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 24

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Submitted: November 8, 2020

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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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Borna Sadeghi

Executive Summary

Project 1 entailed designing a wind turbine blade component which will be used in many wind turbine units by the Sweden Wind Energy Association for a new wind farm. We worked on this project to aid Sweden in fulfilling its plan of reducing net emissions of greenhouse gases to zero by 2045. Our wind turbine blade must efficiently convert the wind's kinetic energy into electricity to generate a sufficient amount of power for multiple cities.

Main Body

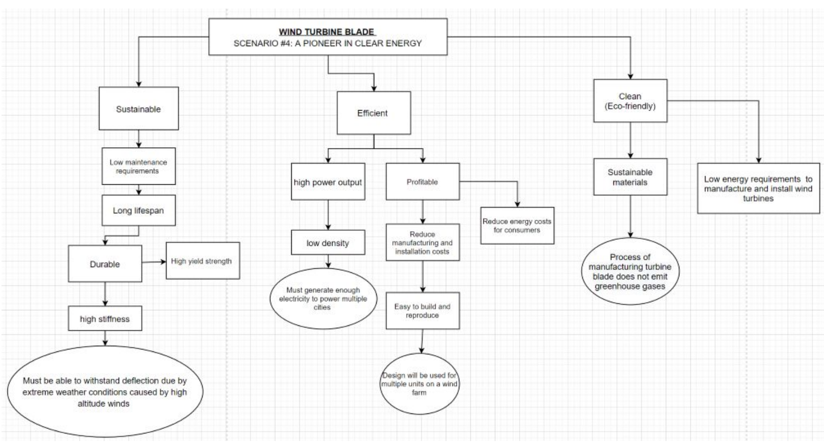


Figure 1, Objective Tree

Justification of Technical Objectives and Material Performance Indices

The type of material used for our wind turbine blade is heavily dependent on our technical objectives. For our scenario, we were required to design a wind turbine that could provide a sufficient amount of electricity for a large population and be simultaneously eco-friendly. Therefore, we indicated that our turbine blade needed to output large amounts of electricity for multiple cities, have a long lifespan, and produce minimal environmental footprint within our objective tree in Figure 1. To ensure the sustainability and longevity of our turbine design, we concluded that the turbine blade must have high yield strength and have high stiffness to withstand deflection. Also, it must be efficient during operation, thus we stated that density must be minimized since heavier blades require more wind to turn the rotor leading to decreases in power outputs [1]. Large energy outputs would result in increased profitability and more affordable energy for consumers. Finally, the blade must also be eco-friendly, meaning that it is produced from a sustainable material and the manufacturing and installation process requires minimal energy quantities. During the MPI selection process, we decided our primary objective was minimizing mass because heavier blades are less efficient in capturing energy in comparison to lighter blades [1]. Our secondary objective was minimizing cost, since many units of our turbine blade are required as the project has a large scale, production and installation will be highly expensive. The requirements for the material according to our decision matrix were lightweight, yield strength, fatigue strength, stiffness, affordability, and availability. These categories chosen for the decision matrix relate to our identified objectives. Lightweight corresponds with minimizing mass, yield strength and fatigue strength are associated with durability, and affordability as well as availability comply with price. Based upon these chosen categories, our group concluded that CFRP would be the best material choice for the turbine blade.

Conceptual Design – Justification of Selected Material

The efficiency and longevity of a wind turbine depends heavily on the material properties of the blade; thus, material selection played a vital role in our design process. After analyzing the material property charts associated with our chosen MPI's on GRANTA, we narrowed our three material candidates down to high carbon steel, medium carbon steel, and carbon fiber reinforced polymer since they consistently ranked highest [3]. Using our weightings, we concluded that CFRP would be our material for our turbine blade design. CFRP ranked the highest because it satisfied our most important material selection factors, which include high yield strength, high fatigue strength, high stiffness, and low density. It is necessary that our chosen material satisfies these factors because high stiffness and yield strength is necessary for minimizing deflection, to reduce gravitational forces and maximize energy output low density is needed, and to lower material demotion and increase longevity long fatigue life is required [2]. CFRP is approximately one-fifth the density and double the yield strength of that of the steels as seen in Table 1[3]. Although our selected material is less affordable, available, and ecologically friendly, our CFRP blade should prove more effective than a high or medium carbon steel blade and eventually offset the initial environmental damage and costs that are associated with the processing and manufacturing of the material and blade [3].

