ENGINEERING

McMaster University

Project One – Renewable technology challenge:

Mechanical design of turbine blades in renewable wind technology

ENGINEER 1P13 – Integrated Cornerstone Design Projects

Tutorial T-05

Team Tues - 26

Sophia Workun (workus1)

Jackson Lippert (lippertj)

Emilia Pisic (pisice)

Sana Khan (khans288)

Ehsaan Khan (khane16)

Submitted: November 8, 2020

Table of Content

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.

Emilia Pisic 400319166

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.

Sana Khan 400315946

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.

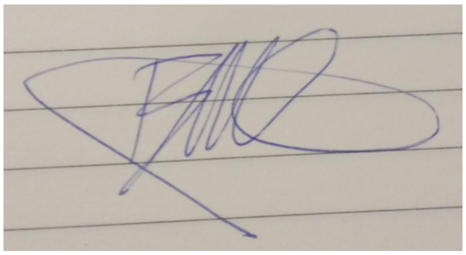
Sophia Workun 400315192

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.

Jackson Lippert 400311584

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.

Ehsaan Khan 400317397



Executive Summary

Wind turbines fall under the category of new technologies for renewable energy sources. New designs are continuously being drafted to improve the reliability of these turbines.

This report examines the measures and steps taken to redefine the design structure of a blade that will be used to install multiple wind turbines in a remote village in Quetzaltenango, Guatemala. These steps include creating a problem statement, deriving material performance indices (MPI), choosing a material based on selective factors, an interview conducted with another team, and final remarks.

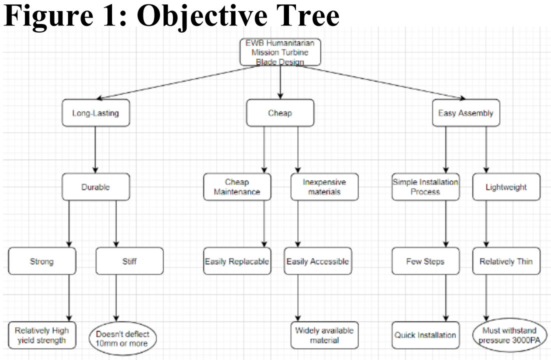
Design Summary

Finalized problem statement:

The objective of the turbine in the following scenario is to create a design that should be long lasting and require little maintenance. The amount of energy produced should be just enough to power simple electrical devices. The turbine must be simple enough to assemble by local villagers that are currently living off the grid in Quetzaltenango, Guatemala, and other inexperienced individuals. The materials used must be easily accessible and durable enough to withstand harsh weather conditions [2].

Justification of Technical Objectives and Material Performance Indices:

Figure 1: Objective Tree



Outlines the main objectives that the EWB humanitarian aid mission turbine must conform to [Figure 1], which helped with decision making for the selection of materials.

Table 1: MPI Derivation for selective objectives [1]:

Objective	Derived MPI
Minimize Mass	$MPI^{(mass)} = \frac{\sigma_y}{\rho}$
Minimize mass (stiffness)	$MPI^{(mass)} = \frac{E}{\rho}$
Minimize cost (strength)	$MPI^{(cost)} = \frac{\sigma_y}{\rho C_m}$

Minimize cost with respect to stiffness	$MPI^{(cost)} = \frac{E}{\rho C_m}$

The top three materials for the materials selection have been chosen and are weighted in the decision matrix [Table 1].

Table 2: Decision Matrix.

Decision Matrix							
	Weight factor	*Medium carbon steel*		*High carbon steel*		*Low carbon steel*	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Lightweight	2	3	**6**	3	**6**	3	**6**
Cheap	5	3	**15**	3	**15**	3	**15**
Strength	4	2	**8**	3	**12**	1	**4**
Stiffness	2	3	**6**	3	**6**	3	**6**
Carbon footprint	1	2	**2**	2	**2**	3	**3**
TOTAL			**37**		**41**		**34**

All three of the material finalists had very similar if not the same properties [Table 2]. For this reason, the total rankings for each of the materials were very close. In the end, high carbon steel had the highest ranking because it has the highest strength compared to the other two materials. High carbon steel satisfies each of our criteria's the most, making it the top material to use for this design.

Table 3: Material Properties [3]

Material Name: High Carbon Steel	Average value:
Young's modulus E (GPa):	210
Yield Strength σy (MPa):	678.5
Tensile strength σUTS (MPa):	1055.5
Density ρ (kg/m^3):	7800
Embodiment Energy Hm (MJ/kg)	32.4
Specific carbon footprint CO_2 (kg/kg)	2.375

The material properties which were used in creating the material in Inventor Professional [Table 3].

