Design Project 1 – Renewable Energy Challenge

A Pioneer in Clean Energy

ENGINEER 1P13 – Integrated Cornerstone Design Projects in Engineering

Tutorial L16

Team Tues-52

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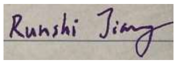

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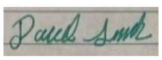

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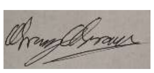

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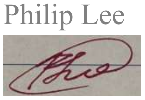

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Finalized Problem Statement

Design a blade that can help the turbines in a wind farm efficiently generate enough power to provide for multiple cities in Sweden, the global leader in the shift to clean renewable energy, at a low cost. Sweden's net greenhouse gas emissions are aimed to be zero by 2045, so the blade must be environmentally sustainable, should have a low carbon footprint, and minimize impact on wildlife. The blade must also be durable, able to withstand expected operational stresses under extreme weather conditions and should be easy to manufacture and repair.

Justification of Technical Objectives & Material Performance Indices

In Figure 1 below, our objective tree focuses on the team scenario of creating turbine blades that pioneer in clean energy.

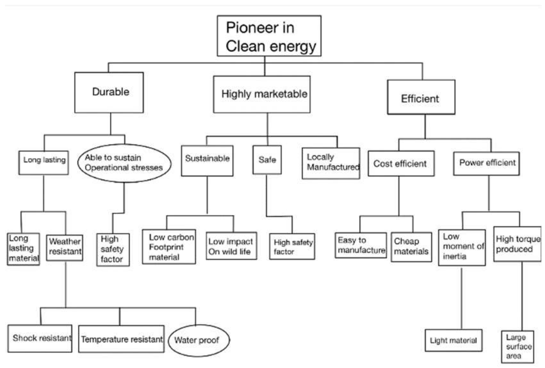


Figure 1. Objective tree of our team scenario, a pioneer in clean energy

Specific towards the country of Sweden, our objectives consist of the blades being durable, highly marketable, and efficient. Of the three objectives, our group decided to focus on the highly marketable and efficient aspect of the blade, hence we prioritized the subobjectives in our objective tree; minimizing carbon footprints from production (primary objective) and minimizing cost (secondary objective). Regarding our team scenario, pioneering in clean energy, a turbine blade that minimizes carbon footprints would be ideal and would greatly contribute to Sweden's goal of eliminating greenhouse gas emissions. Minimizing the cost of the materials is another as it is important for more of said turbine to be created, offering a more efficient and clean way of harvesting wind energy. We also chose the mechanical objectives of stiffness and strength which are important for meeting our objectives of our blades being weather resilient and durable. These technical objectives were combined to create our MPIs (Material Property Indices) which we used for our material selection. Our chosen technical objectives and finalized MPIs are shown in table 1 on the next page:

Table 1, Table of technical objectives and MPIs

	Objective	MPI-Stiffness	MPI-Strength	Justification for this objective
Primary	Minimize carbon footprint from production	EρCO2	σyρCO2	Low carbon footprint is one of the objectives listed in our objective tree. A pioneer in clean energy needs to be climate friendly every step of the way.
Secondary	Minimize Cost	EρCm	σyρCm	A pioneer in clean energy ideally needs to be practical and easily implementable at a large scale, and cost is a major factor in practicality and marketability.

With all these criteria, we are ensuring that we choose the appropriate material that will ensure the country of Sweden a significant boost in harvesting energy efficiently with low environmental impacts.

Conceptual Design – Justification of Selected Material:

After deciding on the MPIs for our material, for each MPI, we graphed the materials accordingly in Granta, and then used a line whose slope was the inverse of the exponent of the constraint variable along with the rank by index value option to determinate the top 5 options for each MPI, as shown in figure 2 below.

Material Property Chart		
Assigned MPI	**Functional Constraint**	**Objective**
Strength $\frac{\sigma_y}{\rho C_m}$	$\sigma < \sigma_y$	Minimize cost

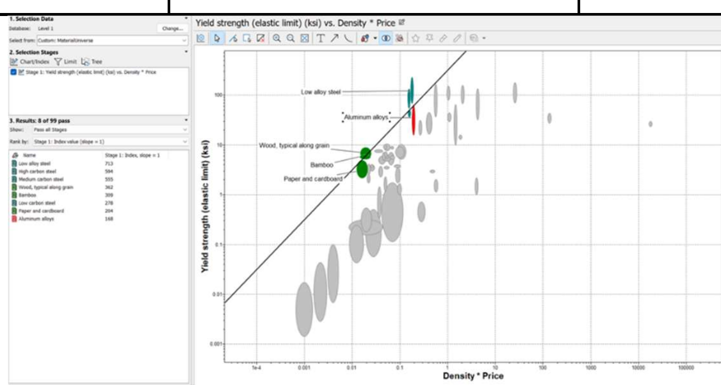


Figure 2: Sample Granta Diagram for Strength and Carbon Footprint

As instructed, we treated steel as one material due to the family of materials having comparable properties, but we also kept track of the ranking of each subtype of steel. Table 2 below records our results for each MPI.

Table 2: Individual Material Rankings

Consolidation of Individual Material Rankings					
	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
MPI 1: $\frac{E}{\rho CO_2}$	Steel (high carbon, medium carbon, low carbon, low alloy, stainless)	Zinc alloy	Bamboo	Wood	Cork
MPI 2: $\frac{\sigma_y}{\rho CO_2}$	Wood	Bamboo	Cork	Steel (low alloy, high carbon, medium carbon, low carbon)	Paper and cardboard
MPI 3: $\frac{E}{\rho C_m}$	Steel (medium carbon, high carbon, low carbon, low alloy, stainless)	Bamboo	Wood, typical along grain	Aluminum alloys	Paper and cardboard
MPI 4: $\frac{\sigma_y}{\rho C_m}$	Steel (low alloy, high carbon, medium carbon, low carbon)	Wood, typical along grain	Bamboo	Paper and Cardboard	Aluminium alloy

We then calculated the appearance rate of each material in each MPI and selected our top 3 materials using that. Our top three materials were steel, wood, and bamboo.

Additional Material Considerations

Recognizing that our MPIs are only able to capture quantifiable aspects of our materials, we decided to use a weighted decision matrix to account for our qualitative requirements for our material. The additional criteria were decided by group discussion and based off the objectives in our objective tree. These considerations can be equally as important as our quantitative considerations. For example, ease of manufacturing of a material contributes to the actual cost associated with using the material, which is something not accounted for by the data given by Granta. Bamboo might be a cheap material in general but crafting a 100-metre-long hollow blade with complex geometry using it is an engineering project never attempted before, making it likely an extremely expensive endeavor, contrary to what Granta's data may suggest. Additionally, to account for how different qualities contribute differently towards our objectives, we assigned each criteria a weighting based off our own judgments of their importance. The resulting matrix is shown below in table 3.

Table 3: Weighted Decision Matrix

Weighted Decision Matrix							
	Weighting	*Material 1: High carbon steel*		*Material 2: Bamboo*		*Material 3: Wood*	
		Score	Total	Score	Total	Score	Total
Ease of Access	3	5	15	1	3	5	15
Weather resistance	5	5	25	2	10	1	5
Ease of maintenance	3	4	12	1	3	3	9
Ease of manufacturing	2	4	8	2	4	2	4
	TOTAL		60		20		33

In the end, steel won by considerable margins, scoring the highest in every criterion. This aligns with the material choice of conventional large scale wind turbines, and according to our selection process, was also the best material for this project. Finally, we analyzed the rankings of several types of steel using the MPIs and observed that high carbon steel consistently scored at the top of the rankings and thus it became the obvious choice for our project.

Design Embodiment – Justification of Solid (CAD) Modelling

Initial Parameters

For our scenario, we need to design a turbine which needs to provide a large amount of energy for Sweden. So, our blade needs to be custom fit for the environment and regulations in Sweden while remaining very efficient. According to the Global wind atlas, high wind speed areas in Sweden average around 8 m/s [1] and the density of air is $\rho=1.29 kg/m^3$ [2]. There are also regulations around noise caused by turbine blades, noise generated is correlated to rotational speed, so we set our turbine speed to 7 RPM accordingly which is on the low end for onshore wind turbines in Sweden [3].

Determination of blade length:

First, we determined our blade length for our turbine. Modern wind turbines have a preferred efficiency of 40% which will serve as our initial estimation for the efficiency of our turbine [4]. Through calculations in Milestone 2 Stage 4, we determined we need 3.56×10^{12} Watt hours generated per year to uphold with the watt usage in Sweden for 3 cities [5]. To calculate the wattage of each turbine, we converted the units of our requirement to watts, and then divided by the total size of our wind farm (100) to arrive at an estimation of the wattage of each turbine.

$$3.56 \cdot 10^{12} \ \frac{Watt\ hours}{year} \cdot \frac{1\ year}{3.154 \cdot 10^{7} s} \cdot \frac{3600\ s}{1\ hour}$$

$$= 4.06 \cdot 10^{8} \ Watts$$

$$= 406\ MegaWatts\ per\ 100\ turbines$$

$$\therefore \sim 4\ MW\ for\ each\ wind\ turbine$$

Then using the wind power equation $P = 0.5\rho A v^3$ and our previously calculated value of P = 4MW, we can find A (swept area) to then find the blade length. This is done by using the A value that we find and substituting it into the equation $A = \pi r^2$, to find the radius of the swept area, which is equivalent to the length of a turbine blade. Assuming an efficiency of 40%, we get:

$$P = 0.5\rho A \nu^3$$

$$A = \frac{4000000}{(0.4)(0.5)(1.29)(7.5)^3}$$

$$A = 36749.92822\ m^2$$

$$A = \pi r^2$$

$$r = \sqrt{\frac{36749.92822}{\pi}}$$

$$r \approx 100\ m$$

Therefore, the blade length of 100 meters is a good approximation for what is needed to meet our decided wattage for our turbine.

Determination of blade angles

We split the blade up to 4 sections: connective component (10m long, does not contribute to lift), root of the blade (30m long), mid-section (30m long) and tip (30 m long). We then selected adequate airfoils for each section. We selected the NREL (National Renewable Energy Laboratory) S818 airfoil for the root as the root needs to sacrifice some aerodynamic performance for structural strength [6]. We selected the NREL S828 airfoil for the tip, which is thin and light with great aerodynamic performance, exactly that the tip of the blade needs [6], and finally we chose the S827 for the mid-section as it is a good intermediate airfoil which offers both structural strength and good aerodynamic performance [6].

Air foils produce lift, but at the same time causes drag, thus the angle of attack of the blades need to achieve the optimal lift to drag ratio for maximum efficiency [7]. This depends on the velocity of the blades. Since the velocity of the blade is not uniform (the tip will move faster than the root), the optimal angle changes depending on the distance to the tip, making it necessary for the blade to have a twisting geometry [3]. Therefore, we took that into account when calculating the optimal angle of the airfoils. We chose 3 airfoil designs, one for the root of the blade, one for the mid-section, and one for the tip. We then added the velocity vector of the wind with the velocity vector of rotation at that part of the blade to find the angle of the local wind velocity [6]. Then using the data on the airfoil, we can find its optimal angle of attack, we can then add the angle of attack to the angle of the local wind velocity vector to get the optimal angle of the airfoil. Figure 3 below shows a sample calculation for the optimal angle of the tip of the blade.

