ENGINEERING

McMaster University

Project One – Renewable technology challenge:

Mechanical design of turbine blades in renewable wind technology

ENGINEER 1P13 – Integrated Cornerstone Design Projects

Tutorial 5

Team Tues-36

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Academic Integrity Statement

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

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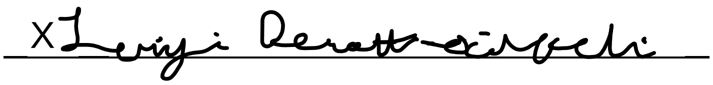

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Finalized Problem statement

The problem scenario requires an eco-friendly device designed for the Swedish Wind Energy Association, to act as an alternative source of power to fossil fuels, so that Sweden can reduce their greenhouse gas emissions to zero by 2045. The device should be an efficient and sustainable mechanism to convert the kinetic energy of the wind into electrical power [1, pg 10-11]. Our finalized problem statement describes a wind turbine blade for the Swedish Wind Energy Association in Sweden that provides power to cities and reduces their carbon emissions. It should have a low environmental impact to produce, efficient, and high yield strength to better harness the energy of the wind. The turbines need a low carbon footprint. It needs to have a deflection value less than 10mm and be able to withstand the pressure load without yielding when experiencing high pressure. [1, pg 8]

Main Body

Justification of Technical Objectives and Material Performance Indices

The objective tree for the "Efficient Wind Turbine" had main objectives as follows: efficient and low environmental impact. Sub-objectives included lowering carbon emissions, strong corrosion resistant material, and lightweight blades (see Figure 1). The decision matrix had criteria CO2 emissions, density, young's modulus, fatigue strength, and cost (weighted most to least), which were chosen as recommended by the project module [1, pg 27]. The MPIs were chosen with primary objective to minimize CO2 footprint and minimize mass, and so the MPIs would therefore be in terms of young's modulus and yield strength by density times CO2, but also only density. These were chosen because the scenario had the main goal of reducing greenhouse gas emissions [1].

Conceptual Design – Justification of Selected Material

Steel was chosen as the best material for several reasons, the first of which being that it was the best material according to the decision matrix, both weighted and unweighted (see Table 1). Additionally, many of the other materials under consideration have critical flaws, making them difficult to use within the constraints of the project. The CFRP epoxy matrix, for instance, has a very high carbon footprint and it would be environmentally damaging to produce, so it would be an unreasonable choice for an eco-friendly objective. Wood is also flawed, as it would be very prone to warping due to moisture or splitting under high stress. It would also be difficult to carve wooden wind turbines blades, because of their physical structure. Steel was also a material that appeared in all the MPI charts showing its versatility and suitability of steel. When analysing other materials such as wood or CFRP it becomes clear that they only excel in one area. CFRP is rated highly under both the mass MPI's but it has little to no presence under the CO2 emissions MPI because of its high CO2 emissions. Wood was the opposite strengths and weaknesses, showing how each of the other materials fail for this specific project, despite both receiving high scores in the decision matrices. Overall, Steel was the best material for the job as it works well in the setting of a wind turbine blade, and it has a low carbon emission. [2]

Design Embodiment – Justification of Solid (CAD) Modelling

Our desired maximum value for the turbine blade was less than but as close as possible to 10 mm. In order find the thickness value that would give us a satisfactory result, we tested four different thickness values: 15 mm, 30 mm, 50 mm, and 150 mm [1, pg 31], which gave values: 14.01 mm, 7.8 mm, 5.37 mm, and 3.54 mm (see Figure 2). The optimal deflection was determined to be between 15 mm – 30 mm. We proceeded to simulate various thickness values in Autodesk Inventor to find our final value, starting from 21 mm. The final thickness was honed to 24.75 mm with a maximum deflection value of 9.92 mm (See Figure 3), satisfying the constrained deflection of less than 10mm [1, pg 8]. [3]

Concluding Remarks

Throughout the course of the project, we've learned to calculate theoretical deflection values using deflection and moment of area formulas [4], as well as how to run stress analysis through Autodesk Inventor yielding values of stress at different points of the blade as well as the resulting displacement [5]. These processes can be applied to other future engineering projects in order to evaluate different scenarios that an object might experience. This would provide important feedback which can be used to alter the design or material of the object, providing a higher quality end result. To conclude, material selection is a vital part of the design process in any engineering project. Some additional engineering considerations that could be worth exploring would include structural design, cost-benefit analysis, and logistics.