Conceptual Design – Justification of Selected Material

The way we began our material selection process was by first deriving MPI stiffness and MPI strength for our primary objective (minimizing cost) and secondary objective (minimizing mass). Then each group member plotted their MPI on a graph in Granta removing certain materials, we were able to rank and choose our top five materials for each of our assigned MPI. Our selection came down to medium carbon steel, high carbon steel, and low carbon steel. We then chose our criteria to decide our final material. Our criteria came down to lightweight, cheap, strength, stiffness, and carbon footprint. Using the decision matrix, we concluded that high carbon steel is the best material for us. The rankings for most lightweight, cheap, and stiffness were the same for all three materials and carbon footprint had a very similar ranking for all three materials. What offset high carbon steel from the other two materials was its strength which was our second most important criteria. Overall, high carbon steel satisfied our decision matrix and our objective to create a turbine that is cost efficient, minimizes mass, and is strong and long lasting for the villagers.

Design Embodiment: Justification of Solid (CAD) Modelling

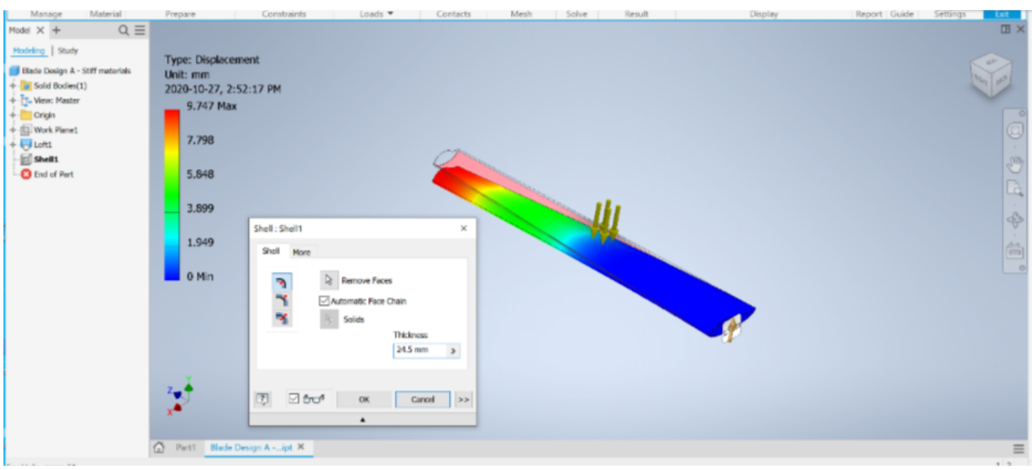


Figure 2: Deflection of Turbine Blade

Through trial and error, as well as through calculated values, the optimal thickness of the turbine blade is 24.5mm [Figure 2]. This is considered optimal because it is below the maximum deflection of 10mm and above the minimum deflection of 8.5 mm, which were constraints given by the instructional assistant [1]. The deflection is numerically closer to the maximum displacement of 10, which is good because it means that the thickness is just below the amount that would fail under the pressure, therefore minimizing material used and therefore cost.

Concluding Remarks

We have learned a lot about the design process in engineering by designing a wind turbine and its blade. We learned the process of material selection and the importance of testing and redesigning our turbine blade to obtain our finished product. The design process is iterative and requires a lot of testing to improve our design. This process was a team effort that required resilience and a lot of perseverance. In the future we will work towards building a much more sustainable and carbon neutral design that would preserve the environment. Through all this, we learned that a successful design comes from multiple perspectives and integrated collaboration.

Appendix A – Peer learning discussion summary:

The team that we discussed with had done their project on Scenario 1: Renewable Energy for a Large Population. Their goal was to design an effective turbine to be used on a wind farm to generate large amounts of renewable energy for a large population. So, their primary objectives based off their problem statement were producing many cost-efficient wind turbines that minimized mass. In addition, maximizing the energy produced and building a structurally sound wind turbine for the city were other important objectives of their wind turbine. Based on these objectives and after using Granta, they concluded that low alloy steel was the best material for their blade. High carbon steel and CFRP-epoxy were the other two materials being compared; however, low alloy steel satisfied their decision matrix the best. Low alloy steel had the highest rating for being lightweight, having an ease of transportability, stiffness, and flexibility. Carbon footprint was the only one with a smaller rating than the other materials, but it was not important for the group which is why its rating did not greatly affect their decision for the material. Flexibility and stiffness from the decision matrix had become constraints for them since they wanted to minimize inertia and maximize efficiency. After doing the simulation in Granta, they found that their deflection was between 15mm-30mm, which does satisfy their constraints. Overall, the group achieved their objectives and met all the requirements and constraints needed to get there.