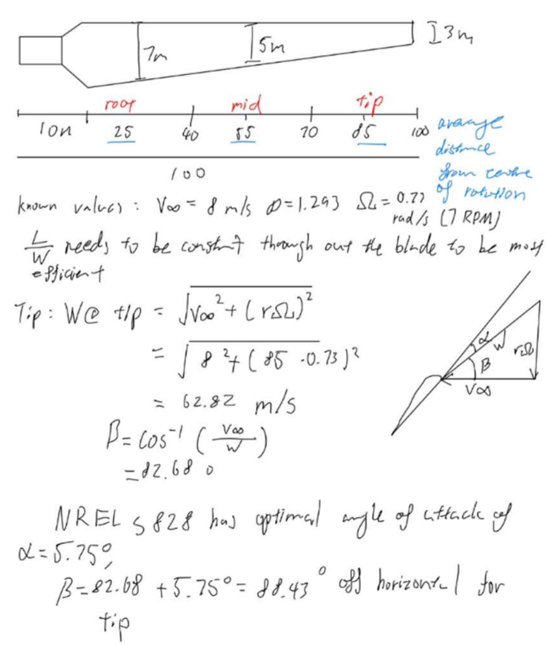


Figure 3, Sample calculation of optimal blade angle for the tip of the blade

Doing so for each blade section gives: 75.42 deg for the root, 84.03 deg for the mid-section, and 88.43 deg for the tip.

Determination of chord length to optimize for even circulation

Having an even circulation around the blade minimizes loss of energy due to air vortexes created by the blade [6]. Circulation is given by the equation: $\Gamma = \frac{L}{\rho W}$ where L is lift, Γ is circulation, ρ is air density, and W is local windspeed [6].

For circulation Γ to be constant we need to ensure the lift to local windspeed ratio is constant (as air density is constant, it is not a concern). We can calculate this using the lift formula and our previously calculated local windspeeds. We first set the chord length at the tip to be 3 meters, solved for the lift to local wind speed ratio, and then used that to calculate the chord length of the other sections.

$\frac{L}{W}$ calculations:

Chord @ tip = 3m

r = section length

$$L = C_L \tfrac{1}{2} \rho W^2 C r$$
$$= 1.1 \cdot \tfrac{1}{2} \cdot 1.293 \cdot (62.82)^2 (3)(30)$$
$$\approx 252580 \text{ N}$$
$$\frac{L}{W} = \underline{4020.7}$$

$$L = C_L \tfrac{1}{2} \rho W^2 C r$$
$$= 1 \cdot \tfrac{1}{2} \cdot 1.293 \cdot (41.10)^2 \cdot C \cdot 30$$
$$= 32762\ C$$
$$\frac{L}{W} = \frac{32762\ C}{W}$$
$$4020.7 = \frac{32762}{41.10} C \qquad C = 5.04\text{m} \approx 5.0\text{m}$$

mid section has chord length 5 m, and is 84.03° off the horizontal

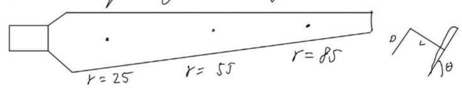
Figure 4: Calculation of L/W ratio and sample calculation of chord length

The calculations are shown above in figure 4. The same is done with the root, and the result is that the tip, mid-section, and root should have chord length 3, 5, and 7 meters for optimized circulation.

Estimated power generation calculation

Now having determined the exact parameters of our blade, we can add together the lift and drag forces produced by each blade section in the direction of rotation to estimate the total torque generated per blade. The total power generated per blade can be obtained by multiplying torque generated by the rotational speed of the blade [6]. The calculations are shown on the next page in figure 5.

Total Torque generated per blade



Torque = the vertical component of lift force · distance from center of rotation

Torque tip $= r \cdot L_y - r \cdot D_y$
$= rL(\cos\beta - \frac{CL}{CD}\sin\beta)$
$= 2475724$ Nm

Torque mid $= r(L_y - D_y)$
$= rL(\cos\beta - \frac{CL}{CD}\sin\beta$
$= 55L(\cos(\beta) - \frac{CL}{CD}\sin(\beta))$
$= 1649348$ Nm

Torque root $= r(L_y - D_y)$
$= rL(\cos\beta - \frac{CL}{CD}\sin\beta)$
$= 791060$ Nm

torque total $= 4.9 \times 10^6$ Nm Nm

Power $= \tau\Omega = 3.6$ Mega watts

Figure 5, Calculation of Power generated

Our calculations show that our blades can theoretically produce 3.6 megawatts per blade, so 10.8 megawatts total with 3 blades. This value is way over the 4 MW goal, but this is not accounting for all the loss of energy and unideal circumstances which occurs during operation; thus, we have determined this power output to be an adequate one for our design. We then created a model of the blade in inventor according to our design.

CAD model and Multiview sketch

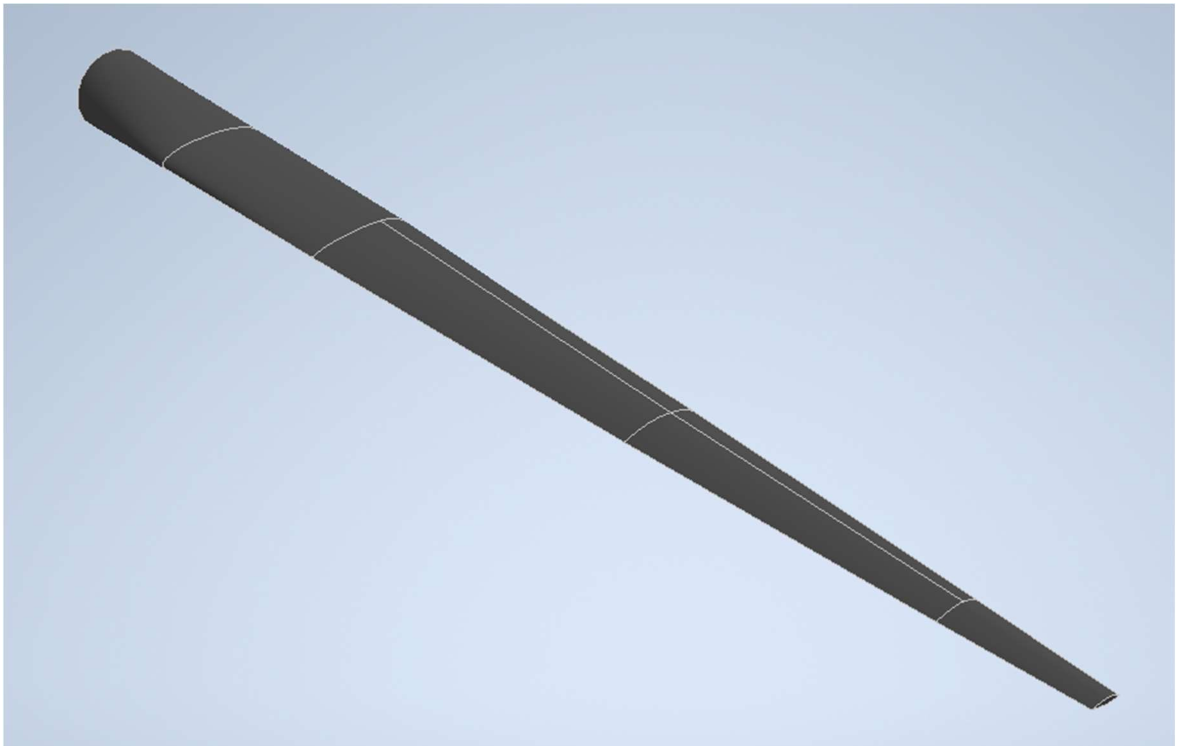


Figure 6: CAD model of the blade design

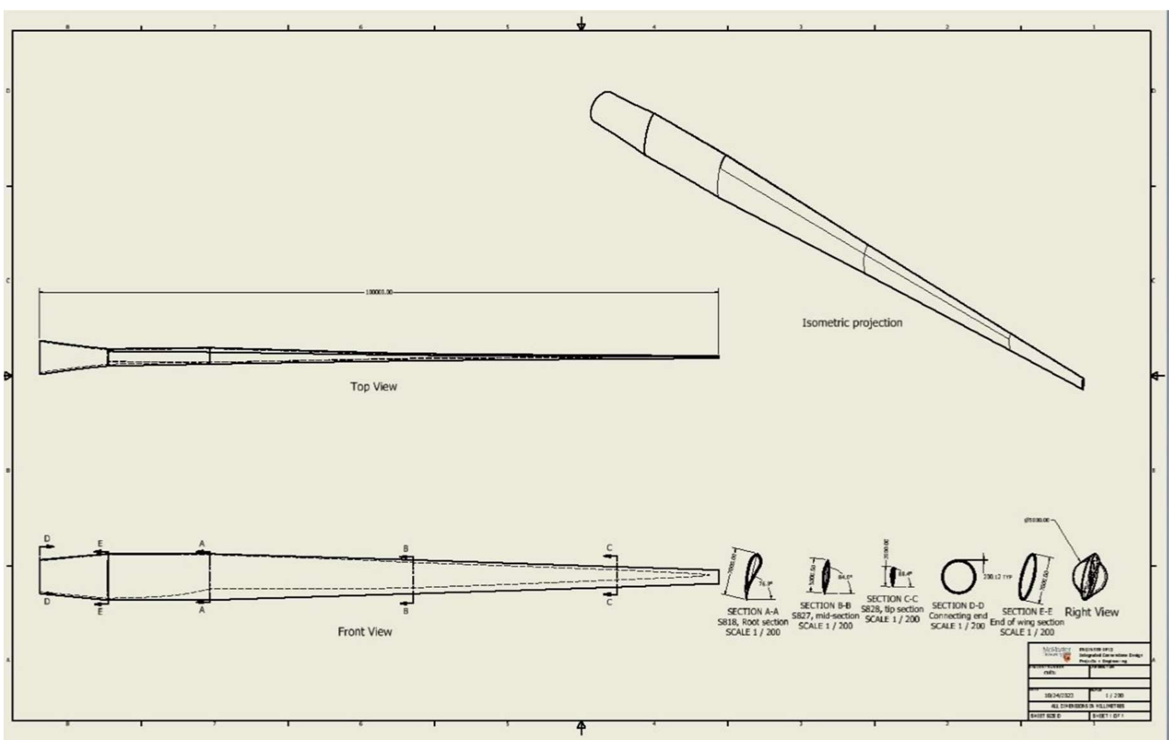


Figure 7: Multiview drawing of the blade design

Deflection Simulation

During the operation of a wind turbine, its blades encounter massive pressure from the wind, causing them to deflect. Deflection of the blade can cause many issues, from reducing the efficiency of the turbine to causing life threatening disasters where the turbine blades hit the tower. Thus, it is important to calculate an allowable deflection constraint and adjust our design parameters accordingly to ensure that our blade design will meet said constraint. For this project we decided to modify our blade thickness to meet the constraint and we did so by doing a deflection simulation in Autodesk Inventor.

