ENGINEERING

McMaster University

Project One – Renewable technology challenge:

Mechanical design of turbine blades in renewable wind technology

ENGINEER 1P13 – Integrated Cornerstone Design Projects

Tutorial 14

Team 57

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Finalized Problem Statement

Designing wind turbines for the new farm at Wolfe Island for a major Canadian hydro company. The main goal of this wind farm is to generate large amounts of electric power for the neighboring city of Kingston, Ontario. The turbine should be designed in a way that is effective enough to power a large population while being manufactured with sustainable and durable materials, so that this renewable resource will be reliable and economically friendly. To take full advantage of the wind pressures in the area, the turbine blades should minimize inertia to maximize efficiency. Since this wind farm will be the primary source of energy for nearby cities, the turbines must be durable and have a long lifespan. The blade should be able to deflect without plastic deformation during extreme weather conditions.

Fig. 1A: Objective Tree of Wind Turbine

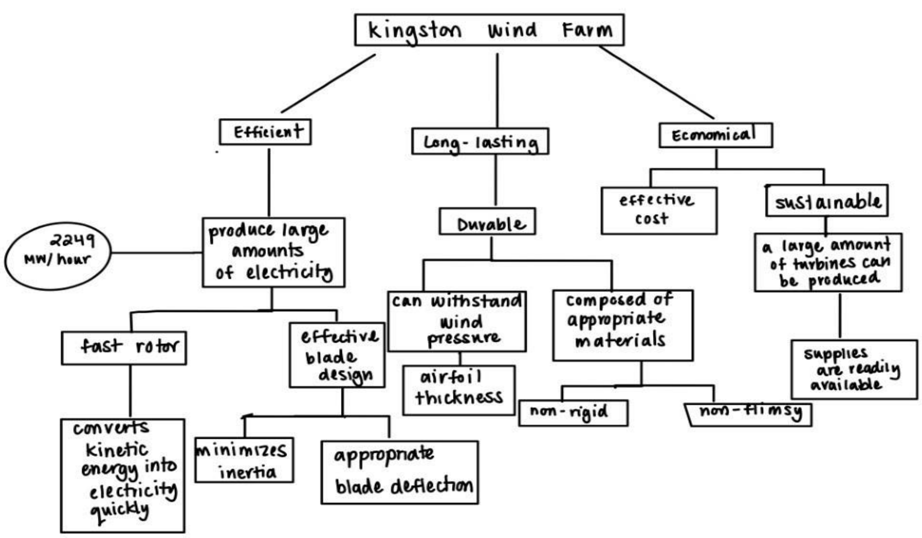
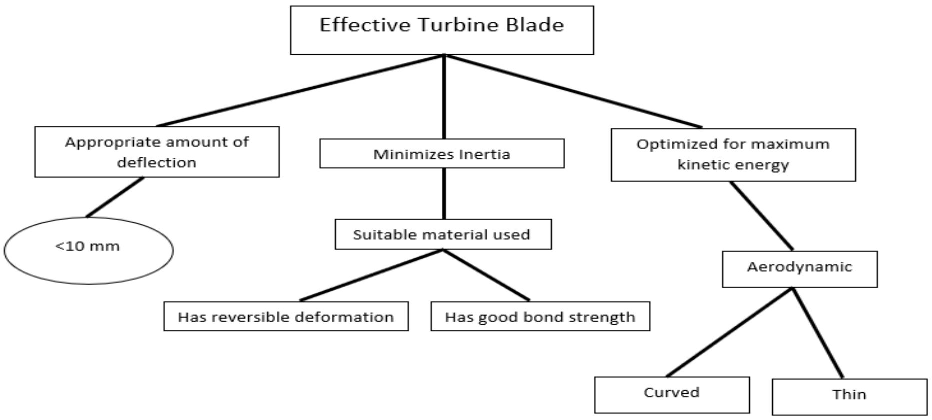