Table 1. Material Properties of CFRP

Material Name: CFRP, Epoxy Matrix (Isotropic)	Average value:
Young's modulus E (GPa):	110
Yield Strength σ_y (MPa):	800
Tensile strength σ_{UTS} (MPa):	800
Density ρ (kg/m^3):	1550
Embodiment Energy H_m (MJ/kg)	689
Specific carbon footprint CO_2 (kg/kg)	48.2

Design Embodiment - Justification of Solid (CAD) Modelling:

With the blade length and width of our wind turbine design already set, we needed to evaluate the optimal blade wall thickness of our wind turbine blade in order to satisfy the stiffness design constraint, which was the blade's maximum deflection must be less than 10 mm. To determine the optimal blade wall thickness, we began by calculating the deflection of our CFRP turbine blade using various material property equations with 4 different air foil thicknesses: 15mm, 30mm, 50mm, 150mm [4]. After doing so, we found that our estimated range of the thickness was 50mm <t<150mm because as blade wall thickness increased from 50mm to 150mm the calculated deflection of the turbine blade decreased below the target threshold. However, as blade wall thickness decreased from 50mm to 30mm the calculated deflection of the turbine blade increased above the target threshold. Our team then used Inventor's built-in deflection simulation to run various simulations on a CFRP turbine blade, continually increasing the thickness of the blade by 1mm from 50mm until the design constraint was satisfied. We chose 50mm as the initial blade wall thickness since our calculations indicated that deflection at this value was 10.3mm, which was close to our target deflection. Through this process, we found that approximately 53mm was the optimal thickness to the nearest +/- 1 mm which satisfied $\delta < \delta*$, where $\delta* =$ 10 mm. Our deflection simulation with a blade wall thickness of 53mm found a deflection of 9.842mm, which was below our threshold, indicating that the blade is suitable for use in production.

Concluding Remarks - Reality Check:

This report discusses the development of mechanical design of turbine blades in renewable wind technology. The objective of this project is to develop and design a wind turbine that is most suitable for our assigned scenario. During project one, our team designed a wind turbine blade component for one of the four assignment scenarios. The scenario our team was given is a pioneer in clean energy. Our team designed wind turbines that can operate on a nationwide scale to help reduce net emissions of greenhouse gases to zero. Our team learned the importance of research and taking all mechanical aspects into consideration when designing the wind turbine blade. We learned that the mechanical design of the wind turbine blades must be structurally integral and function with high aerodynamic efficiency, with regard to local wind speeds and air densities, to maximize power output whilst withstanding potential issues such as deflection, leading-edge erosion, and lightning. We identified the suitable objectives for our given scenario in terms of mechanical performance. We have also learned how to utilize technical objectives and material performance indices when it came to the most suitable material selection for our blade. Additional engineering considerations that are worth exploring in the future when developing the wind turbine include wind turbine foundation dynamics and performance requirements, site selection, and the operation of the wind turbine [5]. To conclude, our team successfully designed a blade component of a wind turbine based on the mechanical requirements of our scenario.