Appendix B – References:

[1] "P1 Milestone 2", Class notes for ENG 1P13, Department of Engineering, Mcmaster University, Fall, 2020

[2] "P1 Milestone 3A" Class notes for ENG 1P13, Department of Engineering, Mcmaster University, Fall, 2020

[3] Ansys Granta EduPack software, Granta Design Limited, Cambridge, UK, 2020

[4] "P1 Milestone 4" Class notes for ENG 1P13, Department of Engineering, Mcmaster University, Fall, 2020

[5] "ENG1P13 P1 Project Module", Class notes for ENG 1P13, Department of Engineering, Mcmaster University, Fall, 2020

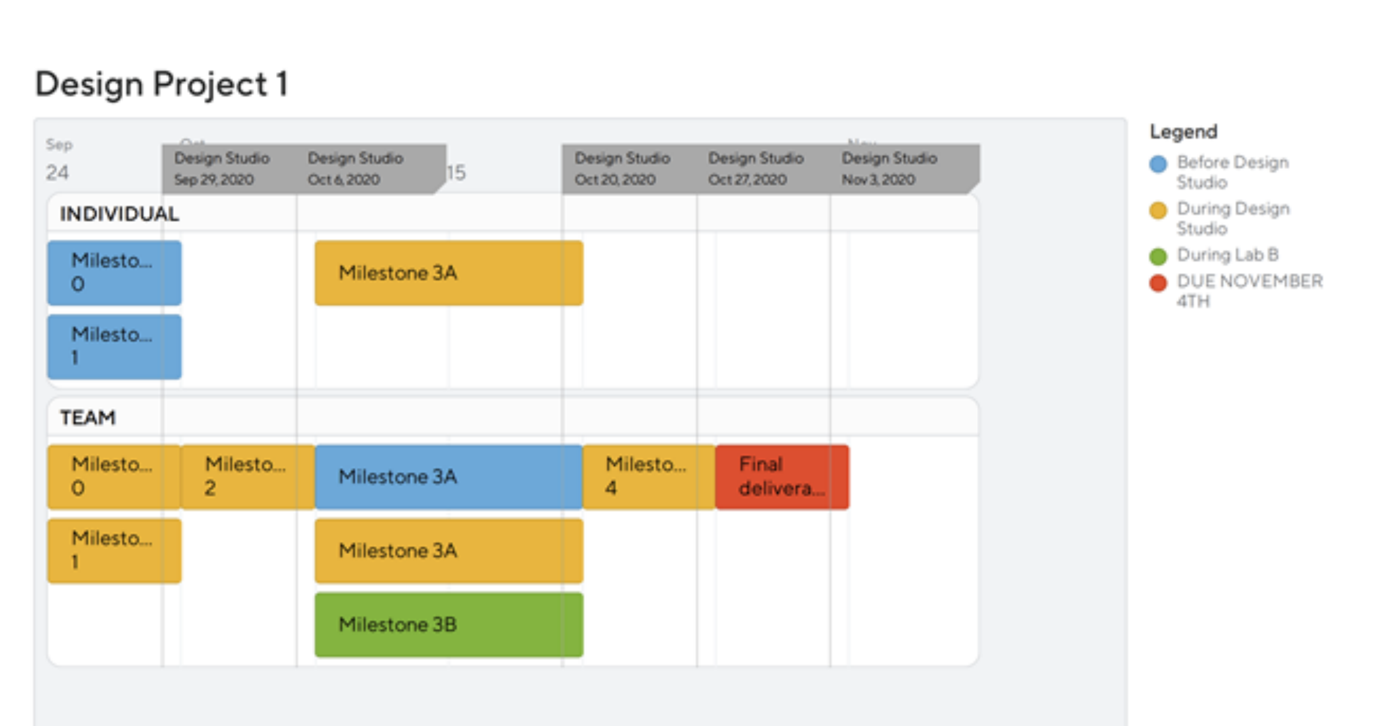
[6] Autodesk Inventor Professional software, Autodesk Incorporated, California, US, 2021

Appendix C – Schedule and Gantt Chart:

Our preliminary Gantt Chart and Final Gantt Chart remained the same. We followed our due dates, deadlines, and how we aimed to complete each assignment exactly as stated below.

