ENGINEERING

McMaster University

Project One – Renewable Technology Challenge:

Mechanical design of rooftop wind turbine blades

ENGINEER 1P13 – Integrated Cornerstone Design Projects

Tutorial 15

Team Mon-63

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Submitted: November 8, 2020

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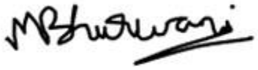

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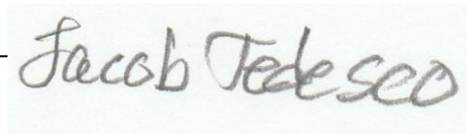

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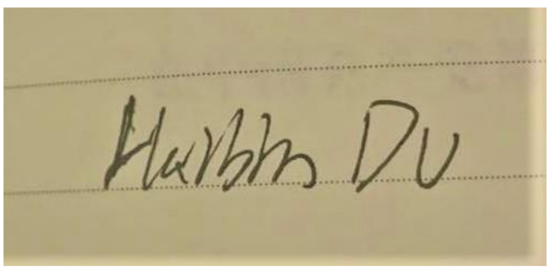


Executive Summary

The purpose of this project was to design a lightweight but durable rooftop turbine blade that is easy and cost effective to produce. For homeowners to see any benefit to using the turbine, the blades aerodynamics should efficiently harness the winds kinetic energy and convert it to mechanical energy while also being easy to replace. The structure of the turbine must be compact and have minimised volume, keeping in mind the closely packed houses. The deflection of the turbine blade under any condition must not exceed 10mm.

Main Body

Justification of Technical Objectives and Material Performance Indices:

For our assigned scenario, an objective tree was created outlining key objectives. The turbine needed to be safe and environment friendly, posing zero threat to wildlife and homeowners. The carbon footprint for manufacturing the turbine would need to be minimized, otherwise it would not fulfil the objective of lowering pollution. In addition, the turbine needed to be installed on a roof, where it is subject to the natural elements. Therefore, it must be sealed and insulated to withstand rain and extreme temperatures, as well as have a low deflection to avoid breaking the blade under high wind speeds. Minimizing cost was our main objective as the goal of our wind turbine was to produce clean energy for homeowners in a cost-effective way. If the turbine cost is higher than the average savings on electricity bills, consumers would not be willing purchase the turbine. To choose a final material for our wind turbine blade, a decision matrix was made to highlight how well the possible materials preformed in terms of their carbon footprint, manufacturing cost, and weather resistance (Refer to *Table 1*). Our MPIs were focused on two main objectives: minimizing cost and minimizing volume, as seen in *Table 2*. Decreasing the volume of the turbine was our secondary objective due to the turbine being placed on the roofs of houses. The blades cannot be overly large to avoid interference with surrounding objects such as trees and powerlines.

Conceptual Design:

One of the most important aspects of the design of a wind turbine blade is the material selection. The material chosen for the rooftop generator needed be able to withstand variable weather conditions and meet the geometrical constraints of the design, including a fixed blade width, length, and height. Most importantly, the material chosen had to meet the design constraint that the deflection could not be more than 10mm. The

MPI's determined earlier were used to produce a list of eligible materials for the blade design, from which 3 materials were chosen to do further research into. Three additional objectives -- reducing carbon footprint, reducing manufacturing cost, and high weather resistance -- were used to further single out the best material. These objectives intended to narrow in on a material that minimizes cost, as well as consider the environmental impact of producing wind turbine blades out of each material. Using the weighted rating system and a decision matrix, it was established that low alloy steel was the best material for this design scenario (Refer to *Table 2*). Low alloy steel met the project objectives because it was cheaper to manufacture than bamboo, it was very strong, and it was not as dense as tungsten. Overall, low alloy steel meets all the functional constraints of this design scenario, including high strength and minimal deflection, and meets all of the project objectives as well.