Appendix A – Peer learning discussion summary:

The team we interviewed for the peer learning discussion is Tuesday-23. The engineering scenario they were given is scenario 3, the roof generator. We learned that the design team's overall objective was to design a suitable wind turbine that can be installed on roofs for homeowners. The main goals of their turbines discussed in the objective tree are visually appealing for homes, easy installation, and low cost. In contrast, the main goals of our turbines discussed in the objective tree are sustainability, efficiency, and eco-friendly. The main goals of their turbine's blades discussed in the objective tree are lightweight, maximized surface area of blade, and low cost. In contrast, the main goals of our turbine's blades discussed in the objective tree are sustainability, efficiency, and eco-friendly. To compare, the design team's technical objectives were identical to ours as we both chose minimizing mass and minimizing cost as our objectives. They chose minimize mass as one of their objectives as they discussed the turbines must be lightweight since the turbines are being installed on roofs of residential homes. Conversely, we chose minimize mass as one of our objectives due to increased efficiency with lighter blades as they are easier to turn, hence capturing more energy. In addition, they chose minimize cost as another one of their objectives to reduce costs for homeowners, while we chose minimize cost since the production and installation of wind turbines will be highly expensive because it is on a larger scale. Both design teams had similar criteria rankings as we both preferred our turbine blades to be lightweight, cost efficient, and to minimize ecological footprint. Additional criteria rankings their design team had included are strong and resistant to heat, in comparison to our team our criteria rankings include yield strength, durability/fatigue strength, stiffness, and availability. The design team had the exact same material finalists as our team. Both design teams had CFRP Epoxy Matrix (Isotropic), high carbon steel, and medium carbon steel as material finalists. However, the material our team had chosen differs from theirs. The material their design team chose high carbon steel as their priority is cost efficiency and this material is very cost efficient since their target clients are homeowners looking to reduce their electricity bill. We chose CFRP, Epoxy Matrix as our material for the turbine blade as we preferred a material that is lightweight, durable, and possesses a high yield strength so the wind blades can be efficient on a nationwide scale. We learned that although both design teams had different scenarios, we both had encountered a various amount of similarities and differences.

Appendix B – References:

[1] . Ennis, C. Kelley, and B. Naughton, "Optimized Carbon Fiber Composites in Wind Turbine Blade Design," *Office of Energy Efficiency and Renewable Energy* [Online]. Available: https://www.energy.gov/sites/prod/files/2019/12/f69/SAND2019-14173-Optimized.pdf, November 2019. [Accessed: October 8, 2020].

[2] S. Mutkule, "Optimum and Reliable Material for Wind Turbine Blade," [Online]. Available: https://www.ijert.org/research/optimum-and-reliable-material-for-wind-turbine-blade-IJERTV4IS020677.pdf February 2015. [Accessed: October 18, 2020].