Satisfying the Constraint

Based on the properties of the material we chose (high carbon steel) we used the given blade design A. We then ran a deflection simulation on the blade, using the material properties we obtained from Granta for our blade and the given wind pressure. Our given deflection constraint stated that the maximum deflection should be 10 millimetres, and for cost and environmental concerns we want the blade to use as little material as possible, so we adjusted the thickness to be as small as possible while still meeting the constraint of 10 millimetres. We found that as thickness decreases the deflection increases, and with a thickness of 24.8 millimetres, we can achieve a maximum deflection of 9.952 millimetres as shown in figure 8, which is very close to but not exceeding our constraint of 10 millimetres. This allows us to maximize for our objectives of low cost and low environmental impact while still ensuring the safety and reliability of our turbine.

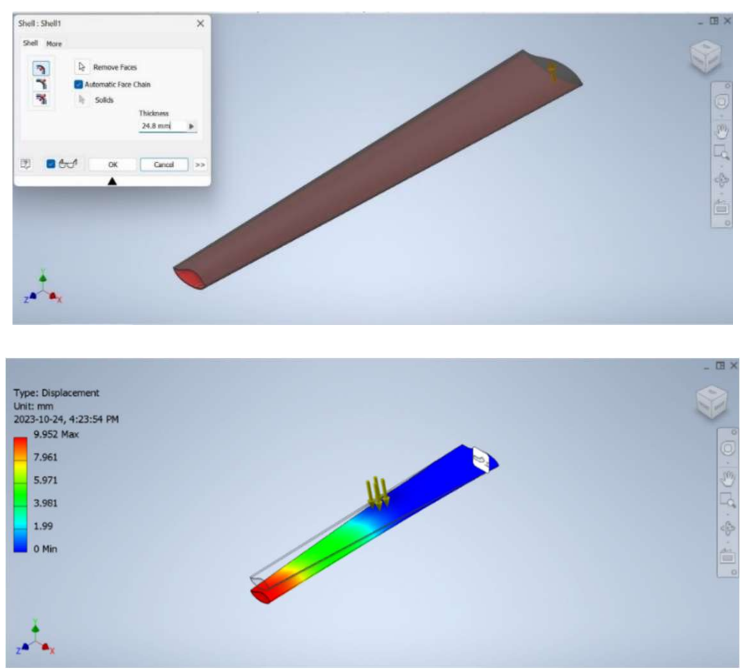


Figure 8: deflection simulation result

Discussion of Regulations

In our scenario, our wind turbine blades are to be used in Sweden, which has its own set of legal requirements, regulations, and zoning laws that are to be abided by. With our scenario, we would be classified as a large offshore wind turbine farm, which has its own set of laws to be followed. These legal requirements include a permitting process which is divided into 3 steps and takes anywhere from 2-3 years to be accepted. The process contains the consultation process where an administrative board and municipal committee are required to approve information like the wind farm's location, technical details, the actual size of the wind farm, environmental impact, and some designs for the wind turbines [9]. Our design does so by providing the exact measurements and drawings of the turbine blades, in design through calculations of power generation per blade and power consumption in Sweden, we were able to determine how many turbines would be required in our wind turbine farm. Also, the materials we used were a factor of the environment we would be affecting around us through transportation of materials, usage during, and how we dispose of the materials when the turbine blades are scrapped. The second step is the EIA which determines how humans, wildlife, climate, and the area are affected by the wind turbines directly and indirectly. This is used to prevent any harmful effects the wind turbines may have when placed [9]. Our design does so by including objectives like sustainability that are measured by the carbon emissions, materials used, and impact on wildlife. Our group tried to cancel as much noise as we could by limiting the number of revolutions per minute to 7. Something our group could have done for the noise pollution with such big turbine blades and how it would harm the environment around it is a technology like noise cancellation barriers around the wind farm to decrease the noise pollution in surrounding areas to both humans and wildlife. Also, something our group should have approached was the exact location our wind turbine farm would be in to reduce the amount of environmental damage when building it. The last step of the process is the drawings and technical details of the project, which include specific details like the wind turbine blade itself, as well as the output ranges, materials used, installation process, estimated emissions, and suggestions on how the wind turbine farm will be controlled [9]. Although this is the main process, other permits required to use the turbine blades are permits under the Cultural Heritage Act, a permit for the construction and use of power lines, an environmental permit after conducting an environmental assessment, a radar permit study, and an aviation obstacle permit [9]. These are not something that we obtain through the design of our turbine blades.

To follow up on the legal requirements and regulations of the project, we also have to understand and follow the analytic safety measures to be followed when designing our wind turbine blade. When creating our wind turbine blade, we had to consider many safety measures such as the safety distance from powerlines that they were to be placed. Since we created large turbines, the safety distance was "For wind turbines with a rotor diameter of 100 metres or greater, the distance between the powerline and wind turbines shall be greater than 250 m" [10]. Our design complies with the permits since seven or more wind turbines together with a height of 150m or greater are considered a large wind farm. Since our blade is the radius of a wind turbine and is larger in diameter, our design complies with the regulations that classify it as a large wind farm and therefore complies with the other regulations [10]. Because of the design of our wind turbine blade, we exceeded the 1.5MW capacity which means we require specific guidelines to be followed [9]. Since our scenario was based in Sweden, most regulations for energy were only determined by the committee and not strict guidelines of how exactly to do it, so we were kind of free to have our guidelines on how exactly to create the turbine blade. However, because of how large we made each turbine blade, we ran into many more problems and processes because we required more than a medium wind farm would need to install and use. One thing our group could have done differently would be to decrease the size to avoid some of the restrictions on larger wind farms. One analytical requirement that we did need to follow was that our wind farm would be able to support electricity for multiple (we chose 3) cities in Sweden. After calculations, we determined the length of our wind turbine that would best relate to the socio-cultural concerns. Seeing that each person consumes on average 11820kWh [7], doing some calculations our group was able to provide the proper length required to generate enough power for the cities, therefore fulfilling the socio-cultural concerns of the area.

Discussion of Sustainable Choices

Given the fact that one integral aspect of our scenario is to create such a wind turbine that is relatively clean, it is therefore without a doubt that sustainability was taken into consideration for most of our decisions and processes. When considering long term sustainability, the deciding factor was the selection of the material. As aforementioned, our selection was high carbon steel, as this was done factoring in for minimizing carbon footprints from production, all while minimizing the costs, and considering the MPIs for strength and stiffness. Yet, looking beyond Granta EduPack, high carbon steel still has properties that make it a suitable contender for sustainability. High carbon steel is strong due to its shock resistant properties, as well as it not being as susceptible to rotting, increasing longevity. It is also relatively easier to recycle compared to other materials, promoting green practices when the wind turbine reaches the end-of-life stage [11]. This means that once not in use anymore, the material can be used for other applications. Generally speaking, the production of steel emits harmful greenhouse gases due to smelting powered by fossil fuels [12]. But because Sweden aims to reduce greenhouse gas emissions and clean energy, these processes can be instead powered by renewable energy being promoted in Sweden. By taking in account for power, efficiency and national statistics, the blade has been designed in such a manner that it has to power multiple large cities in

Sweden. By deciding our length, rotating speed, angles, and sectioning the blade into 4 parts, a farm of 100 turbines can efficiently generate power. When we optimize efficiency, we help the environment by generating the same amount of electricity with fewer wind turbines. A pitfall of this design, in the sense of wildlife, is that the blade length is typically longer than average [13]. There is a trend of wind turbines killing birds, and logically longer blades increase the risk of hitting them [14]. This can potentially cause a decline in populations of flying species. When looking at the locations of the turbines, Sweden offers many good ones thanks to its topography of flat lowlands and rolling hills [15]. When looking at the end-of-life stage of the turbine in the sense of location, oftentimes it is more sustainable to leave the infrastructure below the ground after decommissioning. Removing this infrastructure can cause carbon emissions, water backlog, and erosion [16]. Sweden has multiple regulations in places as mentioned in the above sections, and the main one for ensuring a sustainable environment is the Environmental Impact Assessment (EIA). This means keeping humans, wildlife and climate safe. In conclusion, the sustainable choices that were mentioned above meet, or at least, try to meet the standards of the EIA.

Peer Learning Interview

When interviewing the other team for their turbine blade, we learned from their blade based on their scenario-specific turbine blade design that they based many decisions qualitatively as opposed to analytically. What they did when designing their blade was first had objectives that connected closely to their scenario, which included a primary objective to minimize the volume of each blade because each blade is to fit on the roof of an average house in Calgary. The secondary objective for them was to minimize production energy, which they said was tied in with affordability and production cost. Our group agrees that these are agreeable objectives when looking at factors like marketability and even considering zoning laws. But, considering the scenario, we would focus more on structural integrity instead of affordability so that it can be efficient enough to generate enough electricity to reduce hydro bills as opposed to the initial cost of the turbine. Other objectives included in their objective tree were around the basis of safety, efficiency, and affordability. Another important factor our group would consider is the durability of the turbine blade because the city of Calgary has high average wind speeds [1], we would want the turbine blades to be long-lasting which means durable and easy maintenance. With their objectives, they created a 4-blade, vertical wind turbine design, which was 40% more efficient in not disrupting their airflow within an area, compared to the flow a horizontal wind turbine blade would fabricate. This is something our group highly agrees on because it targets one of the main goals of a turbine, to generate power, and does so efficiently and uniquely. They also focused on affordability a little bit too much when they should not have been so worried about the initial cost, but the efficiency so that later energy bills cost less, and house owners make more profit from the turbine(blades). For their material, they chose tungsten alloy which was a severely huge mistake because of the weight of the material, where with the scenario it is almost certain that the material would fall through the roof seeing that tungsten alloy is very heavy, 0.08lbs for a 0.5inch cube, which as it increases would become very heavy. Also, the tungsten alloy would be a very expensive material to buy which disregards their objectives entirely [17]. Our group would go with a cheaper and lighter, but still heavy enough to be durable, material like carbon steel, aluminum, or fibreglass polyester. With their assigned material, the group used blades with a thickness of 13.633mm which gave them a deflection of 9.999mm, which is highly acceptable since it was so close to a deflection of 10mm. The other group calculated the power used on an average home, which influenced how their design was and how much power their blades would need to generate, which we also would have done. The design challenge for them was making a wind turbine blade that was 20 lbs per square foot, while also being 30ft above anything within 300ft of anything surrounding. Their blades were 1.75m each which is a respectable height with their assigned scenario, which can pick up enough wind but is still not too large. One of the technicalities their group looked at was the noise level and to be under 40dB, however their group did not do any measurements to follow up on that constraint. Faced with this problem our group would put a restraint on the rpm. The main problem with their design is that they did not incorporate many analytical measurements, and therefore did not have much justification for any measurements, whereas our group would have focused more on that by considering factors such as the average wind speeds in Calgary to know the percent efficiency. Overall, if placed with the task of scenario 3 our group would have had many similarities to the other teams, but also many differences.

Concluding Remarks - Reality Check

Upon given the scenario of *A Pioneer in Clean Energy*, we asked ourselves the question: "How can we design such a wind turbine for Sweden, which is capable of generating larger amounts of power while not taking a compromise on clean energy?" We then shifted on the design of the blade with our focus on reducing carbon footprint, sustainability, efficiency, durability, and marketability. With Granda EduPack the MPIs, constraints, and objectives were all considered for. After ranking our top 5 materials in each section, it was clear that high-carbon steel was the best fit material. In terms of modelling the design of the blade, there were multiple factors we had to take in considerations. By using national statistics and climate data, it was decided that the blade length should be 100 m. In terms of more advanced modelling, we decided to go for a 4-section approach for the blade. Each section had their own unique airfoil, for a unique function, and had an ideal blade angle. We also determined the chord lengths for the outer 3 sections as aforementioned. To confirm that our design was ideal, we once again calculated the power generation, for which it satisfied our needs even when considering efficiency losses. After using Autodesk Inventor and using a stress simulation, we determined that our blade thickness should be 24.8 mm because we had a constraint of 10 mm, and it maximized our objectives. Our design is to be applied to large wind farms in Sweden, so, it must go through a 3-step verification process in Sweden. After consultation with the administrative board, then the EIA, the third step is to consider actual technical details of the design, and make sure that they align with the regulations mandated by the government, for which the blades does. In terms of sustainability and the environment, the impact mainly lied in our material selection due to its durability, lower carbon footprint, and end-of-life applications.