	Objective	MPI-stiffness	MPI-strength
Primary	Cost	E/pCm	σ_y/pCm
Secondary	Volume	E	σ_y

Decision Matrix							
	Weight factor	*Steel (Low alloy steel)*		*Tungsten Alloy*		*Bamboo*	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Carbon Footprint (Lower being better)	1	3	**3**	1	**1**	5	**5**
Manufacturing Cost	3	5	**15**	1	**3**	3	**9**
Weather Resistance	2	3	**6**	5	**10**	2	**4**
TOTAL		11	**24**	7	**14**	11	**18**

Table 1 and 2. MPI's for Achieving Various Objectives and Weighted Rating System for Top Material Candidates

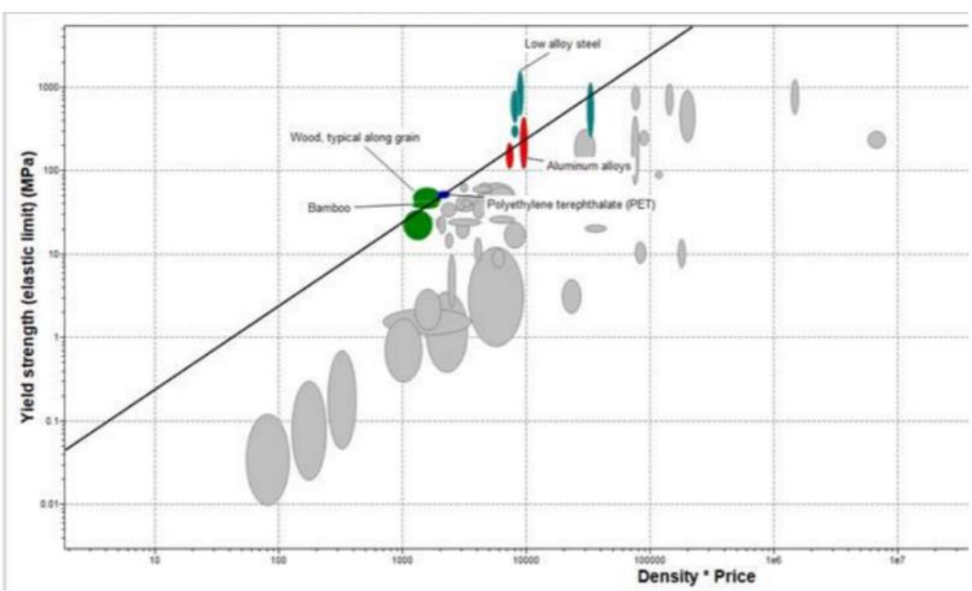
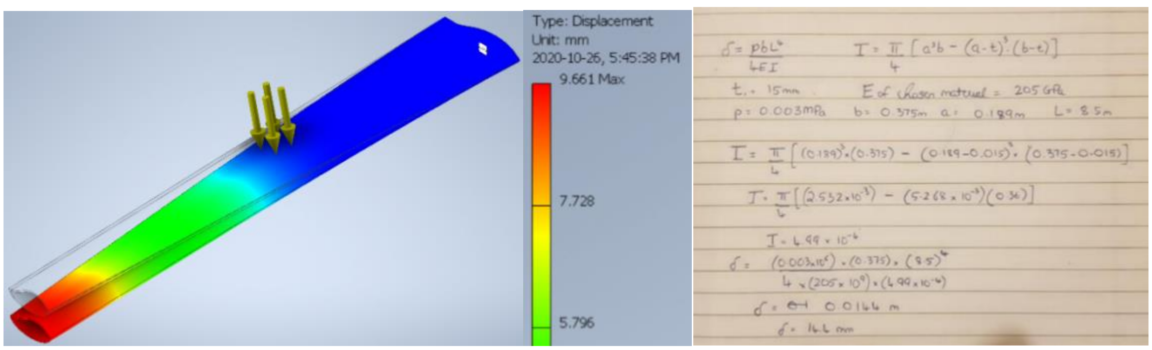


Figure 1. Granta MPI Plot

Design Embodiment:

Using the formulas given as well as several geometric constraints, the deflection of the blade was calculated using a range of thicknesses from 15-150 mm. An example of such calculation can be seen in figure 4. Obtained from these calculations was a range of 15-30 mm for the thickness in order to satisfy the functional constraint that the deflection had to be less than 10mm. Using a model of the turbine blade in AutoCAD and applied pressure from the wind of 0.003 MPa, simulations were conducted to determine what thickness of blade best met this functional constraint. A blade with a thickness of 25mm produced a deflection of 9.661mm, which was within the ideal range for deflection of 8.5-10mm. This can be seen in figures 5 and 6 below.



