# Design Project 1 – Renewable Technology Challenge

*ENGINEER 1P13 – Integrated Cornerstone Design Projects in Engineering*

Tutorial 9

Team Thurs-48

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Submitted: November 1, 2023

Course Instructors: Dr. McDonald, Dr. Doyle, Dr. Ebrahimi, Dr. Fleisig, Dr. Hassan, Dr. Zurob

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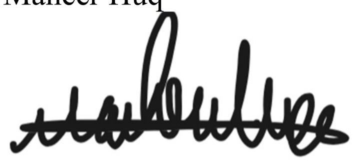
## Academic Integrity Statement

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.

Maheer Huq 400508517



(Student Signature) *

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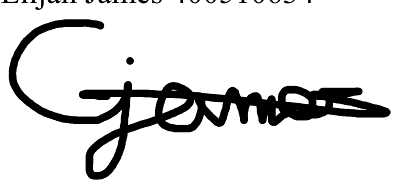
Elijah James 400510634



(Student Signature) *

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Shafer Honigman Deltoff 400496964

(Student Signature) *

**Finalized Problem Statement**

The “Pioneer in Clean Energy” scenario requires the design of a sustainably sourced wind turbine blade optimized to generate large amounts of clean energy to facilitate power for Sweden. The primary purpose of the blades is to generate electricity through movement caused by wind power. These turbines must act as a replacement for non-renewable energy sources, providing reasonable power output and maximized longevity without crossing any regulations set in place by the Swedish Wind Energy Association (SWEA). An optimized blade length would aid in producing large amounts of energy while ensuring durability. To make the area surrounding the wind farm safe while also being durable, the blades must be constrained to a deflection of 10mm. Adding structural support for the blade would improve the strength overall. During the creation of the blades, there should be minimal production energy to lessen the environmental impact and depletion of rare resources. An effort should be made to minimize carbon footprint of the turbines.

## Main Body

**Justification of Technical Objectives and Material Performance Indices**

In our engineering scenario, we used an objective tree to define our technical objectives and material performance indices (MPIs). Our primary objective was to achieve "High Energy Generation" to meet the energy demands of multiple cities. This aligned with the overall goal of the Swedish wind farm project. We focused on energy production and durability as critical factors. During the material selection process, we compared bamboo, wood, and high carbon steel. Our primary objective was to minimize the carbon footprint and prioritize sustainable manufacturing. After careful evaluation, we chose high carbon steel due to its durability, production energy capabilities, and weather resistance. Considering the secondary objective of "Minimize Production Energy," high carbon steel proved to be efficient in turbine blade manufacturing, further validating our choice. We also considered the objective of "Optimal Length of the Blade," which confirmed that high carbon steel allowed for the design of structurally sound and efficient wind turbine blades. Our material selection was deeply rooted in the objective tree, objective matrix, and the prioritization of key criteria. High carbon steel emerged as the most suitable material for our sustainable wind turbine design, ensuring optimal energy generation while addressing factors like transportability and environmental impact.

**Conceptual Design – Justification of Selected Material**

Our group was required to select a material based on scenario 4, A Pioneer in Clean Energy. With multiple steps including Granta EDU Pack, selecting a fitting objective, and utilizing a weighted decision matrix we were able to successfully come to a conclusion of High Carbon Steel as our chosen material. First, we created our primary and secondary objectives, minimizing carbon footprint and minimizing production energy. Along with this we obtained the MPI for strength and stiffness for each objective. Next each group member utilized Granta to rank the materials based on our specific MPIs [1]. After doing this, as a group, we selected the top 3 materials that appeared between the 4 rankings. These were: High Carbon Steel, Wood Typical Along Grain, and Bamboo. Finally, after using a weighted decision matrix, it was obvious that the best material for our scenario was High Carbon Steel. The justification behind this decision was that High Carbon Steel is highly durable making it a great choice for large wind turbines serving many cities. High Carbon Steel was also found to have a very good energy production which was of utmost importance to our scenario. Greenhouse emissions, ease of material access, and weather resistance were also considered but had lower weightings when making the decision. Despite sustainability advantages of wood and bamboo, high carbon steel was the preferred choice. As seen in figure 1 below, Granta was used to determine the most suitable material (this specific example was for minimizing carbon footprint and pertained to strength) [1].

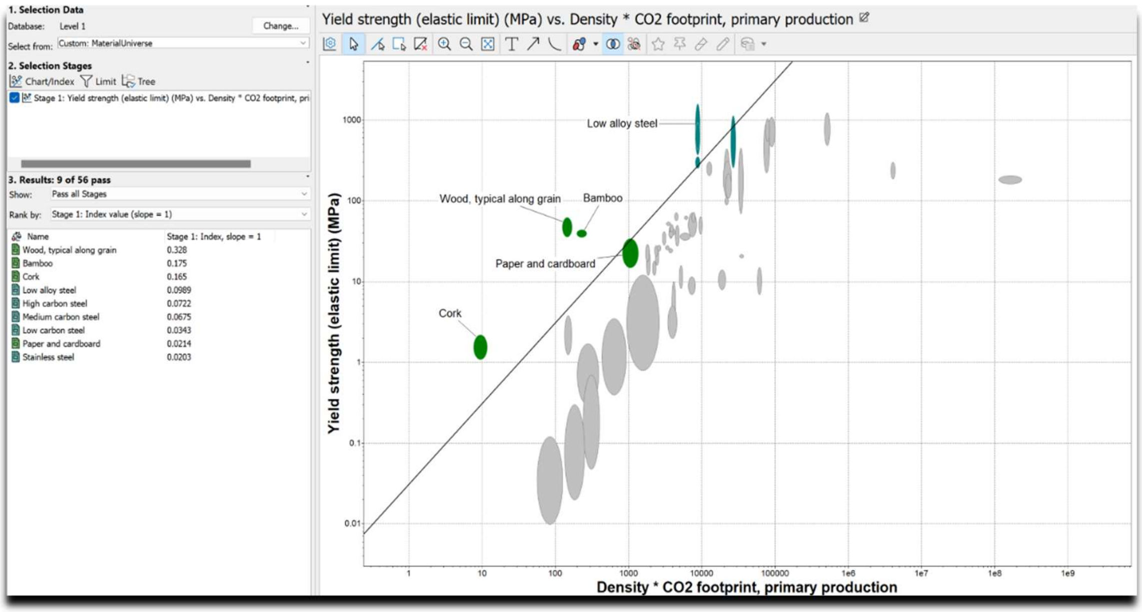



*Figure 1. Materials Chart for Minimizing Carbon Footprint with Constrained Strength*

**Design Embodiment – Justification of Solid (CAD) Modelling**

The goal was to find the optimal thickness of a wind turbine blade of our selected material, high carbon steel, that would get close to but not pass the maximum deflection threshold of 10 mm [2, pg 39]. We tested the blade with thickness values of 15 mm and 50 mm, to begin with a large range where we can easily narrow down to a smaller range until we receive a satisfactory result. The optimal deflection was determined to be between 20 mm and 30 mm. We continued to simulate various thickness values in Autodesk Inventor to find our final value starting from one above the lowest in our range, 21 mm. The final thickness was honed to 26 mm with a maximum deflection value of 9.39 mm (see Figure 2), satisfying the constraints deflection of less than 10 mm. Although the result was satisfactory, it could have been more precise by using thickness values with the difference in the hundredths until we get a consistent maximum deflection value that is even closer to the threshold of 10 mm. [3]

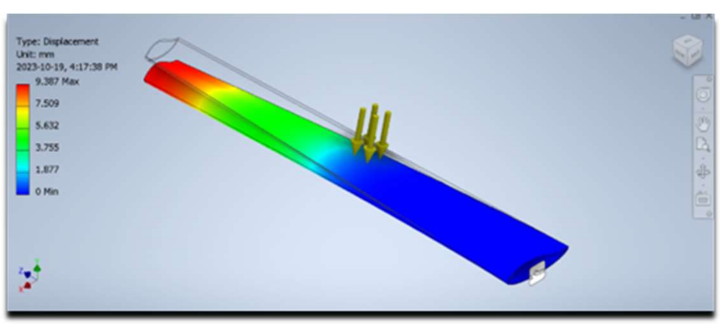


*Figure 2. Stress Analysis on AutoDesk Inventor*

**Discussion of Regulations**

To determine the dimensions of the wind turbine blade, we had to ensure that our design complies with the environmental regulations and policies set by the Swedish government. Sweden has set ambitious goals to increase its renewable energy production and reduce carbon emissions, and our wind turbine design is in line with these objectives. Sweden's regulations for wind energy include permissible noise levels, safe distances from residential areas, and ecological considerations [4]. Our wind turbine blade design incorporates advanced noise reduction technologies through the addition of the curved end of the blade. This extended curve increases the pitch angle, which reduces drag and in turn also reduces noise levels to meet or exceed the national requirements [5]. Additionally, our design maximizes energy production within zones allotted by the government, further promoting the use of wind resources.