One thing we did not take in account for was the blade deflection when calculating the optimal angles. Even beyond the blade itself, there can be other aspects to consider when pioneering clean energy for Sweden. One can be the modification of the tower, in order to properly take advantage of the high-altitude winds. Even the removal of the tower and creating a flying wind turbine through blimps can really maximise efficiency.

All in all, we created such a wind turbine blade that can be applied for pioneering clean energy in Sweden by selecting our material considerably, optimizing the design, and foreseeing long-term sustainability, which resulted in a lower environmental impact while not taking a compromise in efficiency.

Summary of Contributions

Name	Contributions
Daniel Smuk	Discussion of Regulations, Peer Learning Interview, Appendix A, Milestones 1-4, References
Philip Lee	Finalized Problem Statement, Justification of Technical Objectives and Material Performance Indices, Milestones 1-4, Appendix A, References
Afraz Akram	Discussion of sustainable choices, concluding remarks-reality check, Appendix C, Milestones 1-4, References
Leo Jiang	Justification of selected materials, Justification of CAD modelling, Appendix A, Appendix E, Milestone 1-4, References

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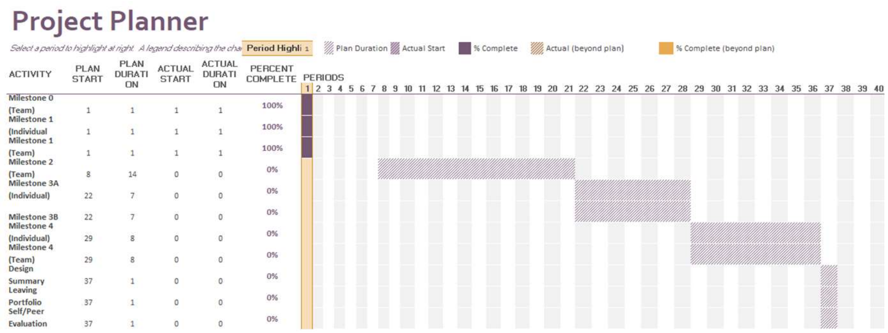
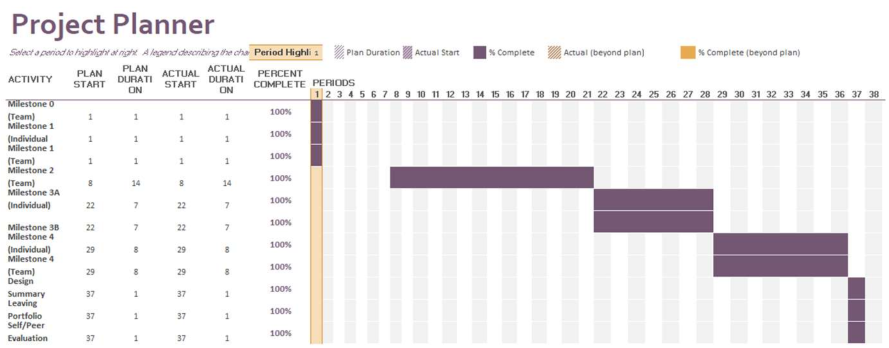
Appendix A: Project Schedule

Preliminary Gantt Chart

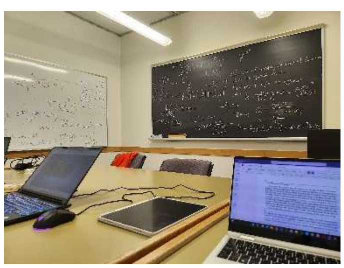


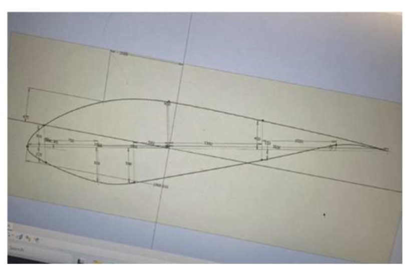
Final Gantt Chart



Logbook of Additional Meetings and Discussions

October 20: Our group has all agreed to meet and work at Thode library to discuss the shape and size of the turbine blade. This was specific to the multi-view sketch and CAD modelling of the blade, and the justification of its design choices. Our group worked for hours collaboratively, as shown in the images below, and was able to complete the written component and CAD model of the blade.





October 26: Our group has again agreed to meet up at the Thode library and distribute the work for the final report. Each group member was assigned to complete two sections of the final report minimum and work collaboratively on remaining components, such as the reference list and summary of contributions. During

this collaborative work period, some of our group members were able to finish some of their report's sections and had others review and give appropriate feedback.

November 2: Our group has agreed to meet at the Thode library for the final time to finalize everything in the report. Our group went over each element of our report and compared it to the standards set on the rubric, improving on sections where needed. For example, there would be some sections where more information could be provided to make our ideas clearer. After about an hour of final revisions, everyone was satisfied with the report, submitting it soon after. The below image shows evidence of the meeting.

Appendix C: Comprehensive List of Sources

Individual Research Memo – Afraz Akram

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Individual Research Memo – Runshi Jiang

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Individual Research Memo – Philip Lee

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Individual Research Memo – Daniel Smuk

[1] Z. Shahan, "History of Wind Turbines," 6 April 2018. [Online]. Available: https://www.renewableenergyworld.com/storage/grid-scale/history-of-wind-turbines/#:~:text=1887%3A%20The%20first%20known%20wind,now%20known%20as%20Strathclyde%20University. [Accessed 1 Oct 2023]

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Appendix E: Design Studio Worksheets

PROJECT ONE MILESTONE (TEAM) WORKSHEETS

Milestone 0 (Team): Cover Page

Team ID: Tues-52

Please list full names and MacID's of all *present* Team Members

Full Name:	MacID:
Philip Lee	leep46
Afraz Akram	akrama7
Daniel Smuk	smukd
Leo Jiang	Jiangr42

Insert your Team Portrait in the dialog box below

Milestone 0 – Team Charter

Team ID: Tues-52

Project Leads:

Identify team member details (Name and MacID) in the space below.

Role:	Team Member Name:	MacID
Manager	Daniel Smuk	smukd
Administrator	Leo Jiang	Jiangr42
Coordinator	Philip Lee	leep46
Subject Matter Expert	Afraz Akram	akrama7

Milestone 0 – Preliminary Gantt Chart (team Manager ONLY)

Team ID: Tues-52

Only the **Project Manager** is completing this section!

Full Name of Team Manager:	MacID:
Daniel Smuk	smukd

Preliminary Gantt chart

Project Planner

Select a period to highlight at right. A legend describing the cha Period Highli 1   Plan Duration   Actual Start   % Complete   Actual (beyond plan)   % Complete (beyond plan)

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	1	100%
Milestone 2 (Team)	8	14	0	0	0%
Milestone 3A (Individual)	22	7	0	0	0%
Milestone 3B	22	7	0	0	0%
Milestone 4 (Individual)	29	8	0	0	0%
Milestone 4 (Team)	29	8	0	0	0%
Design Summary	37	1	0	0	0%
Leaving Portfolio	37	1	0	0	0%
Self/Peer Evaluation	37	1	0	0	0%

PERIODS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40

Milestone 1 (Team) – Cover Page

Team ID: Tues-52

Please list full names and MacID's of all *present* Team Members

Full Name:	**MacID:**
Philip Lee	leep46
Afraz Akram	akrama7
Daniel Smuk	smukd
Leo Jiang	Jiangr42

Any student that is ***not*** present for Design Studio will not be given credit for completion of the worksheet and may be subject to a 10% deduction to their P-1 grade.

Milestone 1 (Stage 1) – Initial Problem Statement

Team ID: Tues-52

Stage 1: Initial Problem Statement:

What is your first draft of the problem statement? Keep it brief and to the point. One or two sentences should be enough. **For this initial problem statement, you should be focusing on the main function(s) of the wind turbine.**

Create a solution that can efficiently convert the kinetic energy of wind into usable electrical energy sustainably to replace unsustainable and inefficient means of energy generation. The design should be eco-friendly, cheap, and durable.

Milestone 1 (Stage 3) – Refined Objective Trees

Team ID:	Tues-52

For each engineering scenario, you will be submitting a modified/revised objective tree agreed upon by the group. Each branch of objective trees should have a minimum of 3 layers. This can be hand-drawn or done on a computer.

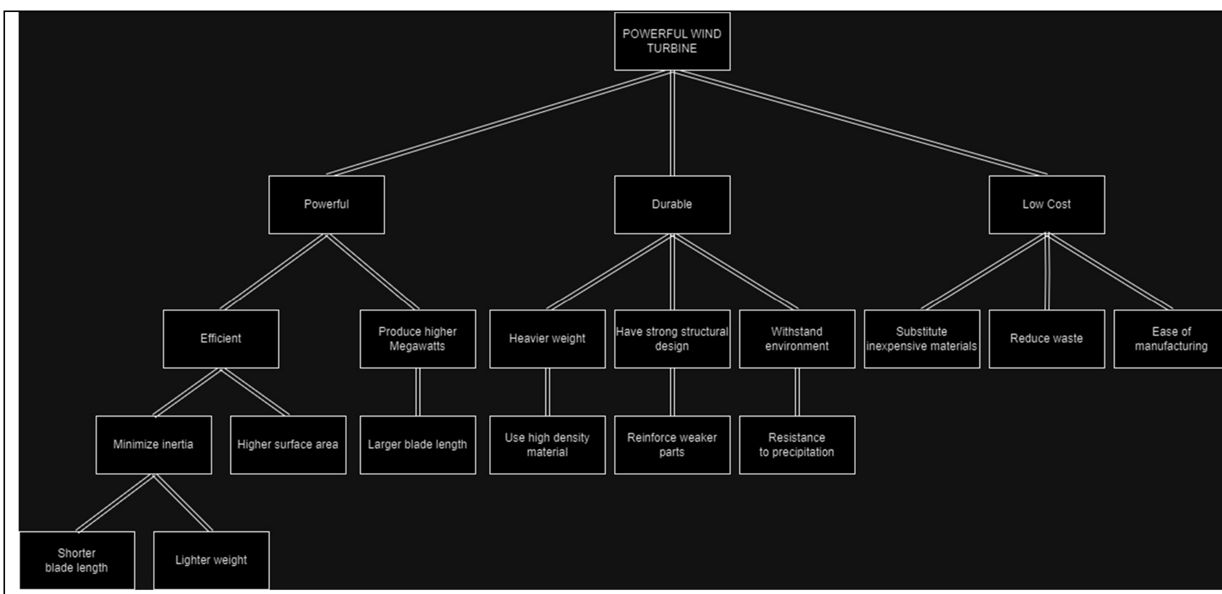
Engineering Scenario #1

The title of the scenario

Renewable Energy for a Large Population

Team objective tree diagram for scenario #1

Please insert a copy of the refined and finalized team objective tree for scenario #1.