Figures 2, 3 and 4. Deflection Simulation Screenshots and Sample Deflection Calculation

Concluding Remarks:

After finishing our first project as engineering students, we discovered and learned the bases of how engineers design and choose materials for their projects. It began with brainstorming ideas and creating objective trees, then gradually proceeded to creating CAD models and choosing our final material using GRANTA. Using models and simulations our team gained a good understanding of the importance of the geometric design and the material selection process. The geometrical design resulted in a deflection which had to be in a specified range to ensure the material is not too stiff nor is it too insubstantial. Further design of the wind turbine will need to consider several other design factors as well, including cheap installation methods, turbine positioning on the roof, and adding a weather-proof coating to the turbine blade. Randomized groups gave us the opportunity to meet and work with each other, build connections, and experience what it's like to work in a group were each person has different strengths and weaknesses. This experience will be helpful during future projects, which require us to work as a team on different engineering challenges.

Appendix A – Peer learning discussion summary:

Our meeting with Team Mon-64 gave us insight into how different design scenarios affect the results of the design process. Mon-64's design scenario was the clean energy farm in Sweden. Their primary objectives were to ensure zero emission, produce a high amount of power for multiple cities, and to minimize embodiment energy (amount of energy required to create the material). Surprisingly, both teams ended up identifying 'low alloy steel' as the material that suits all the objectives in the respective scenarios. The mountainous environment in Sweden is subject to harsh weather conditions, including wind, snow, heavy rainfall, and lightning. Hence, for their design scenario, low alloy steel was better suited than bamboo and wood to withstand these conditions. Similarly, our team also eliminated bamboo due to its inability to handle pests and certain weather. One of the major differences in the two teams was the importance of cost as a factor. Cost was not an important factor for their scenario. They were designing a wind turbine for the government which would have lots of money to spare, whereas we were dealing with homeowners for whom cost-effective solutions take a priority. Overall, we found it interesting how similar our results for the project were considering that we had very different design scenarios.

Appendix B – References:

[1] How Does a Wind Turbine Work? (2020). Retrieved October 31, 2020, from https://www.energy.gov/maps/how-does-wind-turbine-work

[2] How Do Wind Turbines Work? (2020). Retrieved October 31, 2020, from https://www.energy.gov/eere/wind/how-do-wind-turbines-work

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

Appendix C:

Preliminary Gantt Chart

Project 1 Gantt Chart

Select a period to highlight at right. A legend describing the charting follows. Period Highlight: Plan Duration

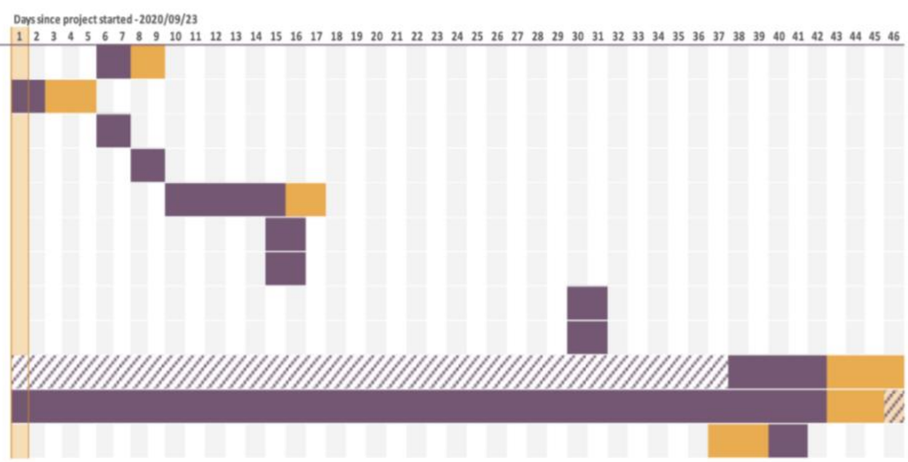
ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	PERIODS Week 3 (Sep 24-30)	Week 4 (Oct 1-7)	Week 5 (Oct 8-21)	Week 6 (Oct 22-28)	Week 7 (Oct 28 - Nov 4)
Team Meeting	24-Sep	1 hour	24-Sep	1 Hour	100%					
Milestone 0	28-Sep	1 Day	28-Sep	1 Day	100%					
Milestone 1	28-Sep	1 Day	28-Sep	1 Day	100%	Milestone 0 and 1 due				
Team Meeting	Undecided	1 Hour			0%					
Milestone 2	06-Oct	1 Day	06-Oct		0%		Milestone 2 due			
Team Meeting	Undecided	1 Hour			0%					
Milestone 3A	20-Oct	1 Day	20-Oct		0%			Milestone 3A due		
Team Meeting	Undecided	1 Hour			0%					
Milestone 3B	20-Oct	1 Day	20-Oct		0%			Milestone 3B due		
Team Meeting	Undecided	1 Hour			0%					
Milestone 4	27-Oct	1 Day	27-Oct		0%				Milestone 4 due	
Team Meeting	Undecided	1 Hour			0%					
Final Deliverable	Due: 4-Nov	1 Day	Due: 4-Nov		0%					Final Deliverable Due