One of the primary regulatory considerations in our wind turbine blade design is adhering to the optimal turbine height. Although the turbine height is not initially part of the project, it was important to consider because the blade length is proportional to the turbine height, generally being half the height. The height is also a factor on how quickly a permit for the construction of the wind turbines can be given. Generally, wind farms for large cities have turbines with a height of 120 m [6] and blades half the height of the turbine [7], therefore we determined the optimal length of our turbine would be 60 m. In summary, our wind turbine blade design in Sweden not only aims to harness green energy but also ensure a smooth transition to a greener and more sustainable energy landscape.

**Discussion of Sustainable Choices**

Choices made in the materials, blade thickness and overall design of the blade play major roles in the long-term environmental effects of the blade. Long term, the blades would require coatings to alleviate rusting, which could have effects on the environment throughout the life of the turbine if the coating used is hazardous in any way. Also, the migration of birds would be affected for the duration of the turbine's life, possibly blocking routes that used to be common for bird migration. As the material chosen is high carbon steel, the carbon used could have repercussions to the environment during the production of the material. Also, the creation of high carbon steel primarily involves the use of iron ore and coal [8]. The availability of these resources is not a problem in Sweden, which is said to be one of the largest sources for iron ore in Europe, while also having coal sites at a smaller scale [9].

In terms of end-of-life considerations, recyclability of materials is at the forefront. In comparison to other common materials used for turbine blades in large wind farms, high carbon steel allows for easy recyclability, as it can be recycled "… without any damage or degradation to its properties- no matter the product or form it takes" [10]. Transporting the materials from these large turbines would be difficult, so an ideal wind farm would be near recycling facilities to lessen the need of transportation, which could be detrimental financially and environmentally. Regarding the build of the turbine itself, it could be structured in a modular fashion, meaning that the blades could be disassembled by their individual parts, easing the end-of-life process. Also, maintaining regular checks on the state of the turbine would ensure that the necessary disassembly of the turbine can be identified in a timely manner.

**Peer-Learning Interview**

By talking to the other team, we learned a lot about how you should tailor your choices to a specific scenario. Because this group had design scenario 3, their job was to create turbines for roofs on homes. This was significantly different to ours where we had to create a turbine blade for a much larger scale to power multiple cities. Ultimately, our objectives were very different. The other teams' objectives were to minimize cost and minimize volume which made sense considering their scenario. We also learned that although our scenarios were so different, we ended up both choosing a form of steel due to its durability, price, and ease of access. If our group was assigned scenario 4, we would have to focus on fine-tuning the blades size and cost-effectiveness. We would potentially have to explore new materials that are more affordable and compact while simplifying our design for ease of installation and maintenance. For next time, we would also ensure that our turbine blade CAD design was feasible and realistic as the design we created for scenario 4 lacked realistic features of a blade.

**Concluding Remarks – Reality Check**

Throughout the course of project 1, it's become clear that engineers must always look to cater to the needs of a specific situation, even when working on the same product in theory. We have learned the importance of identifying objectives and utilizing these in the choice of material selection, which can be done in a logical manner through prioritizing material performance index. We've also been taught the importance of constraints, applying this knowledge in deflection simulations to determine the feasibility of our chosen materials. Overall, selecting the right materials optimized for the situation at hand is focal in the process of engineering.

**Summary of Contributions**

*Table 1. Contribution Summaries*

| Team Member | Summary of Contributions |
|---|---|
| Huzaifa Syed | My contributions began with milestone 1, where I helped draft the initial problem statement and began brainstorming for our team objective trees. As we transitioned to milestone 2, I made mention of our high energy generation objective, providing the rationale while also helping in drafting the complete problem statement. I also played a large role in the research done for the regulations' notes. Moving to milestone 3A, I assisted in brainstorming for the criteria of the weighted matrix while also largely contributing to the justification. In the scenario specific turbine design, I helped brainstorm the unique features of our turbine while also completing all of the justification through the use of notes made by group members. In milestone 4, I worked in experimenting for the refined thickness, adding the screenshots of the stress analysis while also contributing to the peer interview. For the final deliverable (this report), I worked on the discussion of sustainable choices and concluding remarks. I also helped with all the formatting (creating headers, font size, etc.), appendix E and the source database. |
| Shafer Honigman Deltoff | The first portion of my contributions to Project 1 was the brainstorming of functions, objectives, and constraints regarding scenario 3. I then helped the group take these ideas to build an objective tree pertaining to scenario 4. One of my main contributions throughout this project was the conceptual CAD model of a turbine blade. With the help of my other group members, I was able to take key aspects of what we wanted in a turbine blade to create a 3d model of that in CAD. I was then able to create a Multiview sketch using this model. Later in the project, I helped with the deflection simulation of the turbine blade. Working with trial and error, Huzaifa and I were able to successfully optimize a specific thickness that would give us the required deflection of 10mm for the turbine blade. Lastly, I contributed to the final project report by discussing the justifications of the selection material and discussing what was learnt from the peer interview. I also filled out a logbook stating when the group met up to complete work. |
| Shadi El-Fares | I have created the expected Gantt Chart, which outlines the project's timeline and important milestones. I took the initiative to organize and assign tasks, creating an efficient work environment that enhanced our team's productivity. I worked closely |

| | |
|---|---|
| | with Shafer to actively contribute to the initial design of the Scenario Specific Blade, assisting in the creative process. Additionally, I helped with material selection, specifically focusing on finding a material that minimized our carbon footprint while maximizing strength. I conducted evaluations on the deflection of the assigned blade thickness of 50mm. This hands-on approach ensured the practicality and structural integrity of our design. In addition to the tasks met at each step in working up to the final report, I assisted in the first two aspects of the report. I delivered a detailed scenario specific problem statement, technical objectives and the team's MPI choices. |
| Elijah James | I started the project by helping define the initial general problem statement for Project 1 and brainstorming for the individual preliminary objective tree for scenario #4, which was a great aid for our final objective tree because our group's assigned scenario was the same. Then during the material selection milestone, I focused my researched on the MPI-strength for minimizing production energy, which will reduce its carbon footprint, and found the best material to be steel. Additionally, I helped with acquiring any information required for creating and improving our blade design (such as pitch angle, shape, lift & drag forces) as well as justifying our finalized design. Finally, when testing for the optimal thickness of the turbine blade, I started with 30mm, which was closest to our final decision. |
| Maheer Huq | The first thing I contributed to the overall group's progression was brainstorming some functions and objectives for the initial problem statement. This was followed by creating an individual objective tree for scenario #2, and helping the team create a finalized tree for scenario #4. When it came to the material selection milestone, I specialized in researching our secondary objective, minimizing production energy, on the MPI-strength side. This exploration was one of several evidence to choose our material to be steel, specifically high carbon. Another contribution I helped with was the creation of our weighted decision matrix, in terms of weighting numbers and criteria. Furthermore, when each team member was prescribed to work on a different thickness for the turbine blade, I worked on the 150mm option alongside Huzaifa. We achieved the same value, which contributed to our final value for thickness. Lastly, I created the Final Gantt chart used to compare our initial Gantt chart to see how long each milestone actually took. |

## Reference List

[1] Ansys GRANTA EduPack software, ANSYS, Inc., Cambridge, UK, 2023 (www.ansys.com/materials)

[2] “P1 Project Module,” Department of Engineering, McMaster University, Fall, 2023

[3] Autodesk® Inventor 2024 LT™ software, Autodesk, Inc, 2023 (www.autodesk.com).