Team ID: Tues-52

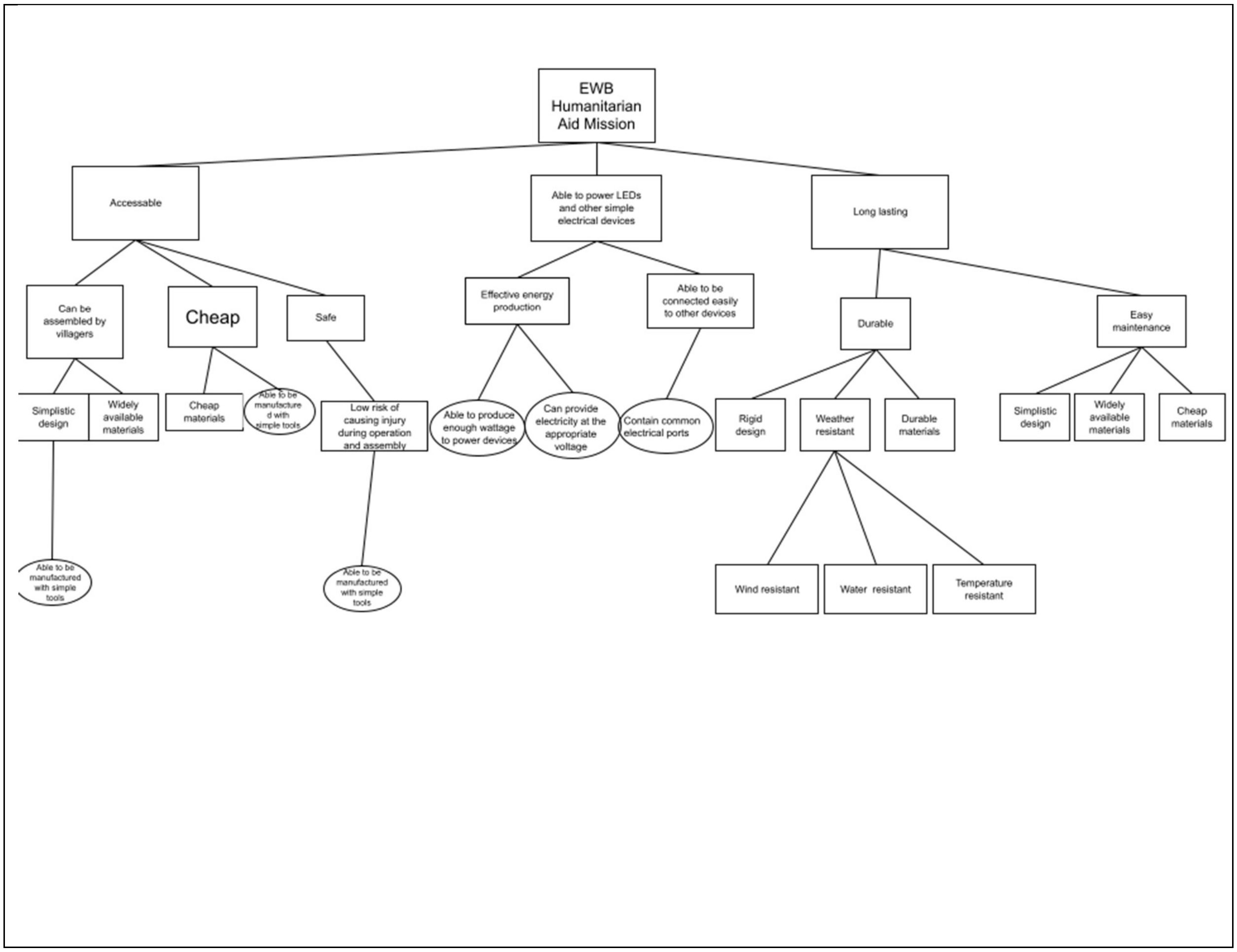
Engineering Scenario #2

The title of the scenario

EWB Humanitarian Aid Mission

Team objective tree diagram for scenario #2

Please insert a copy of the refined and finalized team objective tree for scenario #2.


EWB Humanitarian Aid Mission
Accessable
Able to power LEDs and other simple electrical devices
Long lasting
Can be assembled by villagers
Cheap
Safe
Effective energy production
Able to be connected easily to other devices
Durable
Easy maintenance
Simplistic design
Widely available materials
Cheap materials
Able to be manufactured with simple tools
Low risk of causing injury during operation and assembly
Able to produce enough wattage to power devices
Can provide electricity at the appropriate voltage
Contain common electrical ports
Rigid design
Weather resistant
Durable materials
Simplistic design
Widely available materials
Cheap materials
Able to be manufactured with simple tools
Able to be manufactured with simple tools
Wind resistant
Water resistant
Temperature resistant

Team ID: Tues-52

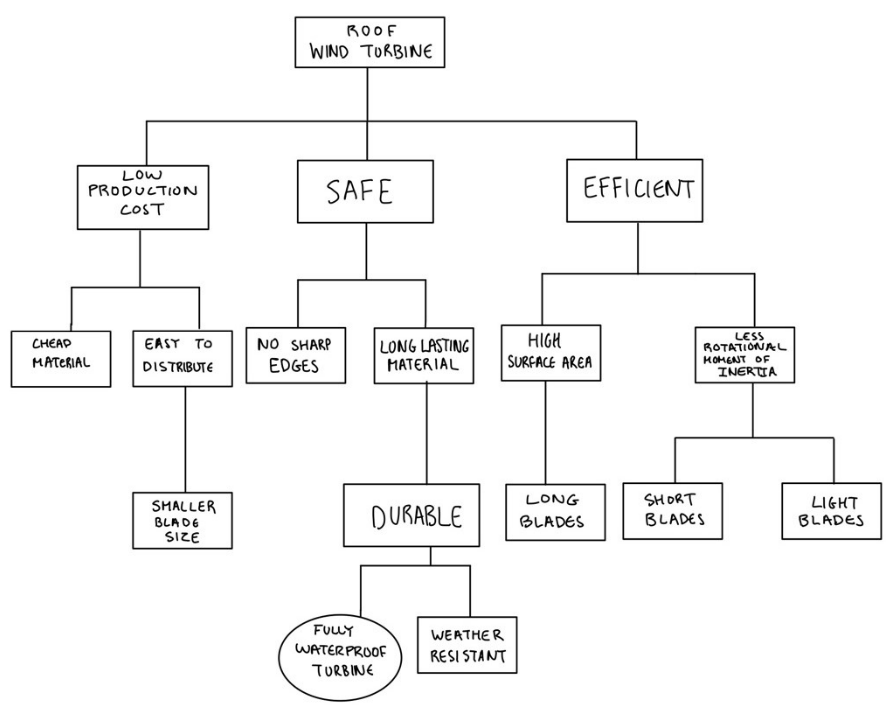
Engineering Scenario #3

The title of the scenario

The Roof Generator

Team objective tree diagram for scenario #3

Please insert a copy of the refined and finalized team objective tree for scenario #3.



Team ID: Tues-52

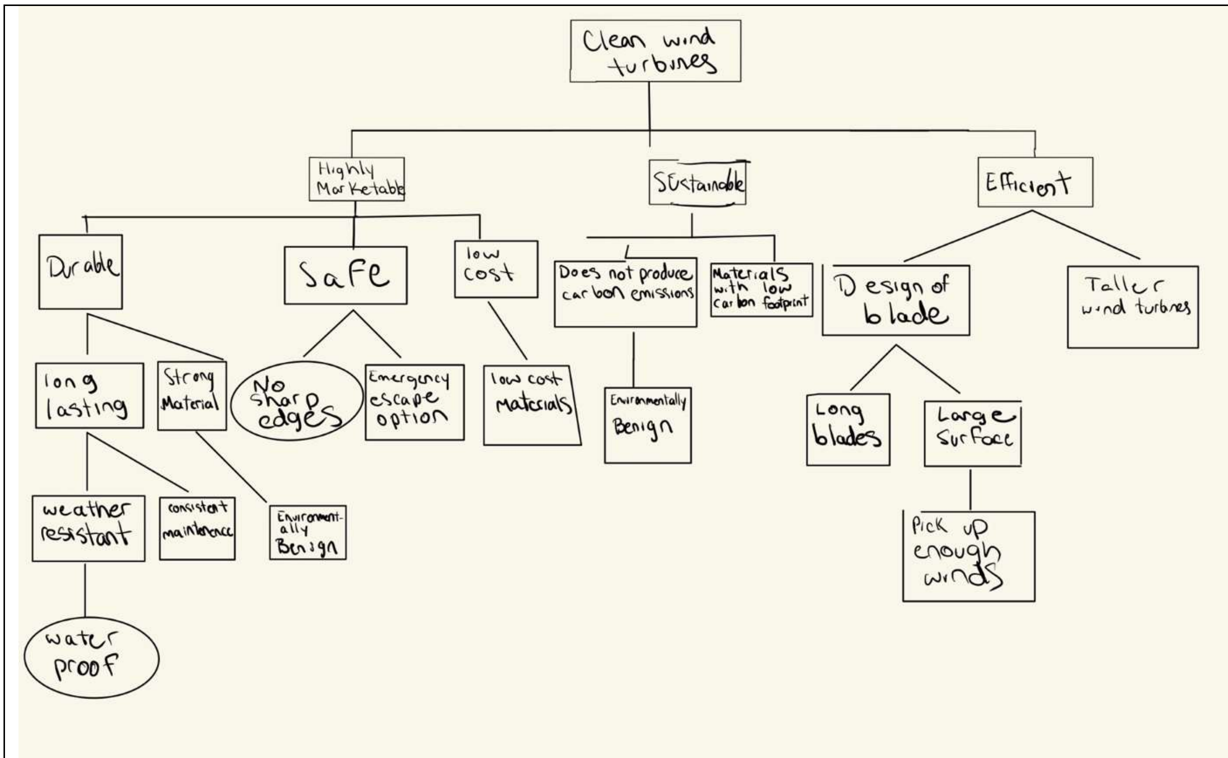
Engineering Scenario #4

The title of the scenario

A Pioneer in Clean Energy

Team objective tree diagram for scenario #4

Please insert a copy of the refined and finalized team objective tree for scenario #4.