Final Gantt Chart

Project - 1 Planner

Select a period to highlight at right. A legend describing the charting follows. Period Highlight: 1 | Plan Duration | Actual Start | % Complete | Actual (beyond plan) | % Complete (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Milstone 0 (Team)	6	2	6	4	100%
Milestone 1 (Individual)	1	2	1	5	100%
Milestone 1 (Team)	6	2	6	2	100%
Milestone 2 (Team)	8	2	8	2	100%
Milestone 3A (Individual)	10	6	10	8	100%
Milestone 3A (Team)	15	2	15	2	100%
Milestone 3B	15	2	15	2	100%
Milestione 4 (Individual)	30	2	30	2	100%
Milestone 4 (Team)	30	2	30	2	100%
Design Summary	1	42	38	9	100%
Learning Portfolio	1	42	1	46	100%
Self/Peer Evaluaton	40	2	37	5	100%



Meeting Logbook

Role:	Team Member Name:	MacID
Manager	Jacob Tedesco	tedescoj
Administrator	Jadyn Yaroshuk	yaroshuj
Coordinator	Mohammad Muntazar Bhurwani	bhurwanm
Subject Matter Expert	Omar Kamel	Kamelo
Subject Matter Expert #2	Haibin Du	duh24

26th September 2020

Design Studio – Project 1 - Milestone 0

- Assigning administrative roles
- Team briefing on Project 1
- Ensuring members are aware of the responsibilities assigned

29th September 2020

Milestone 1

- Reviewing and refining the individual preliminary objective trees created

31st October 2020
1st November 2020

Design Summary and Final Deliverables

- In-depth discussion about the assigned scenario to ensure a well-crafted Design Summary
- Submission of deliverables as per responsibilities held

Appendix D:

A. Jha, Wind Turbine Technology, Boca Raton: Taylor and Francis Group, 2010.

B. Konstantinidis and P. Botsaris, “Wind turbines: current status, obstacles, trends and technologies”, IOP Conference Series: Materials Science and Engineering [Online]. Available: https://iopscience.iop.org/article/10.1088/1757-899X/161/1/012079. [Accessed: September 27, 2020].

C. Fairley, P. (2019, July 1). Full Page Reload. Retrieved September 29, 2020, from https://spectrum.ieee.org/energywise/green-tech/wind/teaching-wind-turbines-wake-steering

D. “Advantages and Challenges of Wind Energy,” Energy.gov, Wind Energy Technologies [Online]. Available: https://www.energy.gov/eere/wind/advantages-and-challenges-wind-energy [Accessed: September 27, 2020]

E. “Basics of Wind Energy,” *AWEA*. [Online]. Available: https://www.awea.org/wind-101/basics-of-wind-energy. [Accessed: September 29, 2020].

F. “Next-Generation Wind Technology,” *Energy.gov*. [Online]. Available: https://www.energy.gov/eere/next-generation-wind-technology. [Accessed: September 29, 2020].