[4] M. Pettersson, “Legal Preconditions for Wind Power Implementation in Sweden and Denmark,” 2006, [Online]. Available: https://www.diva-portal.org/smash/get/diva2:998988/FULLTEXT01.pdf

[5] “Vortex Drag | How Things Fly.” Accessed: Oct. 31, 2023. [Online]. Available: https://howthingsfly.si.edu/aerodynamics/vortex-drag

[6] “Onshore wind power development in Sweden and Finland | Practical Law.” Accessed: Oct. 31, 2023. [Online]. Available: https://content.next.westlaw.com/practical-law/document/I8417d5c51cb111e38578f7ccc38dcbee/Onshore-wind-power-development-in-Sweden-and-Finland?viewType=FullText&transitionType=Default&contextData=(sc.Default)

[7] G. Duval, “How Big Are the Blades of a Wind Turbine?,” Today’s Homeowner. Accessed: Oct. 31, 2023. [Online]. Available: https://todayshomeowner.com/eco-friendly/guides/wind-turbine-blades-size/

[8] “Tata Steel - DIGECA,” *Tata Steel - DigEca*. https://digeca.tatasteel.com/resources/blogs/making-of-carbon-steel-and-its-types

[9] “Swedish mines.” https://www.sgu.se/en/mineral-resources/swedish-mines/#:~:text=Sweden%20is%20by%20far%20the,%2C%20Norrbotten%2C%20Skelleftef%C3%A4ltet%20and%20Bergslagen.

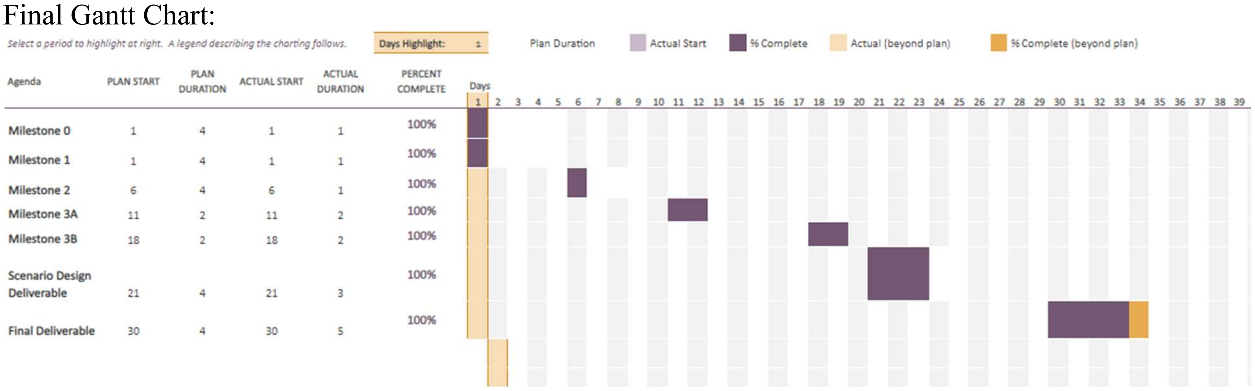
[10] D. Bennett, “Steel recycling: Processes, benefits, and business solutions | Rubicon,” *Rubicon*, Jul. 15, 2022. https://www.rubicon.com/blog/steel-recycling/#:~:text=Steel%20is%20an%20iron%20alloy,product%20or%20form%20it%20takes.

## Appendices

## Appendix A: Project Schedule

Preliminary Gantt Chart:


Final Gantt Chart:




**Logbook of Additional Meetings and Discussions:**

| **When** | **What** |
|---|---|
| October 12, 2023 | Microsoft Teams meeting to work on Milestone 3A (Scenario specific design) |
| October 29, 2023 | Microsoft Teams meeting to work on Final Project 1 Report |
| Ongoing | Chats in teams regarding various Milestones throughout |

**Appendix C: Comprehensive List of Sources**


- "How do wind turbines work?," *Energy.gov*. https://www.energy.gov/eere/wind/how-do-wind-turbines-work

- "What materials are used to make wind turbines? | U.S. Geological Survey," Sep. 23, 2019. https://www.usgs.gov/faqs/what-materials-are-used-make-wind-turbines#:~:text=According%20to%20a%20report%20from,aluminum%20(0%2D2%25).
- A. E. Tutorials, "Wind turbine generator types and design to harness the wind," Alternative Energy Tutorials, https://www.alternative-energy-tutorials.com/wind-energy/wind-turbine-generator.html (accessed Sep. 27, 2023).
- "How do wind turbines work?," Energy.gov, https://www.energy.gov/eere/wind/how-do-wind-turbines-work (accessed Sep. 27, 2023).

- L. Hartman, "Wind Turbines: the Bigger, the Better," *energy.gov*, Aug. 24, 2023. Accessed: Sep. 27, 2023. [Online]. Available: https://www.energy.gov/eere/articles/wind-turbines-bigger-better#:~:text=A%20turbine%20with%20longer%20blades,available%20for%20wind%20development%20nationwide.

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- "RELEASE: New Paper in Nature: Greenhouse Gas Emissions from Global Wood Harvests are Vastly Undercounted," *www.wri.org*, Jul. 2023, Accessed: Oct. 17, 2023. [Online]. Available: https://www.wri.org/news/release-new-paper-nature-greenhouse-gas-emissions-global-wood-harvests-are-vastly-undercounted#:~:text=Washington%2C%20D.C.%20(July%205%2C

- J. Marsh, "Bamboo can help us fight both climate change and poverty," *Sustainability Times*, Jan. 27, 2023. https://www.sustainability-times.com/in-depth/bamboo-can-help-us-fight-both-climate-change-and-poverty/#:~:text=For%20example%2C%20studies%20have%20shown

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- G. Duval, “How big are the blades of a wind turbine?,” *Today’s Homeowner*, Aug. 2023, [Online]. Available: https://todayshomeowner.com/eco-friendly/guides/wind-turbine-blades-size/#:~:text=Blade%20Size,the%20height%20of%20the%20tower

- “Wind turbine blade design, flat, bent or curved,” *Alternative Energy Tutorials*. https://www.alternative-energy-tutorials.com/wind-energy/wind-turbine-blade-design.html

- R. Sudhamshu, M. C. Pandey, N. Sunil, N. S. Satish, V. Mugundhan, and R. K. Velamati, “Numerical study of effect of pitch angle on performance characteristics of a HAWT,” *Engineering Science and Technology, an International Journal*, vol. 19, no. 1, pp. 632–641, Mar. 2016, doi: 10.1016/j.jestch.2015.09.010.

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**Appendix E: Design Studio Worksheets**

# MILESTONE 0 (TEAM): COVER PAGE

Team ID: Thurs-48

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

| Full Name: | MacID: |
|---|---|
| Huzaifa Syed | syedh42 |
| Shafer Honigman Deltoff | honigmas |
| Shadi El-Fares | elfaress |
| Elijah James | jamese13 |
| Maheer Huq | huqm6 |

Insert your Team Portrait in the dialog box below

# MILESTONE 0 – TEAM CHARTER

Team ID: Thurs-48

## Project Leads:

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

| Role: | Team Member Name: | MacID |
|---|---|---|
| **M**anager | Shadi El-Fares | elfaress |
| **A**dministrator | Maheer Huq | huqm6 |
| **C**oordinator | Shafer Honigman Deltoff | honigmas |
| **S**ubject Matter Experts | Elijah James | jamese13 |
| | Huzaifa Syed | syedh42 |

# MILESTONE 0 – PRELIMINARY GANTT CHART (TEAM MANAGER ONLY)

**Team ID:** Thurs-48

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

| Full Name of Team Manager: | MacID: |
|---|---|
| Shadi El-Fares | elfaress |

Preliminary Gantt chart

# Project Planner

*Select a period to highlight at right. A legend describing the charting follows.*