Milestone 2 (Team) – Cover Page

Team Number:	Tues-52

Please list full names and MacID's of all *present* Team Members

Full Name:	**MacID:**
Daniel Smuk	smukd
Afraz Akram	akrama7
Leo Jiang	Jiangr42
Philip Lee	leep46

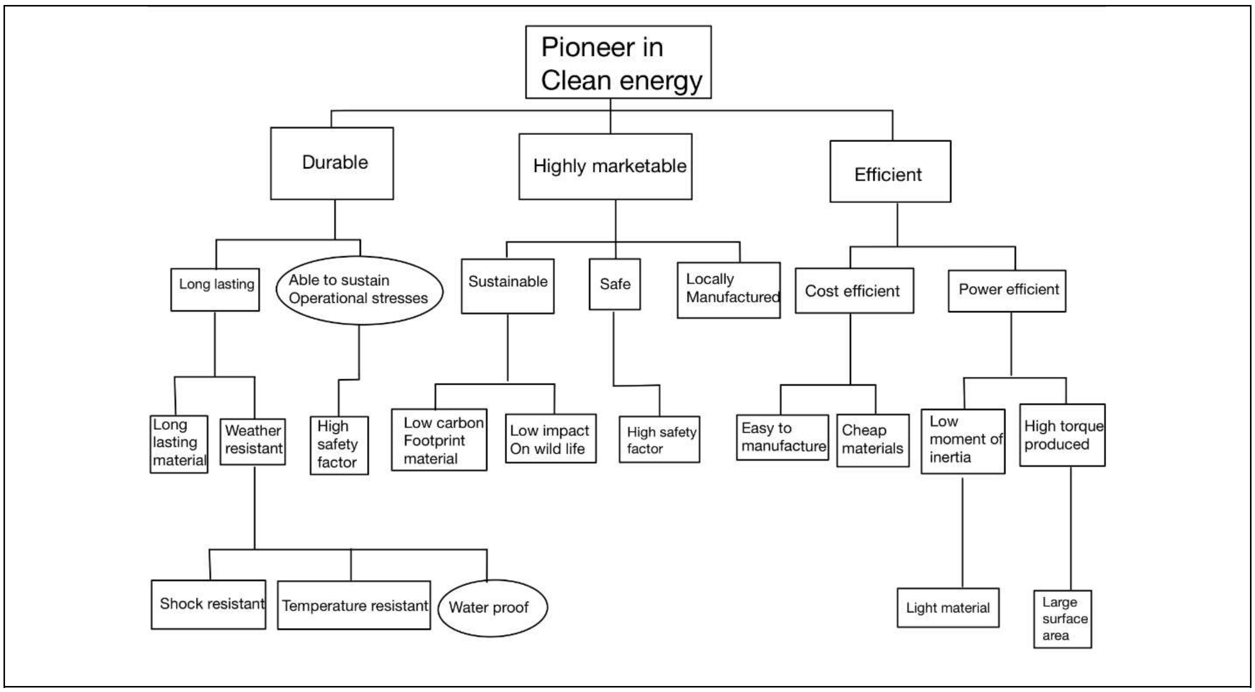
Any student that is ***not*** present for Design Studio will not be given credit for completion of the worksheet and may be subject to a 10% deduction to their P-1 grade.

Milestone 2 (Stage 1) – Design requirements for A turbine blade

Team ID: Tues-52

Objective Tree of turbine blade for assigned engineering Scenario

→ Please insert a copy of your team objective tree for the design of a turbine blade based on your assigned engineering scenario.



Turbine Blade Problem Statement:

→ Write a complete problem statement for the design of a turbine *blade* based on your assigned engineering scenario.

Design a blade that can help the turbines in a wind farm efficiently generate enough power to provide for multiple cities in Sweden at a low cost. The blade must be durable, able to withstand expected operational stresses under extreme weather conditions and should be easy to manufacture and repair. The blade must also be environmentally sustainable, should have a low carbon footprint, and minimize impact on wildlife.

Milestone 2 (Stage 2) – Selection of Top Objectives for a Turbine Blade

Team ID:	Tues-52

List the top three objectives of a turbine blade for your assigned engineering scenario

1: Efficient

2. Sustainable

3: Durable

Include a rationale for selecting each of these objectives

→ Write *maximum* 100 words for each objective

Objective 1: Efficient

Rationale: An efficient blade, in terms of its rotational moment of inertia, is an important objective to have for pioneering in clean energy. Manufacturing a blade with a low rotational moment of inertia will allow for the blade to spin much faster than other blades with heavier loads. As a result, this allows the blade to maximize the amount of energy it produces to power multiple cities in Sweden.

Objective 2: Sustainable

Rationale: A sustainable blade is crucial for pioneering clean energy. The manufacturing of blades on a local scale, with the use of low carbon footprint material, allows the minimization of greenhouse gas emissions in the process. Also, when in operation, sustainable blades are the main contributing factor to clean energy output, all the while having a low impact on wildlife.

Objective 3: Durable

Rationale: High durability is important because it will reduce its operational costs, and also carbon footprint in the long term. The blades will be exposed to extreme weather, and high stress, therefore high durability is also essential for safety considerations.

Milestone 2 (Stage 3) – Metrics

Team ID: Tues-52

For your selected top three objectives fill out the table below with associated metrics (including units) for each objective.

Objective 1:	Efficiency
Unit/Metric:	Rotational Moment of Inertia of blade($kg \cdot m^2$) Torque provided by blade under average environmental conditions per blade (newton- meters)

Objective 2:	Sustainable
Unit/Metric:	Carbon footprint/carbon emissions (tons of co2) in the manufacturing of the blade, during use of the blade, and decomposing of the blade.

Objective 3:	Durable
Unit/Metric:	Expected operational lifespan of blades(years) Stress safety factor (%)

Milestone 2 (Stage 4) – Regulations

Team ID:	Tues-52

Insert your group discussion below

Legal requirements

Large projects (which this one qualifies as) do not have many strict regulations, but instead need to adhere to plans and guidelines given by government committee consultations, which restricts location, technical details, size of wind farm, output range, materials used, the installation process, and more.

Zoning requirements:

Must obtain environmental permit after conducting an environmental assessment. Must have a statement on radar permit study. Must obtain aviation obstacle permit. Must go through consultation process with the County Administrative Board.

safety distance from powerlines:

“wind turbines and masts with braces with a total height of less than 50 metres should be placed at least 100 metres away from power lines. Wind turbines and masts with braces with a total height of more than 50 metres shall be placed not less than 200 metres from a power line. The distance is calculated based on the power plant rotor's periphery. For works with a rotor diameter of 100 meters or more the distance between the tower and the line shall be greater than 250 metres.”-- from the website of the swedish transport agency

Environmental:

Must go through consultation with the Energy information administration

Technical:

All wind turbines and wind farms with capacity over 1.5 MW’s technical requirments are overseen by the Svenska kraftnäts föreskrifter. They must be consulted, and they will provide requirments specific to the project

Must adhere to grid connection standards, must obtain right of wiring.

As a general rule, if the project requires new grid infrastructure (I.e. new power lines, new storage facilities) to be integrated into the grid, it must be funded by the project.

Energy production requirements calculation

The average energy consumption per person in Sweden is about 11820kWh per year, in geography cities are defined to have a population of at least 100,000, and to produce energy for multiple cities, say three, then about 3.56 Tera Wh of power are to be generated per year.

Milestone 3A (Team) – Cover Page

Team Number:	Tues-52

Please list full names and MacID's of all *present* Team Members

Full Name:	**MacID:**
Daniel Smuk	smukd
Afraz Akram	akrama7
Leo Jiang	Jiangr42
Philip Lee	leep46

Any student that is ***not*** present for their scheduled Lab-B session will not be given credit for completion of the worksheet and may be subject to a 10% deduction to their P-1 grade.

Milestone 3A (Stage 1) – Material Selection: Problem Definition

Team ID:	Tues-52

1. Copy-and-paste the title of your *assigned* scenario in the space below.

A Pioneer in Clean Energy

2. MPI selection
   → List one primary objective and one secondary objective in the table below
   → For each objective, list the MPI
   → Write a short justification for your selected objectives

	Objective	MPI-Stiffness	MPI-Strength	Justification for this objective
Primary	Minimize carbon footprint from production	$\frac{E}{\rho CO_2}$	$\frac{\sigma_y}{\rho CO_2}$	Low carbon footprint is one of the objectives listed in our objective tree. A pioneer in clean energy needs to be climate friendly every step of the way.
Secondary	Minimize Cost	$\frac{E}{\rho C_m}$	$\frac{\sigma_y}{\rho C_m}$	A pioneer in clean energy ideally needs to be practical and easily implementable at a large scale, and cost is a major factor in practicality and marketability.

Milestone 3A (Stage 3) – Material Selection: Material Alternatives and Final Selection

Team ID: Tues-52

Document results of each team member's materials selection and ranking on the table below.

- All different types of steel (carbon steels, alloy steels, stainless steels) have very similar Young's moduli. **For this stage in Project 1, please group all variations of steels into one family as "steel"**. Please put **steel** in your material ranking list only once and indicate in a bracket which steels made the top ranks.

Consolidation of Individual Material Rankings					
	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
MPI 1: $\frac{E}{\rho CO_2}$	Steel (high carbon, medium carbon, low carbon, low alloy, stainless)	Zinc alloy	Bamboo	Wood	Cork
MPI 2: $\frac{\sigma_y}{\rho CO_2}$	Wood	Bamboo	Cork	Steel (low alloy, high carbon, medium carbon, low carbon)	Paper and cardboard
MPI 3: $\frac{E}{\rho C_m}$	Steel (medium carbon, high carbon, low carbon, low alloy, stainless)	Bamboo	Wood, typical along grain	Aluminum alloys	Paper and cardboard

MPI 4: $\frac{\sigma_y}{\rho C_m}$	Steel (low alloy, high carbon, medium carbon, low carbon)	Wood, typical along grain	Bamboo	Paper and Cardboard	Aluminium alloy

As a team, fill out the table below and narrow down the possible materials for your assigned scenario by choosing the 3 materials which showed up the most across all MPI rankings in the table above.

- For this stage in Project 1, if **"steel"** is one of your three material finalists, please specify which steel your team chose to continue with, based on which showed up the most in your team's consolidated table.
- Remember to save the datasheets of all 3 material finalists

Narrowing Material Candidate List to 3 Finalists	
Material Finalist 1:	High Carbon steel
Material Finalist 2:	Bamboo
Material Finalist 3:	Wood

Team ID: Tues-52

As a team, compare material alternatives and make a final selection based on either a simple decision matrix or a weighted decision matrix (up to your team to decide)

→ As a team, consider *at least* 3 additional criteria that are relevant to your assigned scenario and discuss your 3 materials finalists for each criterion

- Feel free to pause at this stage and do some quick research on the materials finalists
- You may refer to the material finalists' datasheets for any relevant information that will enable your discussion.
- To help you come up with your additional criteria, below are some question prompts that you may consider. Please note that you are not limited to these suggestions, and they may or may not be relevant to your assigned scenario

Additional Criteria	**Possible question prompt**
Ease of access to material	Is the material easy to source in the country, are there tariffs due to international trade policy?
Chemical, weather and/or corrosion resistance	Will the material degrade over time (e.g. due to chemical resistance, corrosion resistance, fatigue resistance)?
Ease of maintenance	Consider maintenance if the part got damaged. Based on the material, is it easy to fix or will the entire part need replacement?

→ Remember that:

- Your MPI ranking takes into consideration both material and mechanical properties relevant to the objectives of your assigned scenario.
- Your additional considerations should not include previously evaluated objectives e.g. If minimizing the carbon footprint was either your primary or secondary objective, then it should not be an additional criterion

→ Compare the material alternatives and make a final selection based on either a simple decision matrix or a weighted decision matrix (up to your team to decide)

- *Applies to a weighted decision matrix only:* choose a range for the weighting (e.g., 1 to 5) for each criterion. The higher the number on the weighting, the more important that criterion is.
- Choose a range for the score (e.g., 1 to 5) for each material on each criterion. Give each material a score based on how successfully it meets each criterion. The higher the score, the better the material is for that criterion.
- Add additional rows as needed.
- Add up the total score for each material alternative.