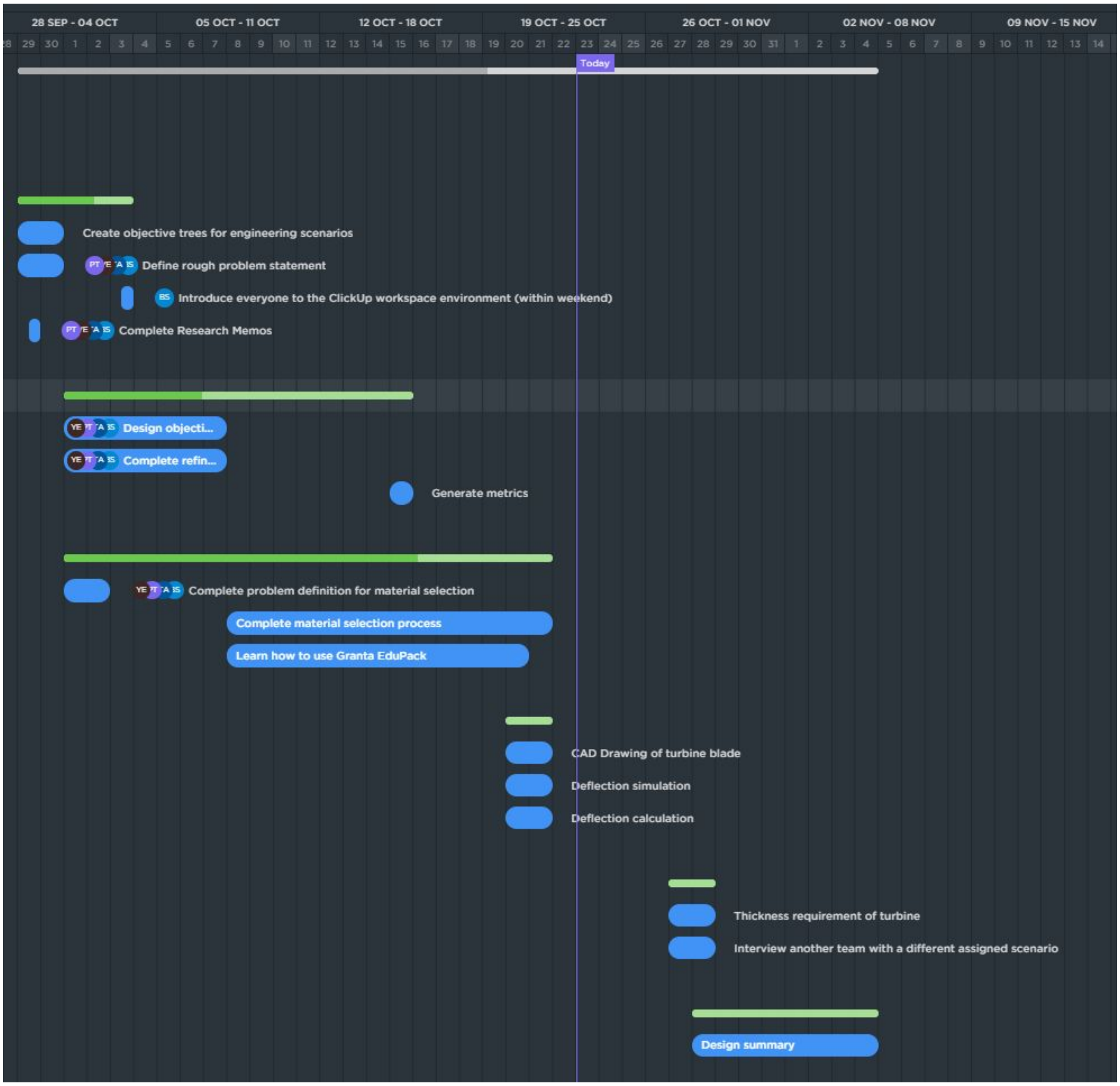
[3] Ansys Granta EduPack software, Granta Design Limited, Cambridge, UK, 2020 (www.grantadesign.com).

[4] "Wk-6 Design Studio (Fall) - P1 Milestone 4 Slides,"class notes for 1P13, Faculty of Engineering, McMaster University, Fall, 2020.