Days Highlight: 1 | Plan Duration | Actual Start | % Complete | Actual (beyond plan) | % Comple

| Agenda | PLAN START | PLAN DURATION | ACTUAL START | ACTUAL DURATION | PERCENT COMPLETE |
|---|---|---|---|---|---|
| Milestone 0 | 1 | 4 | 0 | 0 | 0% |
| Milestone 1 | 1 | 4 | 0 | 0 | 0% |
| Milestone 2 | 6 | 4 | 0 | 0 | 0% |
| Milestone 3A | 11 | 2 | 0 | 0 | 0% |
| Milestone 3B | 18 | 2 | 0 | 0 | 0% |
| Scenario Design Deliverable | 21 | 4 | 0 | 0 | 0% |
| Final Deliverable | 30 | 4 | 0 | 0 | 0% |

Days: 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 3

# MILESTONE 1 (TEAM) – COVER PAGE

Team Number: Thurs-48

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

| Full Name: | MacID: |
|---|---|
| Huzaifa Syed | syedh42 |
| Shadi El-Fares | elfaress |
| Shafer Honigman Deltoff | honigmas |
| Elijah James | jamese13 |
| Maheer Huq | huqm6 |

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: Thurs-48

**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.**

| |
|---|
| Design a wind turbine for generating renewable energy from wind power to replace non-renewable energy sources. |
| |

# MILESTONE 1 (STAGE 3) – REFINED OBJECTIVE TREES

Team ID: Thurs-48

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.

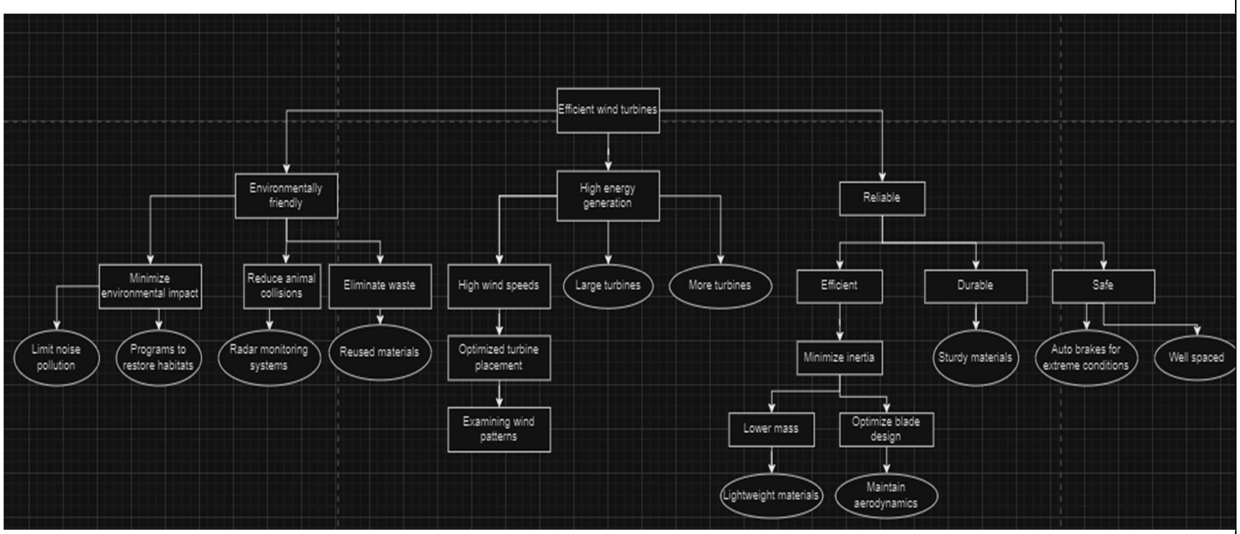
Engineering Scenario #1

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: Thurs-48

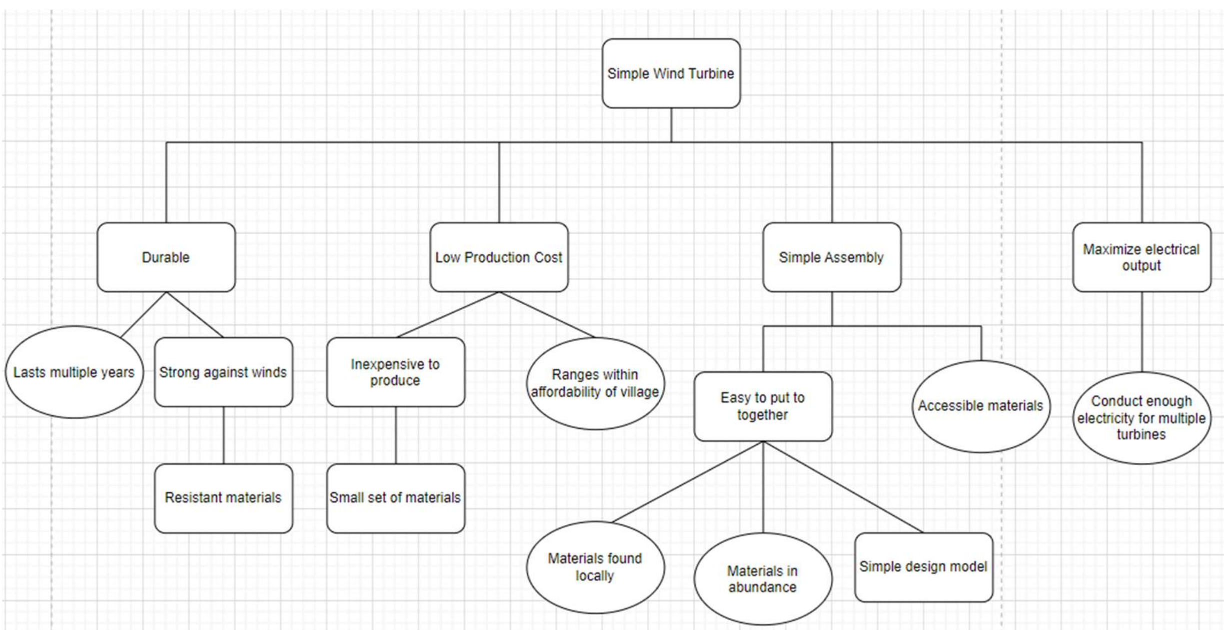
Engineering Scenario #2

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.



Team ID: Thurs-48

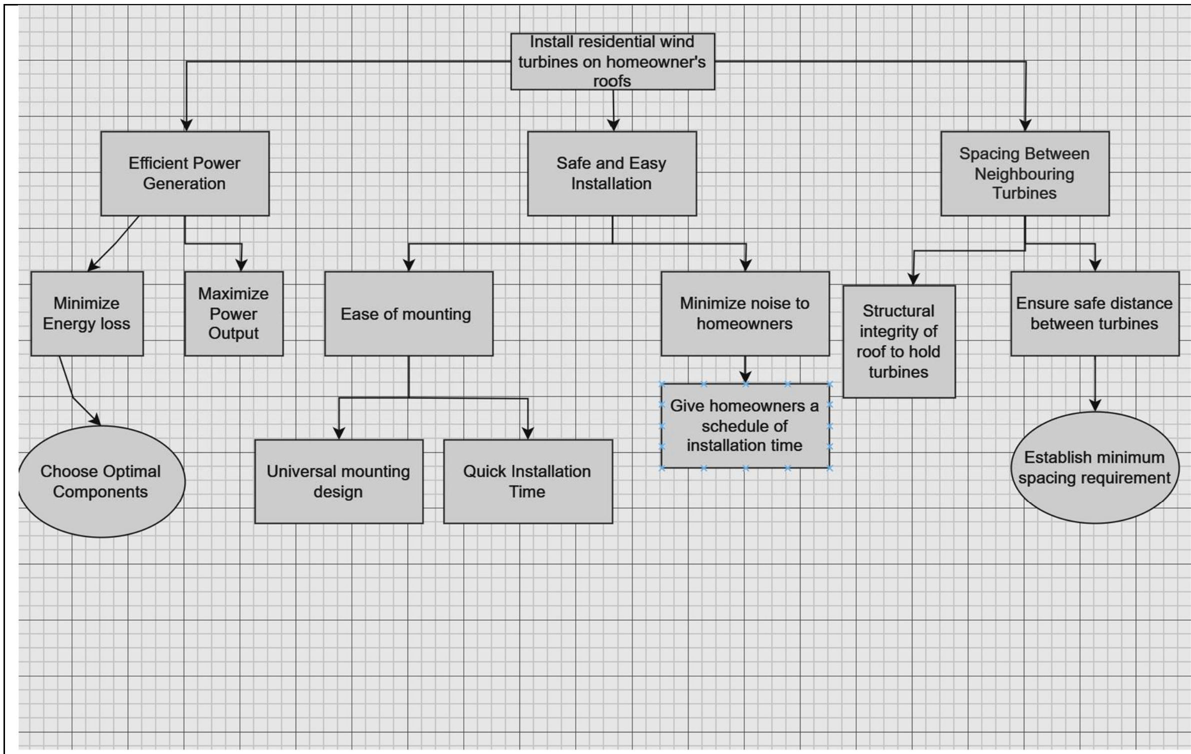
Engineering Scenario #3

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.