Fill one of the following templates only:

Simple Decision Matrix - Template			
Criterion:	*Material 1:*	*Material 2:*	*Material 3:*
Criterion 1			
Criterion 2			
Criterion 3			
...			
TOTAL			

Weighted Decision Matrix - Template							
	Weighting	*Material 1: High carbon steel*		*Material 2: Bamboo*		*Material 3: Wood*	
		Score	Total	Score	Total	Score	Total
Ease of Access	3	5	15	1	3	5	15
Weather resistance	5	5	25	2	10	1	5

Ease of maintenance	3	4	12	1	3	3	9
Ease of manufacturing	2	4	8	2	4	2	4
	TOTAL		60		20		33

→ State your chosen material and justify your final selection

Justification	
Chosen Material:	High carbon steel
Discuss and justify your final selection in the space below (based on the decision matrix results and any other relevant considerations). For large structures like the wind turbine blades proposed in the scenario, high carbon steel is the most accessible, and easiest to manufacture/maintain due to readily available existing infrastructure and supply chains in Sweden. High carbon steel is also significantly more weather resistant than the other two options, and weather resistant was one of the objectives in our objective tree.	

Summary of Chosen Material's Properties

Material Name	Average value
Young's modulus E (GPa):	200-220 GPa
Yield strength σ_y (MPa):	433-924 MPa
Tensile strength σ_{UTS} (MPa):	721-1.39e3 MPa
Density ρ (kg/m^3):	7.8e3 kg/m^3
Embodiment energy H_m (MJ/kg)	15-17.5 MJ/kg
Specific carbon footprint CO_2 (kg/kg)	1.05-1.2 kg/kg

Scenario Specific Turbine Blade Design (Team) – Cover Page

Team Number:	Tues-52

Please list full names and MacID's of all *present* Team Members

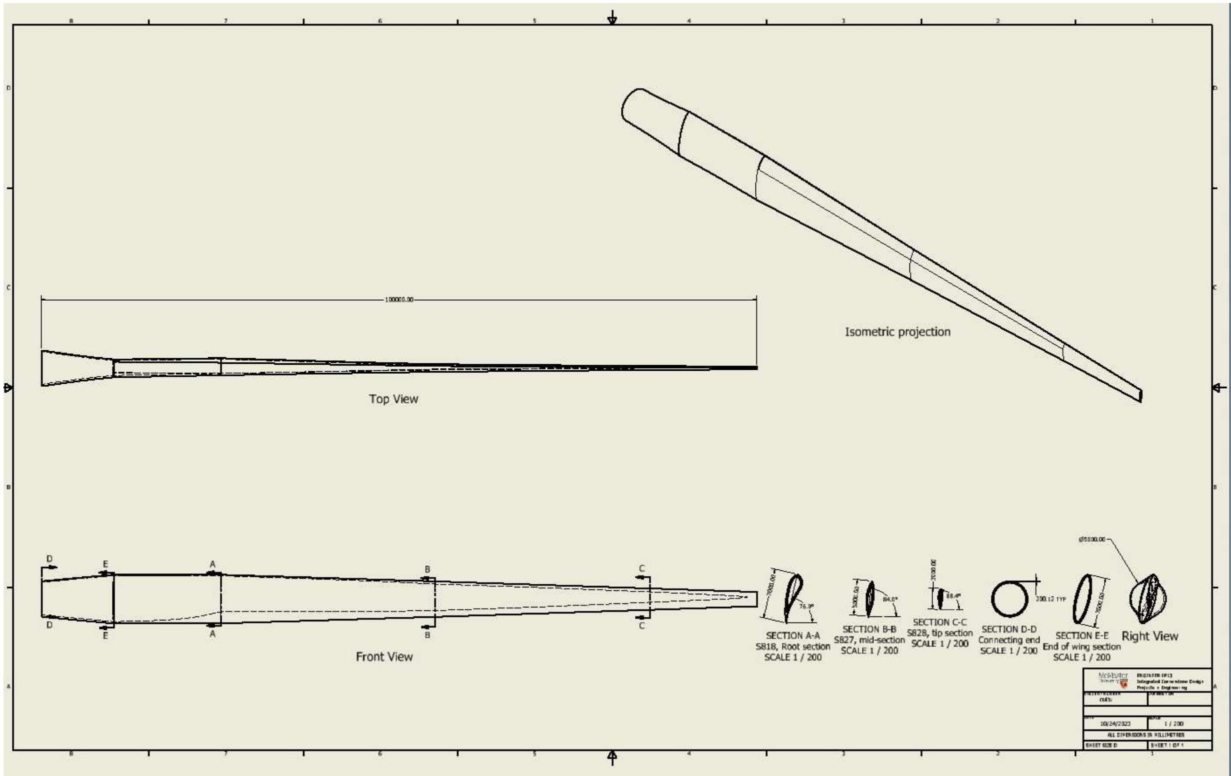
Full Name:	**MacID:**
Daniel Smuk	smukd
Afraz Akram	akrama7
Leo Jiang	Jiangr42
Philip Lee	leep46

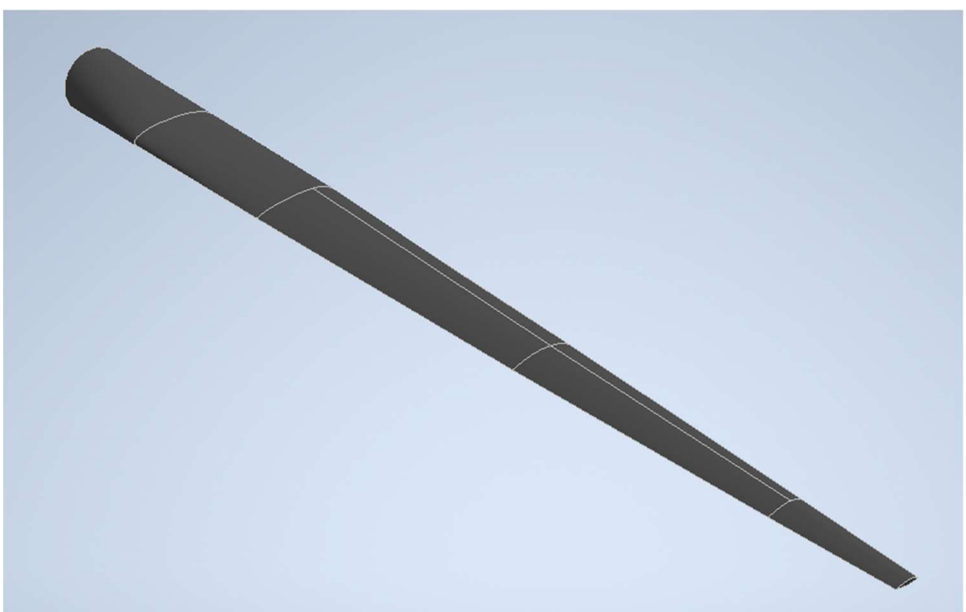
Multiview Turbine Blade Sketch and Justification

Team ID: Tues-52

1. Sketch of Turbine Blade

Insert a multiview sketch of your team's scenario specific turbine design. Multiview sketch must include front, top, and right-side view.





2. Justification of Turbine Blade

Theory:

Air foils produce lift, but at the same time causes drag, the angle of attack of the blades need to achieve the optimal lift to drag ratio for maximum efficiency [1]. This depends on the velocity of the blades and the velocity of the wind which is usually 8 m/s windy areas of Sweden [2]. Since the velocity of the blade is not uniform (the tip will move faster than the root), the optimal angle changes depending on the distance to the tip, making it necessary for the blade to have a twisting geometry [3]. Therefore, we took that into account when calculating the optimal angle of the airfoils. We chose 3 airfoil designs, one for the root of the blade, one for the mid-section, and one for the tip. We then added the velocity vector of the wind with the velocity vector of rotation at that part of the blade. Then the angle of the local wind velocity can be found [1]. Then using the data on the airfoil, we are able to find its optimal angle of attack, we can then add the angle of attack to the angle of the local wind velocity vector to get the optimal angle of the airfoil.

In addition, the blade length increases the area the blades can cover, increasing the amount of wind energy it can capture [1]. However longer blades will lead to more stress on the components of the turbine, driving up cost on top of the cost of having longer blades. As a forementioned, the wind speeds in Sweden average around 7.5 m/s [2] and the density of air ρ=1.29kg/m^3 [5]. Additionally, wind turbines generally have a preferred efficiency of 40% [6]. Through calculations in Milestone 2 Stage 4, we discovered we need 3.56 x 10^{12} Watt hours generated per year to uphold with the watt usage in Sweden for 3 cities [7]. To calculate the amount per second to be generated, we divide the Watt hours per year by the amount of seconds in a year, then followed by multiplying by seconds in an hour to get how many watts(J/s) need to be generated. The amount of Watts would need to be generated in a wind farm of about 100 wind turbines, so we divide by 100 to get the watts produced by a single wind turbine.

$$3.56 \cdot 10^{12}\, \frac{Watt\ hours}{year} \cdot \frac{1\ year}{3.154 \cdot 10^{7} s} \cdot \frac{3600\ s}{1\ hour}$$

$$= 4.06 \cdot 10^{8}\ Watts$$

$$= 406\ MegaWatts\ per\ 100\ turbines$$

$$\therefore\ \sim 4\ MW\ for\ each\ wind\ turbine$$

So, now having the using the wind power equation (P=40%x½ρAV^3) and our previously calculated value of P = 4MW, we can find A (swept area) to find the blade length. With the A value that we find, we can sub it into the equation A= πr^2, to find the radius of the swept area, which is equivalent to the length of a turbine blade. Assuming an efficiency of 40%, we get:

$$P = 0.5\rho A v^3$$

$$A = \frac{4000000}{(0.4)(0.5)(1.29)(7.5)^3}$$

$$A = 36749.92822\ m^2$$

$$A = \pi r^2$$

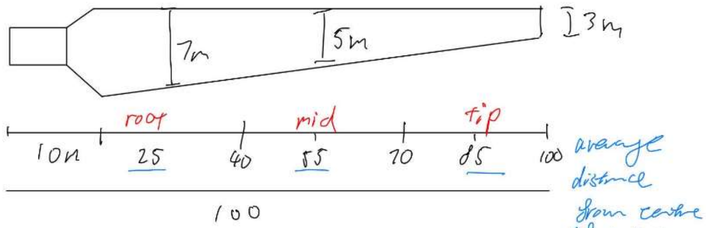
$$r = \sqrt{\frac{36749.92822}{\pi}}$$

$$r \approx 100\, m$$

Therefore, the blade length of 100 meters is a good approximation for what is needed to meet our decided wattage for our turbine. We also set the rotational speed to 7 rpm as to not create too much noise and cause too much of a disturbance to wildlife and nearby residents alike.

