3\ \mathrm{m}} = 1,000\ \mathrm{N/m}$

NO: $125\frac{kg}{m^3}$
YES: $125\ \mathrm{kg/m^3}$

NO: $u(45)$
YES: either $u(45\ \mathrm{m})$ or, even better, $u(L)$, where $L = 45\ \mathrm{m}$

Symbolic manipulation

Your analysis should always be done symbolically, for arbitrary parameter values. Do not "plug" numbers in for parameters until the very end, after the analysis is complete. Not only does this reduce the likelihood of typos and round-off error, it also eliminates the need to change the analysis if (read: when) your design changes. The same principle applies to technical writing. Leave your written analysis general, expressed in terms of arbitrary, symbolic parameters. Then, when you discuss your results, you can report numerical values for the various parameters. Note that, unlike units, scalar parameters are always italicized. Vectors are represented as unitalicized boldface symbols.

NO: $w(x) = -(1,000\ \mathrm{N/m})H(x - 4.5\ \mathrm{m}) + (1,000\ \mathrm{N/m})H(x - 40.5\ \mathrm{m})$
YES: $w(x) = -w_0 H(x - a) + w_0 H(x - b)$,
where $w_0 = 1,000\ \mathrm{N/m}$, $a = 4.5\ \mathrm{m}$, and $b = 40.5\ \mathrm{m}$

NO: $\mathrm{E} = 200\ GPa$
YES: $E = 200\ \mathrm{GPa}$

NO: $v = 1\hat{\imath} + 2\hat{\jmath} + 3\hat{k}\ \mathrm{m/s}$
YES: $\mathbf{v} = v_x\hat{\imath} + v_y\hat{\jmath} + v_z\hat{k}$,
where $v_x = 1\ \mathrm{m/s}$, $v_y = 2\ \mathrm{m/s}$, and $v_z = 3\ \mathrm{m/s}$

Equations and narrative

When presenting your analysis, you should never simply list one equation after another without explanation. You must incorporate your equations into a narrative, with complete sentences, walking the reader through your work and explaining any symbols that have not appeared before.

For example, instead of simply writing

$$(EIu'')'' = w(x)$$

$$EIu''''(x) = w(x)$$

$$w(x) = -w_0 H(x - a) + w_0 H(x - b)$$

$$EIu''''(x) = -w_0 H(x - a) + w_0 H(x - b)$$

incorporate these equations into a narrative, like this:

"In general, the static Euler-Bernoulli beam equation is given by

$$(EIu'')'' = w(x), \tag{1}$$

where $E = E(x)$ is Young's modulus, $I = I(x)$ is the second moment of area of the cross-section, $u = u(x)$ is the deflection curve, $w(x)$ is the distributed force (the force per unit length) acting on the beam, x is the horizontal distance from the leftmost end of the beam, and a prime denotes a derivative with respect to x: $(\cdot)' = d(\cdot)/dx$. In the special case in which E and I are constant along the length of the beam, the Euler-Bernoulli equation (1) reduces to

$$EIu'''' = w(x). \tag{2}$$

For a uniform downward distributed force w_0 between $x = a$ and $x = b$, we may model $w(x)$ using the Heaviside step function $H(\cdot)$ as follows:

$$w(x) = -w_0 H(x - a) + w_0 H(x - b). \tag{3}$$

Substituting (3) into (2), we have that

$$EIu'''' = -w_0 H(x - a) + w_0 H(x - b). \tag{4}$$

We can solve this equation using the Laplace transform technique."

Notice that each equation is part of the sentence in which it appears, complete with appropriate punctuation (like commas and periods). You should be able to read each sentence aloud, including the equation, and it should be a grammatically correct sentence. Notice also that every equation is labeled sequentially (not by section) with a unique number, and that number right-justified in parentheses (LaTeX does this automatically; Microsoft Word requires effort). Make it easy for the reader to follow your work. A good rule-of-thumb is to write as though the reader is not familiar with the material, but you should also avoid being pedantic with the reader. Always keep the intended audience in mind.

Person

It is generally agreed that first person singular pronouns (I/me/my/mine) and the second person pronouns (you/your/yours) are not appropriate in a formal, technical document, especially when the document has more than one author.[1] Expressing ideas in the third person, sometimes with the aid of the passive voice, is generally preferred, although the "royal we" (we/our) is also acceptable, even for documents with only one author.

NO: I removed the specimen from the testing machine after it had ruptured.
YES: The specimen was removed from the testing machine after it had ruptured.

NO: If you substitute Equation (34) into Equation (23), you get the following.
YES: Substituting Equation (34) into Equation (23) yields the following.

NO: If you evaluate $I(x)$ at $x = L/2$, you will find that...
YES: Evaluating $I(x)$ at $x = L/2$, we find that...

[1] Sometimes an exception to this rule is made for less formal documents, such as textbooks, when the document only has one author.

Scientific number format

When expressing a number in scientific format, always put the decimal point after the first digit and write out the power of 10 explicitly.

NO: $0.00602e26$
YES: 6.02×10^{23}

Figures and tables

All figures, plots, and diagrams should be rendered to-scale using appropriate software. Nothing should be sketched by hand. Like equations, figures and tables should be numbered sequentially (not by section). A figure caption appears *below* the corresponding figure, while a table caption appears *above* the corresponding table.

NO: Figure 3.1 shows the free-body diagram for the beam.
YES: Figure 1 shows the free-body diagram for the beam.

Capitalization and case

Very few words need to be capitalized other than proper names, titles (like Dr. or Prof.), cross-references such as Figure 1, Table 2, and Equation (3), and the first word of a sentence. Resist the urge to capitalize other things, no matter how important they are. For example, terms like "law," "theorem," and "elastic modulus" should never be capitalized.

NO: Newton's Second Law of Motion states that $\mathbf{F} = m\mathbf{a}$.
YES: Newton's second law of motion states that $\mathbf{F} = m\mathbf{a}$.

NO: The Euler-Bernoulli Beam Equation involves the Elastic Modulus.
YES: The Euler-Bernoulli beam equation involves the elastic modulus.

NO: The Divergence Theorem is very useful in the field of Applied Mathematics.
YES: The divergence theorem is very useful in the field of applied mathematics.

Consistency

Be consistent with the symbols, notation, and verb tense that you use throughout the report. Do not use the same symbol for two different quantities in the same report. Conversely, do not use multiple symbols for the same quantity in different sections. This will require coordination among the members of your group. In cases where different sections are written by different group members, at least one person needs to proofread the entire report and make sure that the symbols and notation are consistent (ideally, of course, everyone will do this).