Install residential wind turbines on homeowner's roofs
Efficient Power Generation
Safe and Easy Installation
Spacing Between Neighbouring Turbines
Minimize Energy loss
Maximize Power Output
Ease of mounting
Minimize noise to homeowners
Structural integrity of roof to hold turbines
Ensure safe distance between turbines
Give homeowners a schedule of installation time
Choose Optimal Components
Universal mounting design
Quick Installation Time
Establish minimum spacing requirement

Team ID: Thurs-48

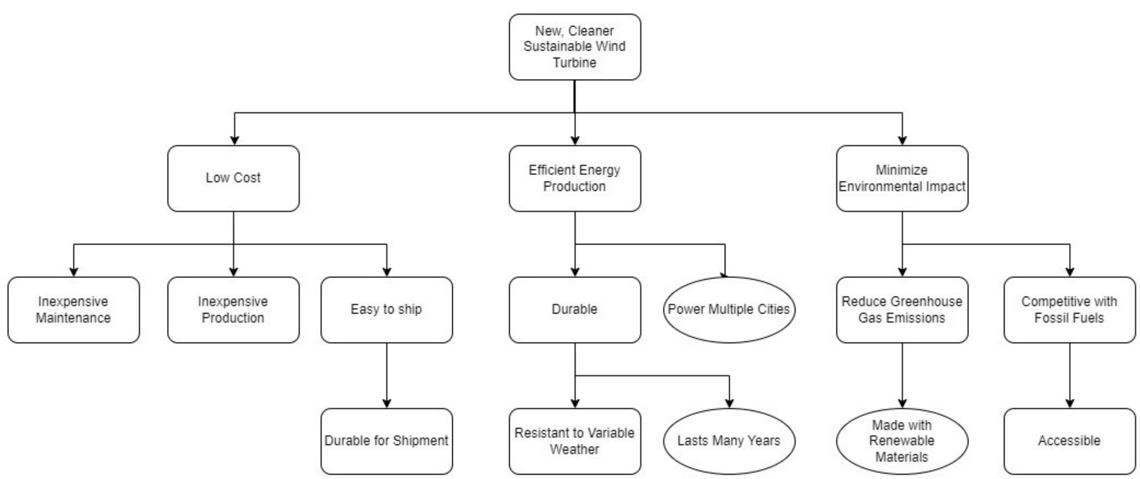
Engineering Scenario #4

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: Thurs-48

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

| Full Name: | MacID: |
|---|---|
| Huzaifa Syed | syedh42 |
| Shafer Honigman Deltoff | honigmas |
| Shadi El-Fares | elfaress |
| Elijah James | jamese13 |
| Maheer Huq | huqm6 |

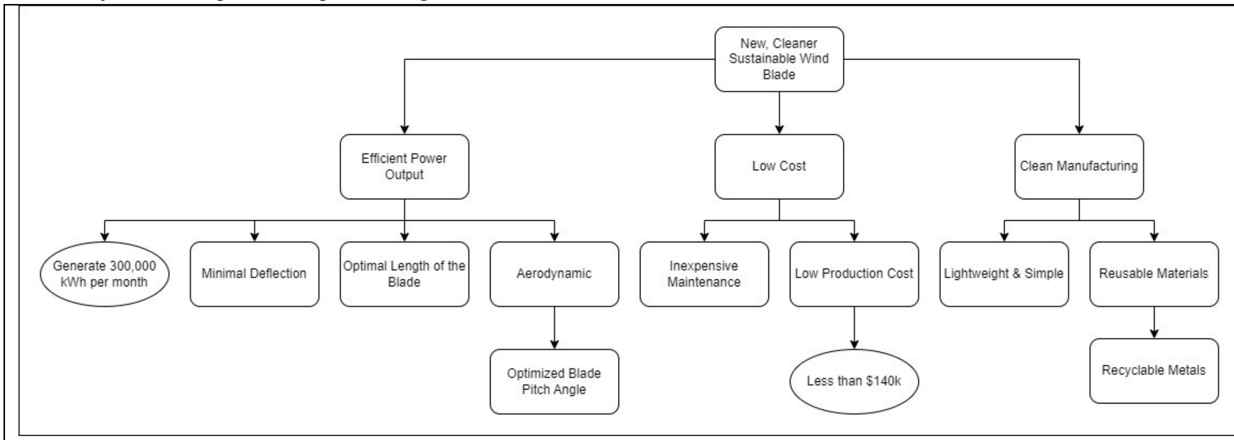
Any student that is ***not*** present for Design Studio will not be given credit for completion of the worksheet and may be subject to a 10% deduction to their P-1 grade.

# MILESTONE 2 (STAGE 1) – DESIGN REQUIREMENTS FOR A TURBINE BLADE

Team ID: Thurs-48

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 clean wind turbine blade optimized to generate large amounts of sustainable energy for multiple Swedish cities.

# MILESTONE 2 (STAGE 2) – SELECTION OF TOP OBJECTIVES FOR A TURBINE BLADE

Team ID: Thurs-48

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

1: High Energy Generation

2: Low Cost

3: Length of the Blade

Include a rationale for selecting each of these objectives

→ Write *maximum* 100 words for each objective

Objective 1: High Energy Generation

Rationale:

Supplying energy to multiple cities would require the energy generation output of the wind turbines to be large. This is why the energy generation is one of the main focuses for the Swedish wind farm.

Objective 2: Low Cost

Rationale:

Clean energy not only seeks for clean manufacturing, but additionally a process with an overall low cost. To generate sustainable power for multiple cities calls for long-term maintenance and usage of the wind turbines. This mean low cost is a must for the manufacturing process to ensure these processes can continue for as long as possible, for as cheap as possible.

Objective 3: Optimal Length of the Blade

Rationale:

The length of a wind turbine blade determines many important factors, such as generation capacity, transportability, and environmental effects like noise pollution. With a blade size too short,

| |
|---|
| there may be issues with capturing enough wind to convert to an effective amount of energy. Whereas a blade too long may be too loud and difficult to transport. Thus, an optimal length is an important objective. |

## MILESTONE 2 (STAGE 3) – METRICS

Team ID: Thurs-48

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

| | |
|---|---|
| Objective 1: | High energy generation |
| Unit/Metric: | $\frac{Kwh}{Day}$ |

| | |
|---|---|
| Objective 2: | Low Cost |
| Unit/Metric: | $ |

| | |
|---|---|
| Objective 3: | Optimal length of the Blade |
| Unit/Metric: | Meters |

# MILESTONE 2 (STAGE 4) – REGULATIONS

Team ID: Thurs-48

Insert your group discussion below

- Height of Turbine – not too tall or too short
- Regional plans are approved my regional council (maakinnan liitto)
- Electricity standards – regulations for how the turbines connect to the electrical grid.
- Noise regulations – turbines should follow local laws regarding noise disturbances.
- Construction permit needed for any turbine taller than 50m
    - Local municipality must be notified.
- Building permit
- Environmental impact assessment
    - Environmental permit
- Aviation obstacle permit
    - Exemption possible
- Permit for infringements of protected areas under the environmental code
- Considered to be a large wind farm if:
    - Two or more wind turbines stand together and at least one of the turbines is more than 150 metres high.
    - Seven or more wind turbines stand together and at least one wind turbine is higher than 120 metres.
- Large wind farm general permitting process:
    - Consultation process
    - EIA preparation
    - Application
- Process usually takes 2 years
    - Another 6-12 month extension is possible