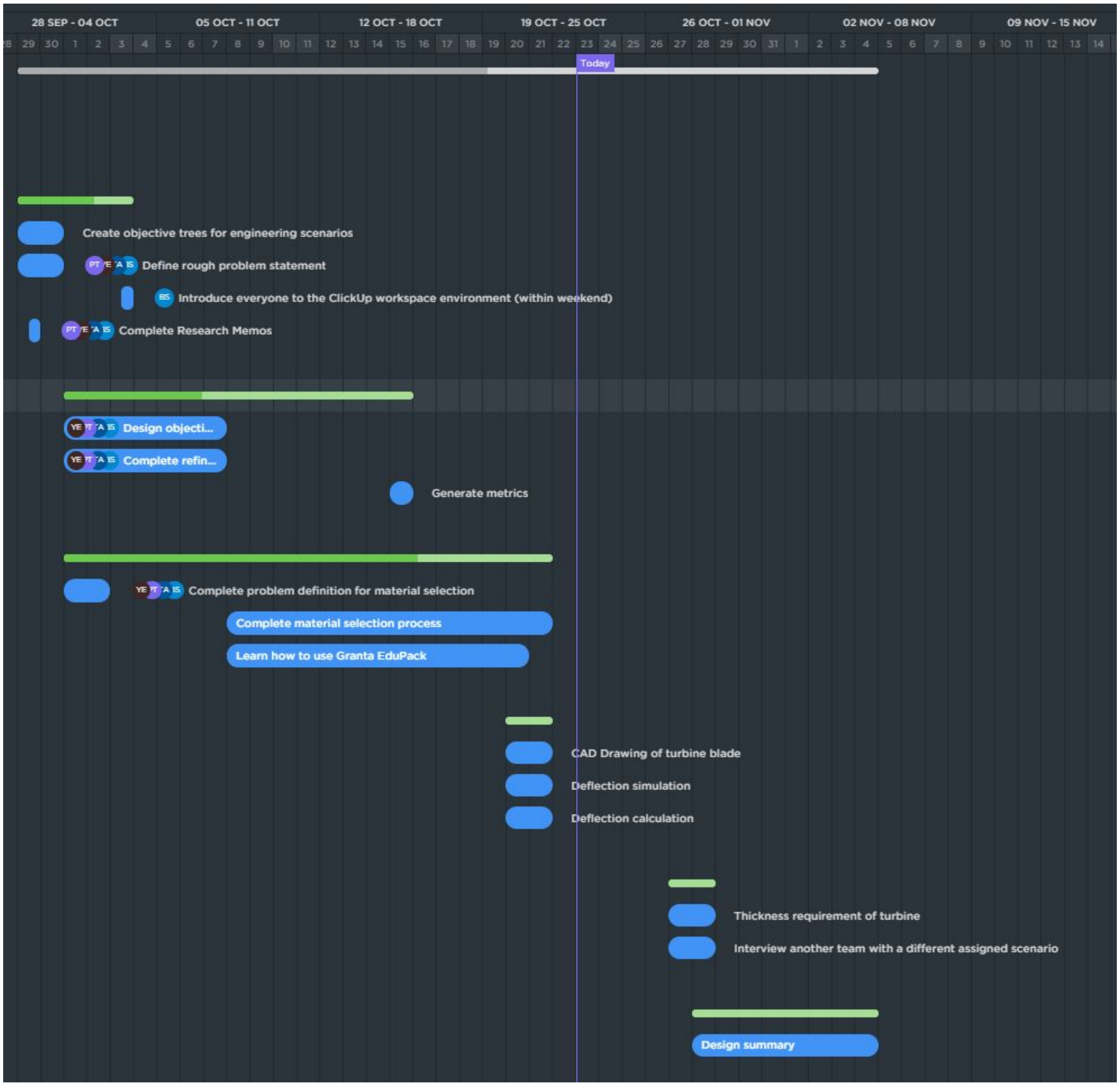
[5] J. Zangenberg, "Wind Turbine Design," [Online]. Available: https://www.sciencedirect.com/topics/engineering/wind-turbine-design. [Accessed: October 18, 2020].

Appendix C – Gantt Chart:

Preliminary Gantt Chart



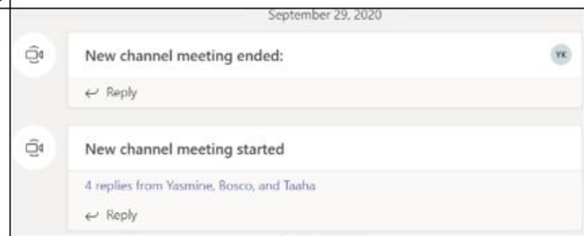
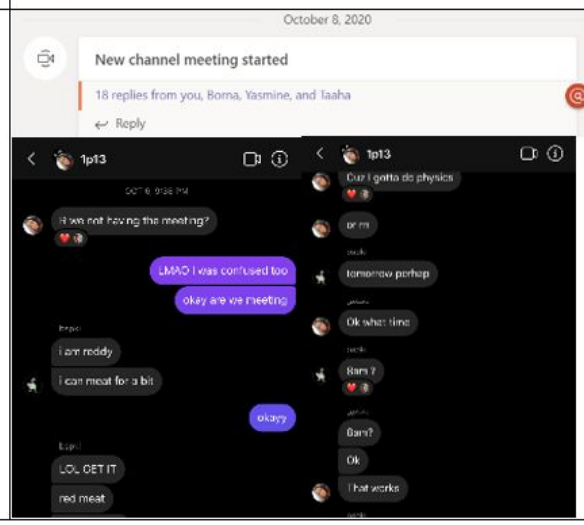
Final Gantt Chart

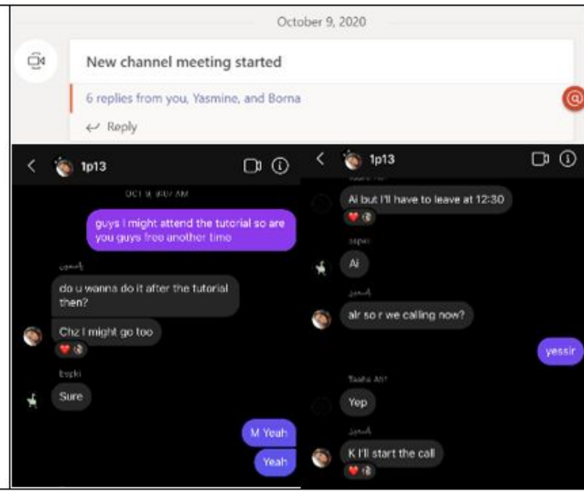
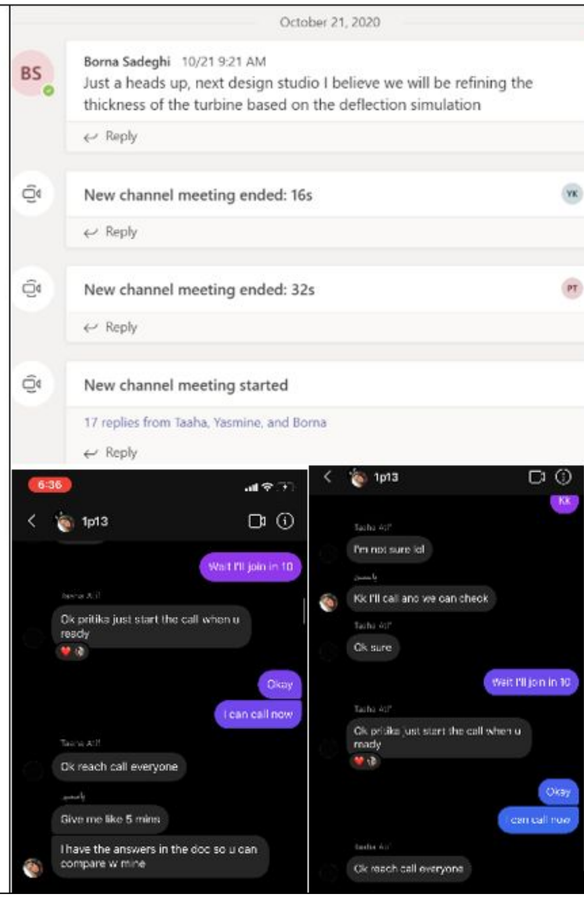