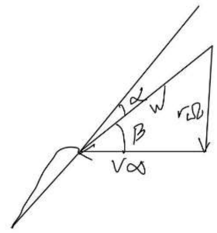
Design:

We split the blade up to 4 sections: connective component (10m long), root of the blade (30m long), mid-section (30m long) and tip (30 m long). We then selected adequate airfoils for each section. We selected the NREL (National Renewable Energy Laboratory) S818 airfoil for the root as the root needs to sacrifice some aerodynamic performance for structural strength [8]. We selected the NREL S828 airfoil for the tip, which is thin and light with great aerodynamic performance, exactly that the tip of the blade needs [8], and finally we chose the S827 for the mid-section as it is a good intermediate airfoil which offers both structural strength and good aerodynamic performance [8].



known values: $V_\infty = 8$ m/s $\rho = 1.293$ $\Omega = 0.73$ rad/s (7 RPM)

$\frac{L}{W}$ needs to be constant throughout the blade to be most efficient



$$\text{Tip: } W @ \text{tip} = \sqrt{V_\infty^2 + (r\Omega)^2}$$
$$= \sqrt{8^2 + (85 \cdot 0.73)^2}$$
$$= 62.82 \text{ m/s}$$
$$\beta = \cos^{-1}\left(\frac{V_\infty}{W}\right)$$
$$= 82.68°$$

NREL S828 has optimal angle of attack of $\alpha = 5.75°$,

$\beta = 82.68 + 5.75° = 88.43°$ off horizontal for tip

Above is a sample calculation showing how the optimal blade angle is calculated. Doing so for each blade section gives: 75.42 deg for the root, 84.03 deg for the mid-section, and 88.43 deg for the tip.

Then we calculated the chord length for optimized bound circulation. Having an even circulation around the blade allows for minimized loss of energy due to air vortexes [8]. Circulation is given by the equation $\Gamma = \frac{L}{\rho W}$ since ρ is constant we must ensure the lift to local windspeed ratio $\frac{L}{W}$ is constant throughout the blade [8]. We can calculate this using the lift formula and our previously calculated local wins speeds. We first set the chord length at the tip to be 3 meters, solved for the lift to local wind speed ratio, and then used that to calculate the chord length of the other sections.

L/W ratio for the tip:

$\frac{L}{W}$ calculations: Chord @ tip = 3m

r = section length

$$L = C_L \tfrac{1}{2} \rho W^2 C r$$
$$= 1.1 \cdot \tfrac{1}{2} \cdot 1.293 \cdot (62.82)^2 (3)(30)$$
$$= 252580 \ N$$
$$\frac{L}{W} = 4020.7$$

Sample calculation of the chord length of mid-section:

$$L = C_L \tfrac{1}{2} \rho W^2 C r$$
$$= 1 \cdot \tfrac{1}{2} \cdot 1.293 \cdot (41.10)^2 \cdot C \cdot 30$$
$$= 32762 \ C$$
$$\frac{L}{W} = \frac{32762 \ C}{W}$$
$$4020.1 = \frac{32762}{41.10} C$$
$$C = 5.04m$$
$$\approx 5.0m$$

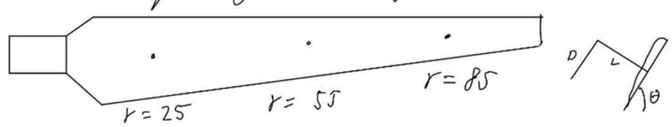
mid section has chord length 5 m, and is 84.03° off the horizontal

The same is done with the root, and the result is that the tip, mid-section, and root should

Have chord length 3, 5, and 7 meters for optimized circulation.

We can then add together the lift and drag forces produced by each blade section in the direction of rotation and estimate the total torque generated per blade, and by multiplying it by the rotational speed, calculate the power generated per blade.

Total Torque generated per blade



Torque = the vertical component of lift force · distance from center of rotation

$$\text{Torque tip} = r \cdot L_y - r \cdot D_y$$
$$= rL\left(\cos\beta - \frac{CL}{CD}\sin\beta\right)$$
$$= 2475724 \text{ Nm}$$

$$\text{Torque mid} = r(L_y - D_y)$$
$$= rL\left(\cos\beta - \frac{CL}{CD}\sin\beta\right)$$
$$= 55\,L\left(\cos(\beta) - \frac{CL}{CD}\sin(\beta)\right)$$
$$= 1644348 \text{ Nm}$$

$$\text{Torque root} = r(L_y - D_y)$$
$$= rL\left(\cos\beta - \frac{CL}{CD}\sin\beta\right)$$
$$= 791860 \text{ Nm}$$

$$\text{torque total} = 4.9\times10^6 \text{ Nm} \quad \text{Nm}$$

$$\text{Power} = \tau\Omega = 3.6 \text{ Mega watts}$$

Our calculations show that our blades can theoretically produce 3.6 megawatts per blade, so 10.8 megawatts total. This value is way over the 4 MW goal, but this is not accounting for all the loss of energy and unideal circumstances which occurs during operation; thus we have determined this power output to be an adequate one for our design.

[1] "Wind Turbine Design for a Wind Turbine System," *Alternative Energy Tutorials*.

https://www.alternative-energy-tutorials.com/wind-energy/wind-turbine-design.html

[2] "Global wind atlas," Global Wind Atlas, https://globalwindatlas.info/en/area/Sweden (accessed Oct. 20, 2023).

[3] Lesics, “Wind turbine design,” YouTube,

https://www.youtube.com/watch?v=p5k2LhKBSgQ (accessed Oct. 2, 2023).

[4] SKYbrary, “Angle of Attack (AOA),” SKYbrary Aviation Safety, https://skybrary.aero/articles/angle-attack-aoa#:~:text=The%20Angle%20of%20Attack%20is,the%20aircraft%20and%20the%20atmosphere. (accessed Oct. 20, 2023).

[5] NASA, “Air Mass/Density,” NASA, https://www.earthdata.nasa.gov/topics/atmosphere/atmospheric-pressure/air-mass-density (accessed Oct. 20, 2023).

[6] E. Protection Agency, “Renewable Energy Fact Sheet: Wind Turbines,” EPA, https://nepis.epa.gov/Exe/ZyNET.exe/P100IL8K.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2011%2BThru%2B2015&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex+Data%5C11thru15%5CTxt%5C00000010%5CP100IL8K.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8%2Fr75g8%2Fx150y150g16%2Fi425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results+page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL (accessed Oct. 20, 2023).

[7] W. Data, “Energy consumption in Sweden,” Worlddata.info, https://www.worlddata.info/europe/sweden/energy-consumption.php (accessed Oct. 20, 2023).

[8] T. L. Burton, Wind Energy Handbook. Wiley & Sons Canada, Limited, John,

2021.

Milestone 4 (Team) – Cover Page

Team Number:	Tues-52

Please list full names and MacID's of all *present* Team Members

Full Name:	**MacID:**
Daniel Smuk	smukd
Afraz Akram	akrama7
Leo Jiang	Jiangr42
Philip Lee	leep46

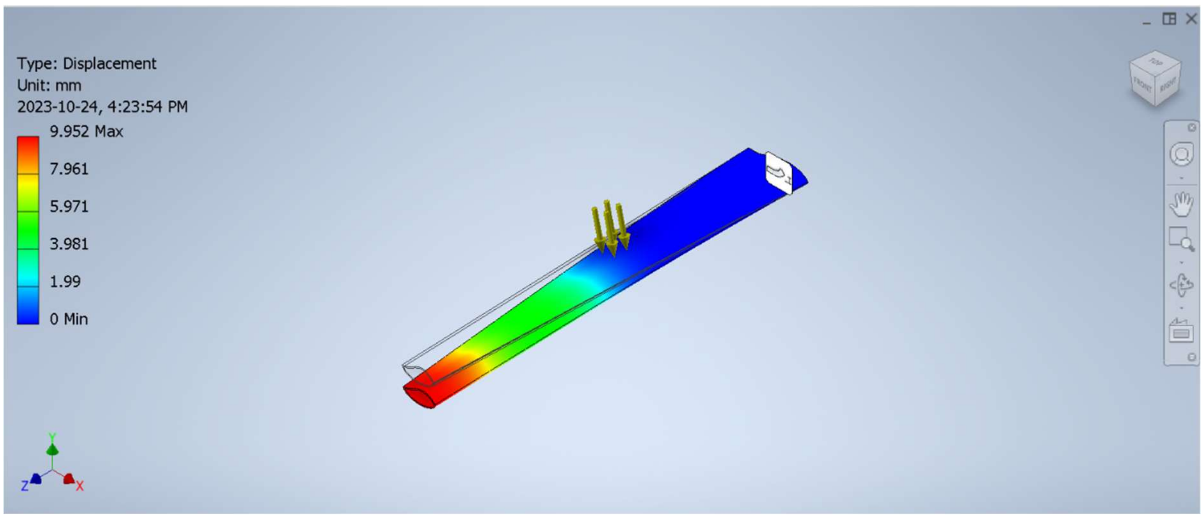
Any student that is ***not*** present for Design Studio will not be given credit for completion of the worksheet and may be subject to a 10% deduction to their P-1 grade.

Milestone 4 (Stage 2) – Refine Thickness Requirement

Team ID:	Tues-52

1. Refine Thickness Requirement to Satisfy Deflection Constraint

Refined turbine blade thickness *t* (mm):	24.8mm



Milestone 4 (Stage 3) – Peer Interview

Team ID: Tues-52

→ Meet another team with a different scenario
- Discuss differences in your design process
- Compare:
    - Primary/secondary objectives
    - Chosen materials, thickness, etc.
- Discuss the relevance of your scenario-specific turbine blade design to your assigned scenario and any design challenges you have encountered.

1. Peer Interview Notes

Scenario 3

Design Process

Looking at our peers and our design processes, we noticed that based on the different scenarios and objectives, we took a more analytic approach involving math to determine certain factors in our wind turbine. In contrast, our peer's design process included a more qualitative approach. For their process, they chose to use a vertical wind turbine design compared to a horizontal one because horizontal blades are 40% less efficient due to the space of each house being so close, which would ultimately affect the flow of wind. Our group chose to use a simple horizontal design. Also, with their design process, they decided to go with a 4-blade design compared to our 3-blade design. They also looked at objectives like safety, and affordability, where we went for durability and efficiency. Their objective of safety focused on the turbine blades with respect to the residential area, as well as being durable to not harm others. Affordability meaning trying to reduce costs like bills of the clients.

Objectives

Their primary objective was to minimize volume because each turbine was to fit on the roof of an average house in Calgary.

Their secondary objective was to minimize production energy. This ties into the objectives of production cost and affordability for homeowners.

Chosen Material + Thickness

- Their group decided to use Tungsten Alloy to make their turbine blade, very heavy and expensive, whereas our group used high carbon steel, a lighter cheaper material with a similar durability.
- With the assigned materials, their group had a thickness of 13.633mm (deflection of 9.999m), while our group had a thickness of 24.8mm (deflection of 9.952m)

Considerations

Like us, they decided to calculate the power used on average per home to calculate how many Watts of power are to be generated. They calculated that 800kW was used per month(15kwh/day) for the average homeowner, which influenced their design. Their turbine went for a safer alternative, with a wind turbine that should have a breaking mechanism in the rotor because of the area it was in.

Challenges

- Some challenges their group faced were that any turbine was to be 30ft above anything within 300ft of anything surrounding (trees, streetlights, buildings, etc.)

- Also, since being built on a roof, a challenge was that it needed to be 20 pounds per square foot (weight the roof can support)

- Under 40dB (noise)

- Finding more info about a vertical wind turbine due to their unique nature.

- Figuring out the regulations associated with wind turbines and Calgary

- Safety because the turbine isn't on a wind farm but in a residence area, so they want their wind blade to be durable enough to not harm environment (prioritizing safety more than efficiency)

Note: Please be mindful that you are expected to write a short reflection on what you have learned from the other team in your final deliverable. Do not forget to discuss your scenario specific design as well.