# MILESTONE 3A (TEAM) – COVER PAGE

Team Number: Thurs-48

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

| Full Name: | MacID: |
|---|---|
| Huzaifa Syed | syedh42 |
| Shafer Honigman Deltoff | honigmas |
| Shadi El-Fares | elfaress |
| Elijah James | jamese13 |
| Maheer Huq | huqm6 |

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: Thurs-48

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 | Minimizing Carbon Footprint | $MPI = \frac{E}{\rho CO_2}$ | $MPI = \frac{\sigma_y}{\rho CO_2}$ | Our goal in scenario 4 is to provide large amounts of energy to multiple cities in a sustainable manner. Minimizing carbon footprint would allow for turbines to be more sustainable throughout the manufacturing process. |
| Secondary | Minimizing Production Energy | $MPI = \frac{E}{\rho H_m}$ | $MPI = \frac{\sigma_y}{\rho H_m}$ | Minimizing production energy would allow for the creation of a more efficient turbine blade. This would also make it more sustainable overall, with less greenhouse gas emissions resulting from the process of manufacturing. |

# MILESTONE 3A (STAGE 3) – MATERIAL SELECTION: MATERIAL ALTERNATIVES AND FINAL SELECTION

Team ID: Thurs-48

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*: $\mathrm{MPI}^{\text{(carbon footprint)}}$ (stiffness) $MPI = \frac{E}{\rho CO_2}$ | Wood, typically along grain | Bamboo | Steels (High Carbon, Medium carbon, Low carbon, Low alloy metal, Stainless) | Wood, typically across grain | Zinc Alloys |
| *MPI 2*: $\mathrm{MPI}^{\text{(carbon footprint)}}$ (strength) $MPI = \frac{\sigma_y}{\rho CO_2}$ | Wood, typical along grain | Bamboo | Cork | Steel (Low Alloy, High Carbon, Medium Carbon, Low Carbon, Stainless) | Paper and Cardboard |
| *MPI 3*: $\mathrm{MPI}^{\text{(energy)}}$ (stiffness) $MPI = \frac{E}{\rho H_m}$ | Steels (Medium carbon, high carbon, low carbon, low alloy, stainless) | Bamboo | Wood | Zinc Alloys | Copper Alloys |

| | | | | | |
|---|---|---|---|---|---|
| *MPI 4*: $\mathrm{MPI}^{(\text{energy})}$ (strength) $MPI = \frac{\sigma_y}{\rho H_m}$ | Steel (low/high/mid carbon, low alloy, stainless) | Zinc alloys | Copper alloys | Nickel alloys | Bamboo |

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:* | Wood, typically along grain |
| *Material Finalist 3:* | Bamboo |

Team ID: Thurs-48

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 | | | |
|---|---|---|---|
| | *Material 1:* | *Material 2:* | *Material 3:* |
| *Criterion 1* | | | |
| *Criterion 2* | | | |
| *Criterion 3* | | | |
| … | | | |
| **TOTAL** | | | |

Weighting Range: 1-5
Score Range: 1-5

| Weighted Decision Matrix - Template | | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Weighting* | *High Carbon Steel:* | | *Wood, typically along grain:* | | *Bamboo:* | |
| | | Score | Total | Score | Total | Score | Total |
| *Greenhouse Emissions* | 3 | 2 | 6 | 1 | 3 | 5 | 15 |
| *Ease of Access to Materials* | 2 | 5 | 10 | 5 | 10 | 1 | 2 |
| *Durability of Materials* | 4 | 5 | 20 | 2 | 8 | 1 | 4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Energy Production* | 5 | 5 | 25 | 1 | 5 | 2 | 10 |
| *Weather Resistance* | 3 | 5 | 15 | 3 | 9 | 2 | 6 |
| | **TOTAL** | 22 | 56 | 12 | 35 | 11 | 37 |

→ 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)*.

High carbon steel was the logical selection for the specific scenario assigned. This was concluded through many factors, starting with the two main objectives in minimizing carbon footprint and minimizing production energy. When graphing the material charts and sorting by MPI (material property index), the highest materials included bamboo, wood and high carbon steel. This means that these materials were the best for the objectives specified. These three were then compared by looking at various additional criteria to determine the feasibility of each material in the assigned scenario. The weighted decision matrix made sure that energy production and durability of materials were the most important factors in the matrix.

The durability of both bamboo and wood were much lower than the durability of high carbon steel, especially when looking at large wind turbines that would have to generate enough electricity for multiple cities. To clarify, the energy production criterion specifically involves how much energy output is produced by the given material, separate from the objective of production energy. We ranked it as the heaviest criterion given that our scenario description emphasizes the importance of supplying energy to multiple cities. High carbon steel was given the highest rating in comparison to wood and bamboo as the material's durability makes it such that it can endure harsh conditions that come with high performance.

Aside from the two most important criterion in durability and energy production, we have also included greenhouse emissions, ease of access of materials, and weather resistance. Regarding greenhouse emissions, we gave it a medium weighting as it is related to our scenario in that we want to prioritize sustainability, but it also is not the central focus. High carbon steel's carbon footprint was not ideal [1]. Wood also fell short of what is most preferrable [2]. Unlike these two, bamboo suited strongly in minimizing carbon footprint as much as possible [3]. Ease of access of materials was given a low weighting due to its relative importance in comparison to our other criterion. It is important, but not up to par with other criteria. Since bamboo is not native to Europe, it's ease of access is the lowest amongst the three. Conversely, steel and wood are abundant in Sweden given its development and natural greenery. Our final criterion is weather resistance, where the strength of steel has significant advantages over the other two, providing another great reason as to why we chose it. It can be noted that high carbon steel will be prone to rust, but the addition of a protective coating makes it much more weather resistant than wood and bamboo overall.

To conclude, while wood and bamboo have their respective advantages in sustainability and minimized greenhouse emissions, the facets of high carbon steel are overwhelming in comparison. Thus, due to its prominence in durability, ease of access, energy production, and weather resistance, our group agreed that high carbon steel was our best option.

References

[1] "What is the carbon footprint of steel?," *Sustainable Ships*. https://www.sustainable-ships.org/stories/2022/carbon-footprint-steel#:~:text=Global%20steel%20emissions&text=Steel%20production%20is%20a%20significant

[2] "RELEASE: New Paper in Nature: Greenhouse Gas Emissions from Global Wood Harvests are Vastly Undercounted," *www.wri.org*, Jul. 2023, Accessed: Oct. 17, 2023. [Online]. Available: https://www.wri.org/news/release-new-paper-nature-greenhouse-gas-emissions-global-wood-harvests-are-vastly-undercounted#:~:text=Washington%2C%20D.C.%20(July%205%2C

[3] J. Marsh, "Bamboo can help us fight both climate change and poverty," *Sustainability Times*, Jan. 27, 2023. https://www.sustainability-times.com/in-depth/bamboo-can-help-us-fight-both-climate-change-and-poverty/#:~:text=For%20example%2C%20studies%20have%20shown

Summary of Chosen Material's Properties

| Material Name | Average value |
|---|---|
| Young's modulus $E$ (GPa): | 210 |
| Yield strength $\sigma_y$ (MPa): | 678.5 |
| Tensile strength $\sigma_{UTS}$ (MPa): | 1055.5 |
| Density $\rho$ (kg/m$^3$): | 7800 |
| Embodiment energy $H_m$ (MJ/kg) | 16.25 |
| Specific carbon footprint $CO_2$ (kg/kg) | 1.125 |