Title	Lane	Legend	Description
Milestone 0	INDIVIDUAL	Before Design Studio	-Review the administrative responsibilities section of the P1 project module.
Milestone 1	INDIVIDUAL	Before Design Studio	-Complete pre-project memo
Milestone 3A	INDIVIDUAL	During Design Studio	-Complete material selection process
Milestone 0	TEAM	During Design Studio	-Complete Team charter worksheet
Milestone 1	TEAM	During Design Studio	-Complete initial problem statement and objective trees for the 4 different engineering scenarios of a wind turbine.
Milestone 2	TEAM	During Design Studio	-Complete refined problem statement of wind turbine, design requirement of wind turbine bladed of a specific scenario, design objectives of a turbine, and the metrics of the design objectives.
Milestone 3A	TEAM	Before Design Studio	-Learn how to use Granta EduPack as a design tool material selection (in materials science lab #1)
Milestone 3A	TEAM	During Design Studio	-Complete problem definition of a turbine blade for material selection, compare material alternative, select the more suitable material your turbine blade should be made of.

Title	Lane	Legend	Description
Milestone 3B	TEAM	During Lab B	-Complete deflection calculation, CAD drawing of a turbine blade, and deflection simulation turbine blade CAD file
Milestone 4	TEAM	During Design Studio	-Estimate the thickness requirement of the turbine made of your chosen material, refine the thickness requirement based on deflection simulation turbine based CAD file, and interview another team with a different assigned scenario and take notes of what you have learned.
Final deliverable	TEAM	DUE NOVEMBER 4TH	Include the following in your Design Summary: finalized problem statement of the turbine blade design, justification of technical objective and material performance index, justification of selected materials, justification, justification of solid (CAD) modelling, and peer-learning interview summary.



Logbook

Date	Milestone	Topics Discussed	Description
September 30	Milestone 1	Initial Problem Statement	• We further discussed our initial problem statement
October 6	Milestone 2	Final Objective Tree Refined Problem Statement Rationale for Objectives	• Finalized our objective tree • Edited the final problem statement • We discussed the rationale for the objectives we selected
October 9	Milestone 3	Organization	• Worked on organizing our files and doing the pre-design studio work • Looking ahead for the next week
Oct 21	Milestone 3B	Simulated Deflection for Blade	• Due to an error we made originally, we redid the simulation to achieve the simulated deflection value
October 26	Milestone 4	Peer Interview	• Before the interview we met to organize our files • Discuss which parts of our project each member will present
October 28	Milestone 4	Peer Interview	• After the interview we compared our notes

			• Made a document with our collective notes
October 30 November 4	Final Deliverable	Final Deliverable	• Collected our information from the project • Organized it on the final deliverable template • Completed the final deliverable

Appendix D – Materials Source Database

[1] "P1 Milestone 2", Class notes for ENG 1P13, Department of Engineering, Mcmaster University, Fall, 2020

[2] "P1 Milestone 3A" Class notes for ENG 1P13, Department of Engineering, Mcmaster University, Fall, 2020

[3] Ansys Granta EduPack software, Granta Design Limited, Cambridge, UK, 2020

[4] "P1 Milestone 4" Class notes for ENG 1P13, Department of Engineering, Mcmaster University, Fall, 2020

[5] "ENG1P13 P1 Project Module", Class notes for ENG 1P13, Department of Engineering, Mcmaster University, Fall, 2020

[6] Autodesk Inventor Professional software, Autodesk Incorporated, California, US, 2021

[7] "Basics of Wind Energy," *AWEA*. [Online]. Available: https://www.awea.org/wind101/basics-of wind-energy. [Accessed: 29-Sep-2020].

[8] P. J. Schubel and R. J. Crossley, "Wind Turbine Blade Design," *MDPI*, 06-Sep-2012. [Online]. Available: https://www.mdpi.com/1996-1073/5/9/3425/htm. [Accessed: 29-Sep-2020].

[9] "How Does a Wind Turbine Work?," *Energy.gov*. [Online]. Available: https://www.energy.gov/maps/how-does-wind-turbine-work [Accessed: 29-Sep-2020].

[10] Alternative Energy Tutorials, "Wind Turbine Blade Design, Flat or Curved Blades," *Alternative Energy Tutorials*, 08-Feb-2020. [Online]. Available: https://www.alternative-energy tutorials.com/energy-articles/wind-turbine-blade-design.html. [Accessed: 29-Sep-2020].