Fig. 1B: Objective Tree of Turbine Blade



Design Process

Technical Objectives and Material Performance Indexes

For the objective tree for the turbine blade, the leading three branches were 'the appropriate amount of deflection,' 'minimized inertia,' and 'optimized for maximum kinetic energy' as these follow the main ideas and requirements for the following problem statement. Getting specific for each category, 'optimized for maximum kinetic energy' is branched further into 'aerodynamic' and is broken down into its shape as 'curved' and 'thin.'. Then the categories branched 'minimizes inertia' into 'suitable material' to meet the condition to deflect without plastic deformation during harsh weather and is further sub-branched into 'has reversible deformation,' and 'has good bond strength.' Finally, the constraint, <10mm, is specified for 'appropriate amount of deflection.' The three objectives were decided by looking at the most critical factors from the objective tree. Objective one, which was that the blade should not deflect past its yield strength, was priorly found to be <10mm, so our metric was the deflection. The second objective was to minimize inertia. The metric was the pressure the blade can withstand as it is necessary for this scenario for the blade to withstand harsh conditions. The final objective was that the blade shape is able to optimize the maximum amount of kinetic energy, so the metric was the thickness, thus the thin blades would be best. For the objective matrix, the more points given meant that it was better for meeting our certain objective. It was determined that the relevant MPIs were minimizing CO2 footprint from production and minimizing production energy. These objectives were cohesive with the turbine's problem statement because it considers the economic objective through sustainable and easily sourced materials so that multiple turbines can be produced and sourced, in addition to the mass/density of the blade which influences the minimization of inertia. Then, using the specific MPI formulas for stiffness and strength (stiffness: $MPI^{(\text{energy})}=E\ /\ \rho CO2$, $MPI^{(\text{energy})}= E\ /\ \rho H_{\text{m}}$; Strength:

$MPI^{(energy)} = \sigma y / \rho CO2$, $MPI^{(energy)} = \sigma y / \rho Hm$) we found our MPIs and the specific materials using the Granta software.

Conceptual Design- Material Selection

The material of the turbine that was selected was low carbon steel. Low carbon steel is the best material for multiple reasons. According to the primary and secondary objectives and their respective MPI's, it has the most optimal mass and yield strength compared to its competitor's bamboo and wood (typical, long grain). According to *Table 1. Decision Matrix,* low carbon steel received the highest rating for mass and yield strength. Since it weighs the least, the material will minimize inertia and maximize the efficiency of the turbine blade, and because it has the ideal yield strength it should also be flexible and ductile under stress and strain. As mass and yield strength are weighted as the most important criteria, the carbon footprint and embodiment energy are not as large of a deciding factor. Low carbon steel is ranked in between bamboo and wood for these criteria as shown by the following table. Lastly, based on the description of low carbon steel provided in Granta, it is commonly used for tower cranes and beams, and has a reputation for being strong, tough, easily formed and cheap. These characteristics are beneficial and can be applicable to the proposed objectives that have been outlined in the turbine blade design. In conclusion, due to its ideal mass, flexibility, durability, cost and reputation in constructing large equipment for construction, low carbon steel is the best material for the turbine blade.

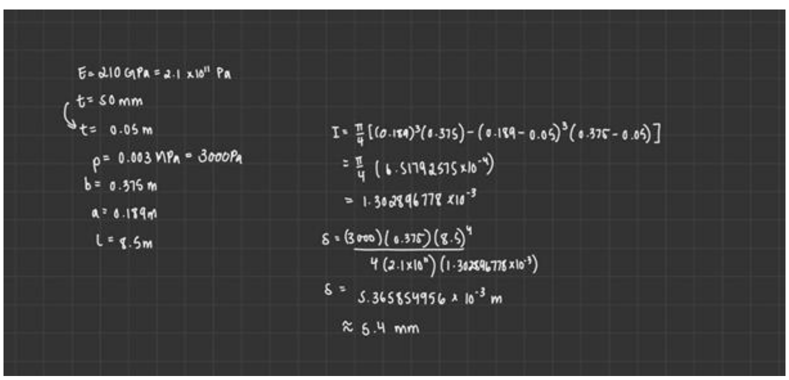
Table 1. Decision Matrix

Decision Matrix							
	Weight factor	*Material Finalist 1 (Wood)*		*Material Finalist 2 (Bamboo)*		*Material Finalist 3 (Low carbon steel)*	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Yield Strength	3	1	**3**	1	**3**	5	**15**
Minimize Mass	4	3	**12**	2	**8**	5	**20**
CO2 Footprint	2	5	**10**	3	**6**	2	**4**
Embodiment Energy	1	5	**5**	2	**2**	3	**3**
TOTAL	10	15	**30**	9	**19**	15	**42**