# SCENARIO SPECIFIC TURBINE BLADE DESIGN (TEAM) – COVER PAGE

Team Number: Thurs-48

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

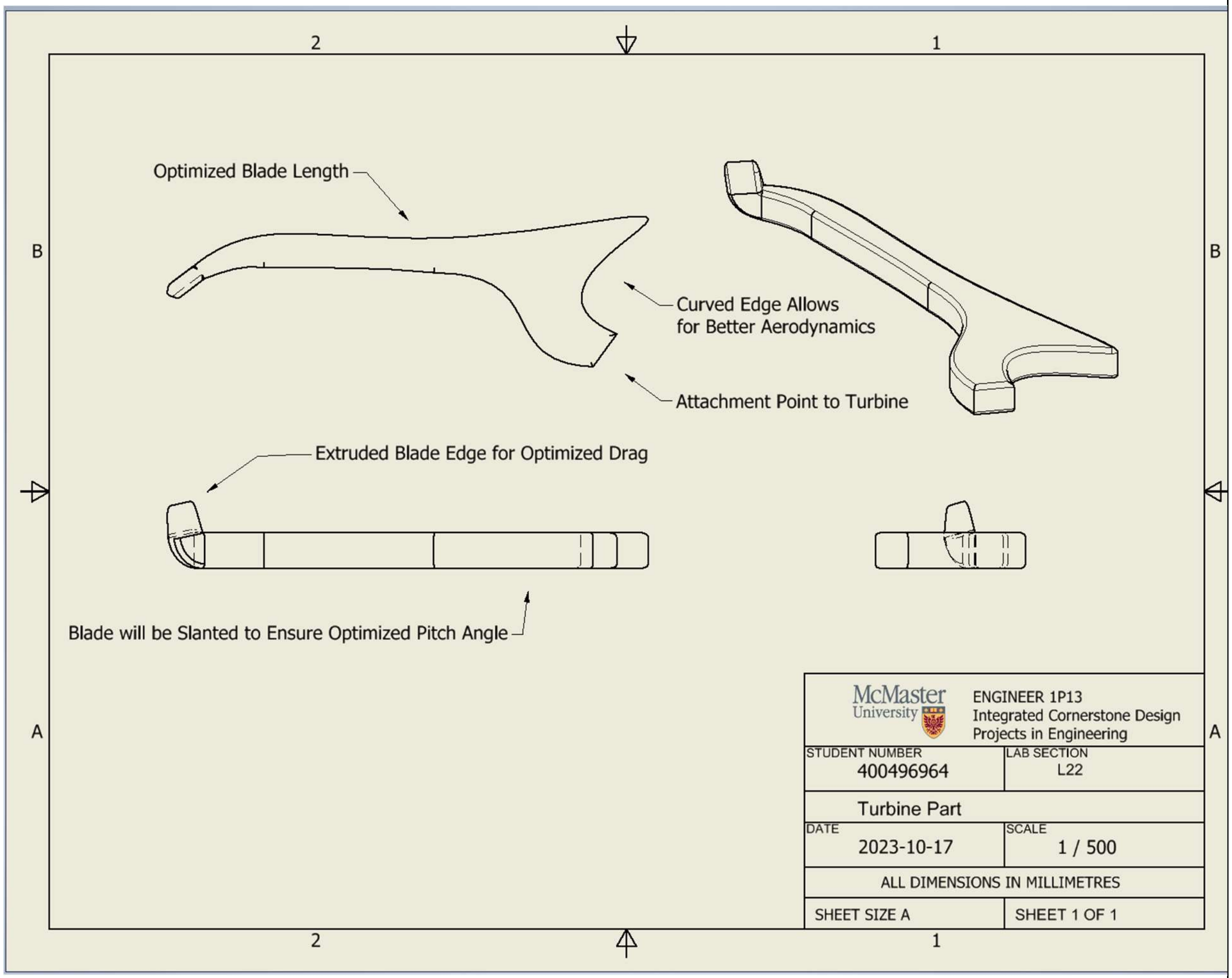
| Full Name: | MacID: |
|---|---|
| Huzaifa Syed | syedh42 |
| Shafer Honigman Deltoff | honigmas |
| Shadi El-Fares | elfaress |
| Elijah James | jamese13 |
| Maheer Huq | huqm6 |

# MULTIVIEW TURBINE BLADE SKETCH AND JUSTIFICATION

Team ID: Thurs-48

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

*Include an explanation on how your turbine blade design meets your assigned scenario. Be sure to discuss the creative elements behind your design and provide justification for them.*

When creating clean wind turbines to supply energy to multiple cities in Sweden, there are many key factors to consider. To meet the needs of the community, the blade includes an optimized blade length, pitch angle, and unique extruding curved edges. Altogether, these blade components provide the ideal vessel for immense wind power generation in a clean manner.

To determine the length of the turbine blade optimized for this scenario, it is important to think about the technicalities of the assigned location. This blade is being designed for multiple cities in Sweden, meaning large farms with high power outputs are required while also following Swedish turbine regulations. In Sweden, wind farms are said to be qualified as large wind farms depending on the height of the turbine. To qualify as a large wind farm, seven or more turbines would have to stand together with at least one of them having a height of 120 m or more [1]. Since energy needs to be supplied to multiple cities, this height of 120 m can be a standard benchmark for the turbines. The height of the wind turbine can be used to determine the blade length. The blade length is optimal when it is equal to half of the height of the turbine [2]. Since the height of the turbine is a standard of 120 m, the blade length is optimal at half of this, which would be 60 m.

The pitch angle of the blade is another vital component to its movement and power generation. This angle between the wind's direction and the blade is sometimes referred to as the "angle of attack," as it enables the blade to generate power from wind incoming at many angles while also using the wind to create a lift force to keep the blade moving [3]. Although substantial amounts of lift are obtained by having a larger pitch angle, after reaching a point of about 20°, this lift begins to decrease [4]. Therefore, the angle of attack used for the blade was concluded to be optimal at 20°, maximizing the lift force while also allowing for wind to hit the blade at various angles.

The curved extruding edges of the turbine blade are a unique design component that provide many of the same benefits as the pitch angle. As the curves extrude out, they can improve the lift force of the blades, which is especially helpful to keep the turbine moving in low wind conditions [4]. This in turn generates more power, helping reach the goal of generating enough energy for multiple cities. In addition, drag is often caused by tip vortices, which are "spirals of air that trail off the tips" of blades [5]. The curved edges negate the formations of tip vortices, allowing for smoother movement with less drag, as there are no tip vortices to steal energy from the motion of the turbine [5].

During the final stages of the design process, it was concluded that an estimated energy output specific to the blade designed would better depict the effectiveness of the turbines in Sweden. Although some components could not be factored in, this rough estimate uses the length of blade, average wind speeds/air density in Sweden, sweep area of the blade, etc. to predict the energy output in kWh [6]. A 3-blade turbine with design-specific metrics is predicted to be outputting 5,153,225 kWh every year before losses [7]. Overall, this unique turbine blade design supports sustainability and can efficiently generate enough power to supply multiple cities, when produced in large farms.

References

[1] "Onshore wind power development in Sweden and Finland | Practical Law." https://content.next.westlaw.com/5-521-8954?__lrTS=20210417045720263&transitionType=Default&contextData=(sc.Default)&firstPage=true

[2] G. Duval, "How big are the blades of a wind turbine?," *Today's Homeowner*, Aug. 2023, [Online]. Available: https://todayshomeowner.com/eco-friendly/guides/wind-turbine-blades-size/#:~:text=Blade%20Size,the%20height%20of%20the%20tower

[3] "Wind turbine blade design, flat, bent or curved," *Alternative Energy Tutorials*. https://www.alternative-energy-tutorials.com/wind-energy/wind-turbine-blade-design.html

[4] A. R. Sudhamshu, M. C. Pandey, N. Sunil, N. S. Satish, V. Mugundhan, and R. K. Velamati, "Numerical study of effect of pitch angle on performance characteristics of a HAWT," *Engineering Science and Technology, an International Journal*, vol. 19, no. 1, pp. 632–641, Mar. 2016, doi: 10.1016/j.jestch.2015.09.010.