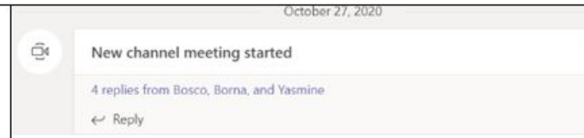
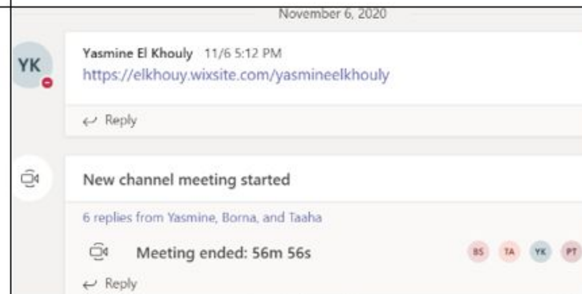
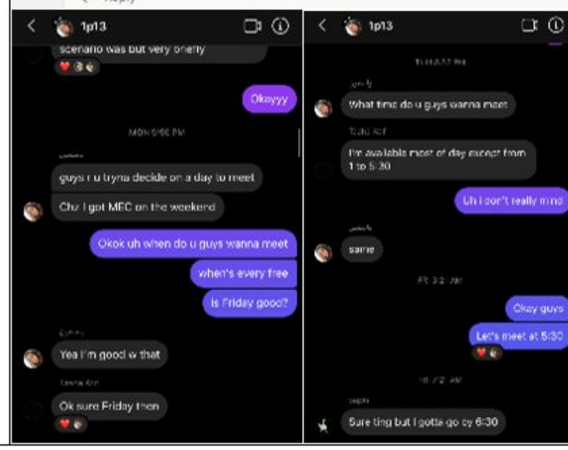
Note: The preliminary gantt chart stayed identical to the final gantt chart as all tasks/assignments were completed on time. (Everything was done as scheduled)

Log Book

Project 1 Logbook

Date	Milestone	Start Time	End Time	Meeting Discussion	Target Met: Yes/No	Image/	Attendees
09/29/2020	P1 MILESTONE 1	2:20PM	3:05PM	To refine and finalize team objective tree for each scenario after design studio	yes		Taaha Atif Yasmine Elkhouly Borna Sadeghi Pritika Thevakanthan
10/06/2020	P1 MILESTONE 2	2:20PM	2:50PM	To complete initial and refined problem statement after design studio	yes		Taaha Atif Yasmine Elkhouly Borna Sadeghi Pritika Thevakanthan
10/07/2020	P1 MILESTONE 2	8:00AM	10:40AM	To complete turbine blade problem statement and objectives	yes		Taaha Atif Yasmine Elkhouly Borna Sadeghi Pritika Thevakanthan

10/09/2020	P1 MILESTONE 3A	12:00PM	2:10 PM	To complete material selection	yes		Taaha Atif Yasmine Elkhouly Borna Sadeghi Pritika Thevakanthan
10/21/2020	P1 MILESTONE 3B	2:45PM	3:30 PM	To finalize simulated deflection	yes		Taaha Atif Yasmine Elkhouly Borna Sadeghi Pritika Thevakanthan

10/27/2020	P1 MILESTONE 4	2:20PM	3:10PM	To complete thickness requirement and summarized notes for peer interview after design studio	yes		Taaha Atif Yasmine Elkhouly Borna Sadeghi Pritika Thevakanthan
11/06/2020	P1 DESIGN SUMMARY	5:30PM	6:30PM	To complete and discuss final deliverable	yes		Taaha Atif Yasmine Elkhouly Borna Sadeghi Pritika Thevakanthan

Appendix D – Source Material Database:

[1] "Wind Power," *National Geographic* [Online]. Available: https://www.nationalgeographic.com/environment/global-warming/wind-power/. [Accessed: September 26, 2020].

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[15] C. Conner and A.M.Oke, “Vertical Axis Wind Turbines vs Horizontal Axis Wind Turbines,” *Windpower Engineering & Development*. [Online]. Available: https://www.windpowerengineering.com/vertical-axis-wind-turbines-vs-horizontal-axis-wind-turbines/. [Accessed: September 27, 2020].

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