Figure 1. Finalized objective tree

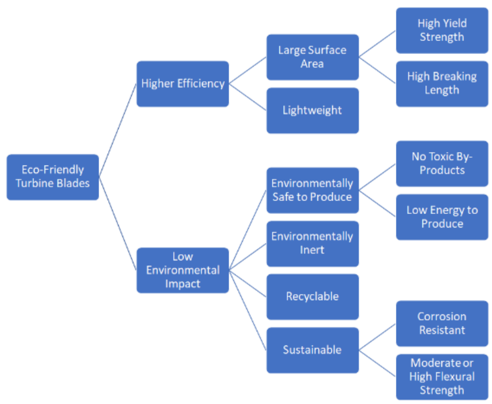


Figure 2. Sample calculation of deflection

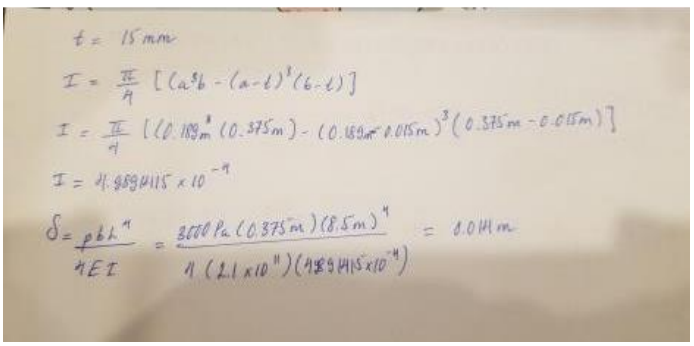


Figure 3. Autodesk Inventor final deflection simulation

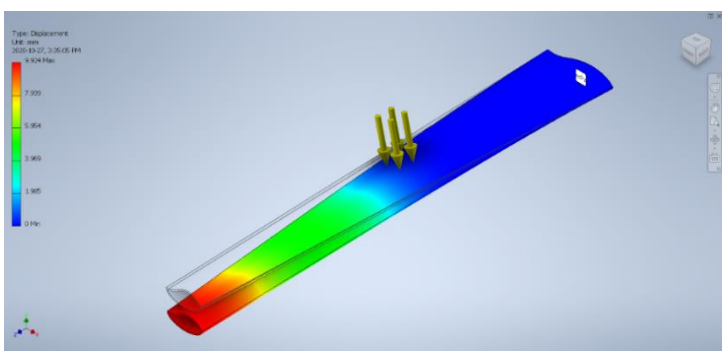


Table 1. Material properties of steel

Young's modulus E (GPa)	210 GPa : 200 - 220 GPa
Yield strength σ_y (MPa)	295 MPa : 255 - 335 MPa
Tensile strength σ_{UTS} (MPa)	456 MPa : 379 - 532 MPa
Density ρ (kg/m^3)	7.81e3 kg/m^3 : 7.8e3 - 7.82e3 kg/m^3
Embodiment Energy H_m (MJ/kg)	30.8 MJ/kg : 29.3 - 32.3 MJ/kg
Specific carbon footprint CO_2 (kg/kg)	2.33 kg/kg : 2.21 - 2.44 kg/kg

Appendix A – Peer learning discussion summary:

The scenario of the design team we interviewed was Renewable Energy for a Large Population. Because their scenario was different from ours, their objectives differed from ours – this main difference was the reason for every following difference (objectives, MPIs, materials, thickness). Despite this, both groups had some top-ranking materials in common such as CFRP and steel. The criteria chosen by both groups were similar, but the weighting of the criteria differed as each group was considering their respective objectives. The other group also ended up having a much larger chosen thickness value for their blade than ours (a thickness of 60 mm, as opposed to our 24 mm). Overall, we can come to the conclusion that there would not be a single solution to multiple design scenarios: there will be a different solution for every problem, although it's possible solutions may have common factors.

Appendix B – References (if necessary):

[1] "P1 Project Module," class notes for ENG 1P13, Department of engineering, McMaster University, Fall, 2020

[2] Ansys Granta EduPack software, Granta Design Limited, Cambridge, UK, 2020 (www.grantadesign.com).