[5] "Welcome to How Things Fly." https://howthingsfly.si.edu/aerodynamics/vortex-drag

[6] "Statistics." https://www.energimyndigheten.se/en/facts-and-figures/statistics/

[7] T. S. Energy, "Windy physics: how is power of a wind turbine calculated?," *Thunder Said Energy*, Dec. 2022, [Online]. Available: https://thundersaidenergy.com/downloads/wind-power-impacts-of-larger-turbines/#:~:text=The%20best%20overall%20formula%20for,Location%20matters%20most

# MILESTONE 4 (TEAM) – COVER PAGE

Team Number: Thurs-48

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

| Full Name: | MacID: |
|---|---|
| Huzaifa Syed | syedh42 |
| Shafer Honigman Deltoff | honigmas |
| Shadi El-Fares | elfaress |
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| Maheer Huq | huqm6 |

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.

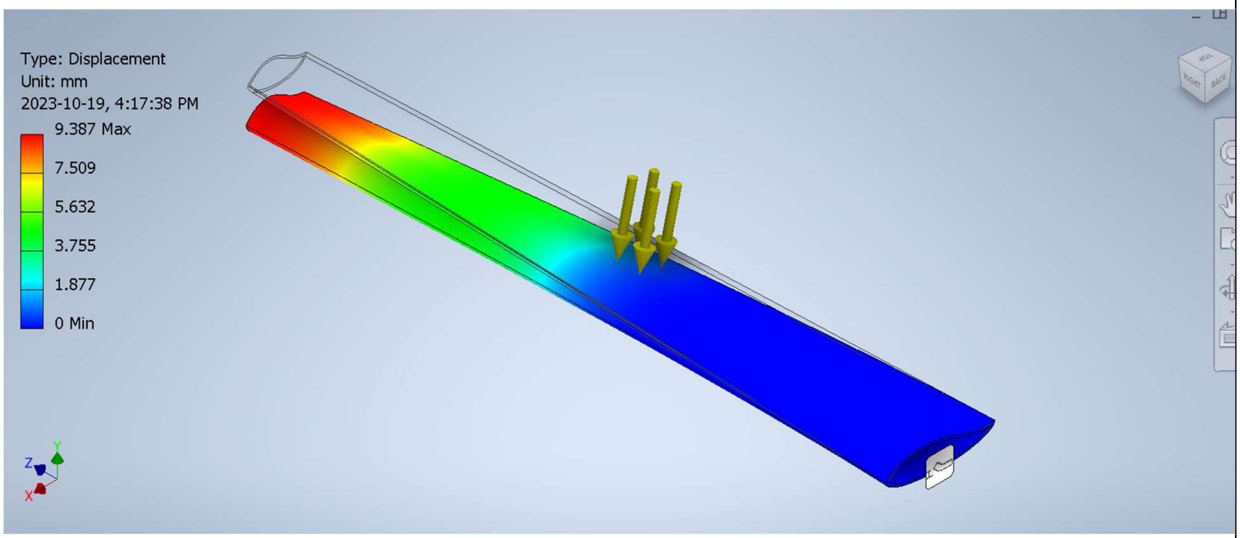
# MILESTONE 4 (STAGE 2) – REFINE THICKNESS REQUIREMENT

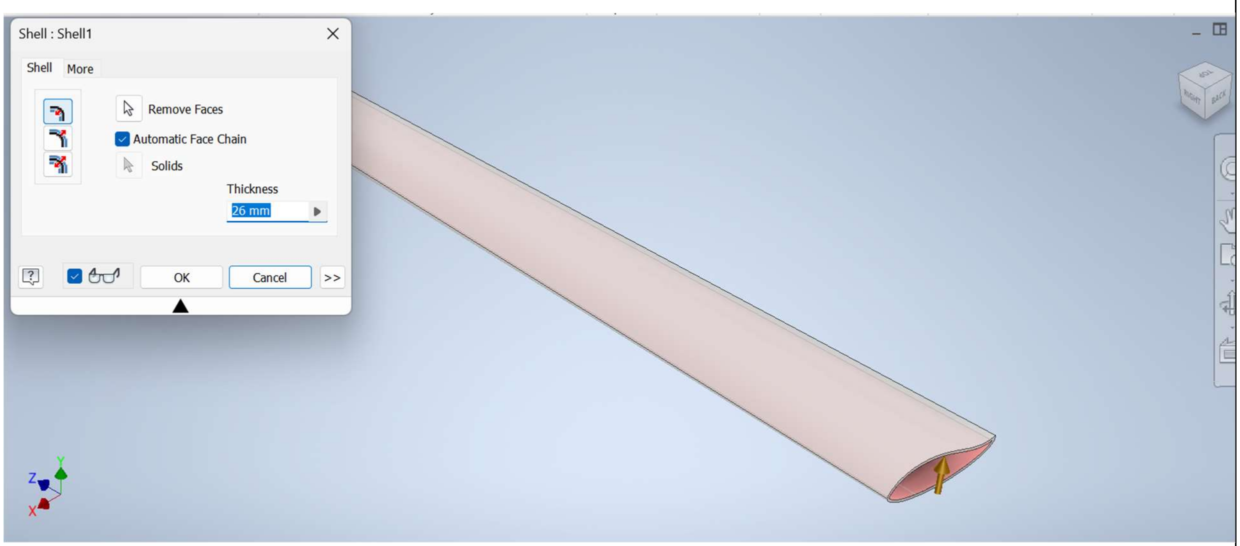
Team ID: Thurs-48

1. Refine Thickness Requirement to Satisfy Deflection Constraint

| | |
|---|---|
| Refined turbine blade thickness *t* (mm): | 26mm |

*Insert screen captures of the refined deflection simulation and provide evidence that the deflection satisfies the design constraint. Must show scale that is present on the left side of the screen.*



# MILESTONE 4 (STAGE 3) – PEER INTERVIEW

Team ID: Thurs-48

→ 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

*Discuss what you have learned from another group*.

While talking to the other group, we learned about scenario 3, which involved the making of a Calgary residential use turbine that was designed to be compact enough to not collide with anything while also saving money for homeowners who want to reduce their electricity bills. Their primary/secondary objectives were minimizing volume and cost. Reflecting on these choices, we believe that they made the right choices of objectives. Minimizing volume would mean smaller dimensions, in turn allowing the turbine to not collide with anything. Minimizing cost was also smart for their scenario, as this was a choice that allowed homeowners to save on their bills as wanted.

The material they chose was low alloy steel. Upon looking at the summary of this material's properties, it looked to be an appropriate material choice. This material was seen to be strong enough due to its Yonge's modulus being higher than 100, which shows that it's stiffness is appropriate for being on top of a roof throughout many types of weather in Calgary. Also, they said their refined thickness ended up being 30 mm.

Reflecting on the difference between our scenario and theirs, we had to look at the blade on a much bigger scale since the turbines we looked to create would be generating electricity for multiple cities, whereas theirs would be for a single residence. Their objectives were also seen to be very different from ours, as they looked to minimize dimensions and cost while we looked to create clean energy on a large scale, minimizing carbon footprint and production energy. We both ended up choosing steel, as it's the strongest when factoring in price, durability, ease of access and more.

In terms of our turbine blade design for scenario 4, we faced design challenges when figuring out how to incorporate the extruding turbine edge. This was a design we thought about a lot, and our main goal was to mix practicality with creativity. As the design evolved and we decided to create it on inventor to easily obtain a Multiview, we found it very difficult to accomplish and extruding edge. We also didn't figure out how to add the pitch angle in the way explained in our justification, so that became more of a theoretical piece that we would look to have.

While talking to the other team, we learned a lot about other methods of keeping a good structure going in the group. The other group we talked to mentioned how divide and conquer was the main method they used in getting their assignments done. They also mentioned some shared calendar system that they found convenient for getting their individual pieces of team assignments done in a timely manner, making it easier for the administrator. They would also assign deadlines for their individual pieces to make the time they will be done an assignment concrete. In terms of our specific blade, they gave us feedback involving how feasible the blade would be if implemented on as large of a scale as mentioned in scenario 4. They felt as though some parts of the body would need work to make it usable, but also mentioned that they liked our creative outlook on the blade.

***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.**