[11] "Wind Turbine Blade Aerodynamics - Kimerius Aircraft." [Online]. Available: https://www.kimerius.com/app/download/5784129509/Windturbinebladeaerodynamics.pdf. [Accessed: 29-Sep-2020]. Peter Jamieson, Innovation in Wind Turbine Design. John Wiley & Sons, Incorporated, 2011

[12] Vaughn Nelson, Kenneth Starcher, Wind Energy: Renewable Energy and the Environment. Boca Raton: CRC Press, 2018

[13] "Blades (wind turbine) Selection Guide", Engineering360. Available:https://www.globalspec.com/learnmore/electrical_electronic_components/power_generation_storage/alternative_power_generators/blades_wind_turbine [Accessed: Sep. 25, 2020]

[15] N. R. Canada, "Government of Canada," *Natural Resources Canada*, 02-Mar-2020. [Online]. Available: https://www.nrcan.gc.ca/energy/energy-sources-distribution/renewables/wind-energy/7299. [Accessed: 27-Sept-2020].

[16] "How Do Wind Turbines Work?," *Energy.gov*. [Online]. Available: https://www.energy.gov/eere/wind/how-do-wind-turbines-work. [Accessed: 28-Sept-2020].

[17] "Wind Turbine Design," *Wind Turbine Design - an overview | ScienceDirect Topics*. [Online]. Available: https://www.sciencedirect.com/topics/engineering/wind-turbine-design. [Accessed: 28-Sept-2020].

[18] Alternative Energy Tutorials, "Wind Turbine Blade Design, Flat or Curved Blades," *Alternative Energy Tutorials*, 08-Feb-2020. [Online]. Available: https://www.alternative-energy-tutorials.com/energy-articles/wind-turbine-blade-design.html. [Accessed: 28-Sept-2020].

[19] "National Wind Markets," canwea [online]. Available: https://canwea.ca/wind-energy/national/ [Accessed: September 23, 2020]

[20] "Windvision 2025," canwea [online]. Available: https://canwea.ca/pdf/windvision/Windvision_summary_e.pdf [Accessed: September 23, 2020]

[21] "How digitalization and private wireless are increasing wind farm safety and productivity," Windpower Engineering & Development [online]. https://www.windpowerengineering.com/how-digitalization-and-private-wireless-are-increasing-wind-farm-safety-and-productivity/ [Accessed: September 23, 2020]

[22] "Wind Turbine Design: Basic Load Considerations," Danish Wind Industry Association [online]. http://ele.aut.ac.ir/~wind/en/tour/design/index.htm#:~:text=To%20limit%20the%20influence%20of,the%20turbines%20rotate%20relatively%20quickly. [Accessed: September 23, 2020]

[23] J. Zangenberg, P. Brøndsted, “Wind Turbine Design,” ScienceDirect [online]. https://www.sciencedirect.com/topics/engineering/wind-turbine-design [Accessed: September 23, 2020]

[24] M. Jenkins, “Wind Turbine Blade Design Optimization with SimScale,” SinScale [online]. https://www.simscale.com/blog/2019/09/wind-turbine-blade-design/#:~:text=Wind%20turbine%20blades%20generate%20lift,of%20the%20blade%2Dshaped%20aerofoil. [Accessed: September 23, 2020]

[25] “How Do Wind Turbines Work?” Energy Efficiency & Renewable Energy [Online]. Available: https://www.energy.gov/eere/wind/how-do-wind-turbines-work. [Accessed: September 26, 2020]

[26] K. Miller-Wilson, “Design of a Wind Turbine.” lovetoknow [Online]. Available: https://greenliving.lovetoknow.com/Design_of_a_Wind_Turbine. [Accessed: September 26, 2020]

[27]. L. Villazon, “Why do wind turbines have three blades?” Science Focus: The Home of BBC Science Focus Magazine [Online]. Available: https://www.sciencefocus.com/science/why-do-wind-turbines-have-three-blades/. [Accessed: September 26, 2020]

[28] M. Froese, “How are blade materials and manufacturing changing to keep up with larger turbines.” Windpower Engineering & Development [Online]. Available: https://www.windpowerengineering.com/blade-materials-manufacturing-changing-keep-larger-turbines/. [Accessed: September 26, 2020]

[29] “Next-Generation Wind Technology.” Energy Efficiency & Renewable Energy [Online]. Available: https://www.energy.gov/eere/next-generation-wind-technology#:~:text=Modern%20wind%20turbines%20are%20increasingly,averaging%202.15%20MW%20of%20capacity [Accessed: September 26, 2020]

[30] "Wind Turbine Blade Design, Flat or Curved." Alternative Energy Tutorials [Online]. Available: https://www.alternative-energy-tutorials.com/energy-articles/wind-turbine-blade-design.html [Accessed: September 26, 2020]

[31] Z. Khaled, Z. Soraya, and Z. Adel. *Fatigue strength prediction in composite materials of wind turbine blades under dry-wet conditions: An artificial neural network approach.* Sage Publications, Ltd., 2016