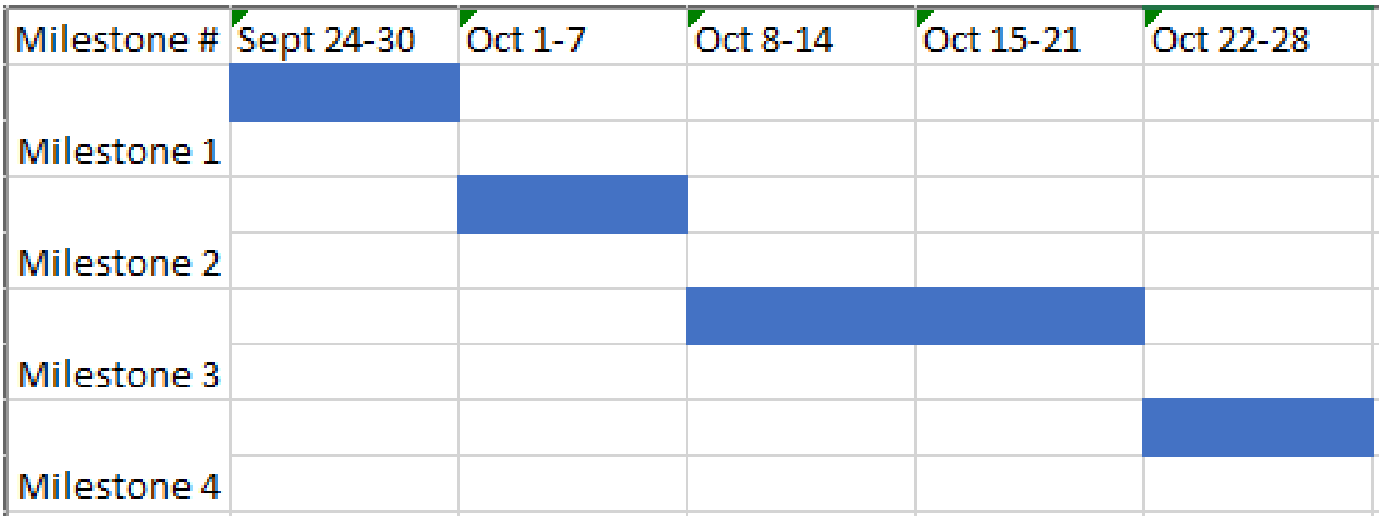
[3] Autodesk® Inventor LT™ software, Autodesk, Inc, 2020 (www.autodesk.com).

[4] "Wk-5 Design Studio (Fall) - P1 Milestone 3B Slides" class notes for ENG 1P13, Department of engineering, McMaster University, Fall, 2020

[5] "Project 1 - Deflection Simulation Tutorial" video tutorial for ENG 1P13, Department of engineering, McMaster University, Fall, 2020

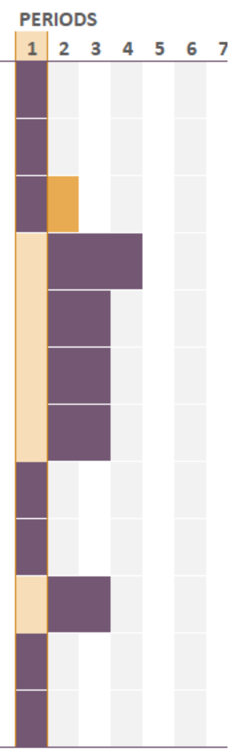
Appendix C – Gantt Chart:

Preliminary Gantt Chart:



Final Gantt Chart:

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Milestone 0(team)	1	1	1	1	100%
Milestone 1(individual)	1	1	1	1	100%
Milestone 1(team)	1	1	1	2	100%
Milestone 2(team)	2	3	2	3	100%
Milestone 3A(individual)	2	2	2	2	100%
Milestone 3A(team)	2	2	2	2	100%
Milestone 3B	2	2	2	2	100%
Milestone 4(individual)	1	1	1	1	100%
Milestone 4(team)	1	1	1	1	100%
Design summary	2	2	2	2	100%
Learning Portfolio	1	1	1	1	100%
Self Peer Evaluation	1	1	1	1	100%



Appendix D – Source Materials Database:

- "P1 Project Module," class notes for ENG 1P13, Department of engineering, McMaster University, Fall, 2020
- Ansys Granta EduPack software, Granta Design Limited, Cambridge, UK, 2020 (www.grantadesign.com).
- R. Lacal-Arántegui, "Materials use in electricity generators in wind turbines - – state-of-the-art and future specifications," Journal of Cleaner Production, Vol. 87. pp. 277, 280, Aug. 2014. Available: https://doi.org/10.1016/j.jclepro.2014.09.047
- E. Hau, Wind Turbines: Fundamentals, Technologies, Application, Economics. New York: Springer Heidelberg, 2013.
- M. Froese, "How are blade materials and manufacturing changing to keep up with larger turbines?," Windpower Engineering & Development, Jan. 4, 2017, [Online]. Available: https://www.windpowerengineering.com/blade-materials-manufacturing-changing-keep-larger-turbines/#:~:text=%E2%80%9CToday's%20turbine%20blades%20and%20components,and%20a%20high%2Dtemperature%20tolerance [Accessed: Sept. 28 2017].
- M. Veljkovic et al., Wind Energy Systems: Optimising Design and Construction for Safe and Reliable Operation. Woodhead Publishing, 2011.
- J. Nicholson, "Design of wind turbine tower and foundation systems: optimization approach," Iowa Research Online, pp. 8-9, May. 2011. Available: https://doi.org/10.17077/etd.bhnu76gr
- "Modulus of elasticity of: Steel, concrete & aluminum," Study.com [Online]. Available: https://study.com/academy/lesson/modulus-of-elasticity-steel-concrete-aluminum.html#:~:text=The%20modulus%20of%20elasticity%20is,69%20GPa%20(10%2C000%2C000%20psi). [Accessed:Sept 28 2020].
- K. Daware, "Basic construction and working of a DC generator, ElectricalEasy," [Online Article]. Available: https://www.electricaleasy.com/2012/12/basic-construction-and-working-of-dc.html [Sept. 27, 2020].
- Energy.gov. 2020. How Do Wind Turbines Work?. [online] Available at: <https://www.energy.gov/eere/wind/how-do-wind-turbines-work> [Accessed 28 September 2020].
- T. Maedam G, Shepers, Wind Energy Systems. Woodhead Publishing, 2011.
- AENews. 2020 What Factors Affect The Output of Wind Turbines?. [online] Available at <http://www.alternative-energy-news.info/what-factors-affect-the-output-of-wind-turbines/> [Accessed 27 September 2020].

- Wind 101 by American Wind Energy Association. Made in USA in 2020. [Online.] Available: http://www.awea.org/faq/wwt_basics.html
- Wind Power Generation and Wind Turbine Design by W. Tong. Made in the USA by WIT Press in 2010. [Online]. Available : https://www.witpress.com/books/978-1-84564-205-1
- Ramakrishnan, V, Chapter 2" Mathematical Modeling of Wind Energy System", Simulation Study of Wind Energy Conversion Systems, Bharath University, http://hdl.handle.net/10603/30.
- Olimpo Anaya-Lara,Nick Jenkins, Janaka Ekanayake, Phill Cartwright, Mike Hughes, Wind Energy Generation: Modeling and Control, 2009 John Wiley & Sons, Ltd.
- Jamieson, P., 2018. Innovation In Wind Turbine Design. 2nd ed. Hoboken: J. Wiley & Sons.
- Miller-Willson, K., n.d. Design Of A Wind Turbine. [online] Greenliving.lovetoknow.com. Available at: <https://greenliving.lovetoknow.com/Design_of_a_Wind_Turbine> [Accessed 29 September 2020].
- Blog.swantonweld.com. 2017. Different Types Of Wind Turbine Towers Made With Steel. [online] Available at: <https://blog.swantonweld.com/steel-wind-turbine-towers> [Accessed 29 September 2020].
- Froese, M., 2017. How Are Blade Materials And Manufacturing Changing To Keep Up With Larger Turbines?. [online] Windpower Engineering & Development. Available at: <https://www.windpowerengineering.com/blade-materials-manufacturing-changing-keep-larger-turbines/> [Accessed 29 September 2020].
- A. S. Darwish and R. Al-Dabbagh, "Wind energy state of the art: present and future technology advancements" Renewable Energy and Environmental Sustainability [Online], vol. 5, no. 7, pp. 1 Apr. 2020. Available: https://www.rees-journal.org/articles/rees/full_html/2020/01/rees190010/rees190010.html#S1
- M. Froese "World's first floating wind farm delivers promising results" Windpower Engineering [Online] Oct. 2018. Available: https://www.windpowerengineering.com/worlds-first-floating-wind-farm-delivers-promising-results/
- "how do wind turbines work?" Renewable Energy Supplier [Online] Available: https://www.goodenergy.co.uk/how-do-wind-turbines-work/
- P. Belton "What happens to all the old wind turbines?" BBC News [Online] 7 Feb. 2020. Available: https://www.bbc.com/news/business-51325101
- https://www.researchgate.net/publication/307614361_The_environmental_impact_of_wind_turbine_blades
- https://www.ewea.org/wind-energy-basics/faq/#:%7E:text=The%20output%20of%20a%20wind,average%20EU%20households%20with%20electricity