Design Embodiment

Once the material (low carbon steel) had been selected, what came next was to determine the appropriate thickness of the turbine blade. In order to decide a range for the thicknesses, analytical calculations were carried out to estimate what the deflections were corresponding to the thicknesses of 15, 30, 50 and 150 mm. From those calculations, a range of 15mm<t<30mm was established. The constraint for the deflection was constricted to be no more than 10mm, so the best initial thickness would be the one corresponding to a deflection that lies in the range of 8.5-10mm. To test out the thicknesses, pressure was simulated on a turbine blade model using Autodesk Inventor. After testing out a few values for thickness within the previously chosen range, it was found that 25mm was a suitable initial thickness. It satisfied the stiffness-limited design constraint by giving a deflection of 9.43mm, which also meant it suited the required constraint.

Fig. 2: Analytical Calculation for 50mm



Concluding Remarks

During Project 1, we learned how to analyze a given scenario to determine how the situation should be approached and hence determine what the necessary objectives that should be met are. We also learned how to use tools within *Granta EduPack* and *AutoDesk Inventor* to choose and test an appropriate material depending on our pre-determined objectives and constraints.

Appendix A – Peer learning discussion summary:

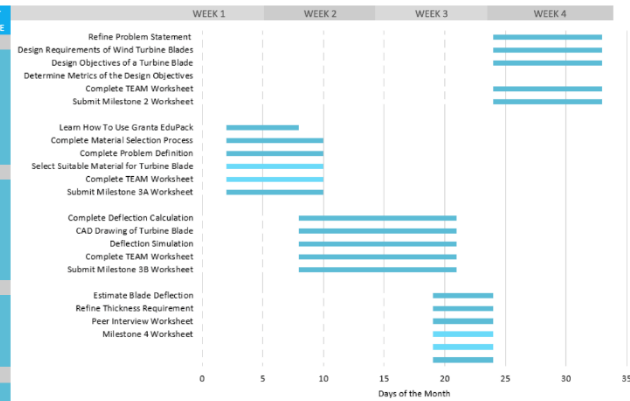
As part of our peer discussion, we interviewed team 59 who had done the roof generator scenario. They chose "minimizing volume" as their primary objective. This is because the turbines should not take up a lot of space as they will be placed on the roofs of homes. Their secondary objective was to "Minimize cost." The turbines should be cost-effective and a practical purchase so that money would be saved on electricity. They should be worth buying in the long run. For the materials they chose aluminum alloy as their top material and has magnesium alloy and steel as their runner-up's. They chose aluminum since it was a better overall material to build the turbine with that would fall within budget. It's a bit more costly than the other materials but it is long-lasting, strong, sturdy, and durable. This makes it a better choice than the other two materials. Finally, for thickness, they chose a final refined thickness of 25mm.

Appendix B – References (if necessary):

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

Appendix C – Gantt Chart:

Project 1: Renewable techonology challenge	START DATE	DAY OF MONTH*	END DATE	DURATION* (WORK DAYS)	DAYS COMPLETE*	DAYS REMAINING*	TEAM MEMBER	PERCENT COMPLETE
Milestone 2								
Refine Problem Statement	9/24	24	10/2	9	9	0	TEAM	100%
Design Requirements of Wind Turbine Blades	9/24	24	10/2	9	9	0	TEAM	100%
Design Objectives of a Turbine Blade	9/24	24	10/2	9	9	0	TEAM	100%
Determine Metrics of the Design Objectives	9/24	24		8			TEAM	100%
Complete TEAM Worksheet	9/24	24	10/2	9	9	0	Firas	100%
Submit Milestone 2 Worksheet	9/24	24	10/2	9	9	0	Mary	100%
Milestone 3A								
Learn How To Use Granta EduPack	10/2	2	10/7	6	6	0	ALL	100%
Complete Material Selection Process	10/2	2	10/9	8	8	0	ALL	100%
Complete Problem Definition	10/2	2	10/9	8	8	0	TEAM	100%
Select Suitable Material for Turbine Blade	10/2	2	10/9	8	0	8	TEAM	100%
Complete TEAM Worksheet	10/2	2	10/9			8	Firas	100%
Submit Milestone 3A Worksheet	10/2	2	10/9	8	8	0	Mary	100%
Milestone 3B								
Complete Deflection Calculation	10/8	8	10/20	13	13	0	TEAM	100%
CAD Drawing of Turbine Blade	10/8	8	10/20	13	13	0	TEAM	100%
Deflection Simulation	10/8	8	10/20	13	13	0	TEAM	100%
Complete TEAM Worksheet	10/8	8	10/20	13	13	0	Firas	100%
Submit Milestone 3B Worksheet	10/8	8	10/20	13	13	0	Mary	100%
Milestone 4 - Final Deliverables								
Estimate Blade Deflection	10/19	19	10/23	5	5	0	ALL	100%
Refine Thickness Requirement	10/19	19	10/23	5	5	0	TEAM	100%
Peer Interview Worksheet	10/19	19	10/23	5	5	0	TEAM	100%
Milestone 4 Worksheet	10/19	19	10/23	5	0	5	Firas	100%
Submit Individual Milestone 4 Worksheet	10/19	19	10/23	5	0	5	ALL	100%
Submit TEAM Milestone 4 Worksheet	10/19	19	10/23	5	5	0	Mary	100%
Design Summary	10/23	23	11/4	12	0	12	TEAM	100%
Final Project Gantt Chart	10/23	23	11/4	12	0	12	Mary	100%
Logbook of Additional Meetings & Discuss	10/23	23	11/4	12	0	12	Firas	100%
Source Materials Database	10/23	23	11/4	12	0	12	Abyan	100%
Submit Design Summary	10/23	23	11/4	12	0	12	Mary	100%



Appendix D – Research Memo References:

[1] Surya Santoso, Ph.D.; H. Wayne Beaty, *Standard Handbook for Electrical Engineers, Seventeenth Edition.* New York, Chicago, San Francisco, Athens, London, Madrid, Mexico City, Milan, New Delhi, Singapore, Sydney, Toronto: McGraw-Hill Education, 2018.

[2] Francis M. Vanek, Ph.D.; Louis D. Albright, Ph.D.; Largus T. Angenent, Ph.D., *Energy Systems Engineering: Evaluation and Implementation, Third Edition.* New York, Chicago, San Francisco, Athens, London, Madrid, Mexico City, Milan, New Delhi, Singapore, Sydney, Toronto: McGraw-Hill Education, 2016.

[3] "When will fossil fuels run out?", Ecotricity [Online]. Available: https://www.ecotricity.co.uk/our-green-energy/energy-independence/the-end-of-fossil-fuels#:~:text=Globally%2C%20we%20currently%20consume%20the,in%20just%20over%2053%20years. [Accessed: September 24, 2020]

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[5] J.F. Manwell, J.G. McGowan and A.L. Rogers, *Wind Energy Explained – Theory, Design and Application.* John Wiley & Sons Ltd, 2002.

[6] Sun, D. Huang, and G. Wu, "The current state of offshore wind energy technology development," *Energy*, 30-Mar-2012. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S0360544212001685#:~:text=Wind power has been the,in electricity generation in 2050. [Accessed: 24-Sep-2020].

[7] Alison Campbell, and others, "Wind power," *Wind power - Energy Education*. [Online]. Available: https://energyeducation.ca/encyclopedia/Wind_power#:~:text=The three main factors that,than having occasional high winds. [Accessed: 24-Sep-2020].

[8] Meg Jenkins,"Wind Turbine Blade Design Optimization with SimScale: Blog," *SimScale*, 07-Nov-2019. [Online]. Available: https://www.simscale.com/blog/2019/09/wind-turbine-blade-design/. [Accessed: 24-Sep-2020].

[9] "Wind Energy," *Wind Energy - Introduction*. [Online]. Available: https://energypedia.info/wiki/Wind_Energy_-_Introduction. [Accessed: 22-Sep-2020].

[10] J. F. Manwell, M. G. J. G., and A. L. Rogers, "Wind Turbine Design," in *Wind energy explained*, Chichester: John Wiley & Sons, 2002.