Taller Wind Turbine for Low Wind Speed Regions

Midterm Report

Team Number: 25

Submission Date: 10/31/2014

Submitted To: Dr. Nikhil Gupta
Dr. Scott Helzer
Dr. Sungmoon Jung
Dr. Kunihiko Taira

Authors: Steven Blanchette: srb12c (ME)
David Delie: dad10 (ME)
Kimberly Martinson: kam11z (CE)
Jeremiah McCallister: jjm10j (ME)
Abigail McCool: aam11f (ME)
Theodore Meros: tm12n (CE)

Table of Contents

Table of Figures*

Table of Tables*

Abstract

Current wind turbines are not effective to use in Florida because the average wind speed is too low to provide adequate power. This problem has led to the need for a taller wind turbine that can be used in low wind speed regions. This report outlines the progress the team has made during the first half of the Fall 2014 semester on the development of this turbine. So far the group has completed research into wind turbine technology and created initial designs for both the structure and blades of the turbine. Descriptions of the designs and their CAD models are provided in this report. Additionally, decision matrices selecting the optimal designs are provided. The team is currently working on force analysis for each of these designs using FAST software from the National Renewable Energy Laboratory (NREL). The next report will go into further depth of the forces on a wind turbine and how our designs respond to these forces along with material selection for the turbine.

1 Introduction

In order to reduce global carbon emissions and continue to generate electricity, renewable energy is a dependable alternative to current power generation methods. There are many renewable sources to access including wind, solar, and hydro energy. In the United States, wind energy accounts for 30% of all renewable energy generated. To generate power a certain wind speed must be present. Unfortunately, the Southeastern United States does not have sufficient average wind speed to make current turbines viable. The goal of this project is to develop a wind turbine that would be effective in low wind speed regions like the Southeastern United States. By designing a wind turbine that is taller than current turbines we will be able to harness larger wind speeds at higher altitudes. We will be working with students from the civil engineering department on developing and designing the tower and blades of a new wind turbine.

This report details a basic background of the project and why there is a need for a taller wind turbine for use in the southeast. To complete the project several objectives and constraints must be met within the class time frame. The team has developed several different design ideas for both the blades and structure of the wind turbine and they are shown in this report. The designs are then compared and the best designs are selected by way of a decision matrix. With progress being made the Gantt chart and allocation of resources have been changed accordingly.

2 Project Definition

2.1 Background research

Wind energy is one of the leading sources of renewable energy in many countries. The Unites States is increasing its investment into renewable clean energy opposed to dirty energy like coal and gas power plants. In 2013, 13% of the country's electricity generated was from renewable sources. Wind power constituted 30% of the total renewable energy generated.[1] The growing use of wind energy in the country has not traveled to the Southeastern United States due to low wind speeds. Most of Florida's renewable energy comes from solar plants. Light winds make commercial wind farms not currently viable.[2] This project seeks to explore new ideas that would make wind power a feasible method to generate power in Florida and the Southeastern United States. Figure 1 below shows average annual wind speeds throughout the United States, higher wind speeds are shown in purple/red.

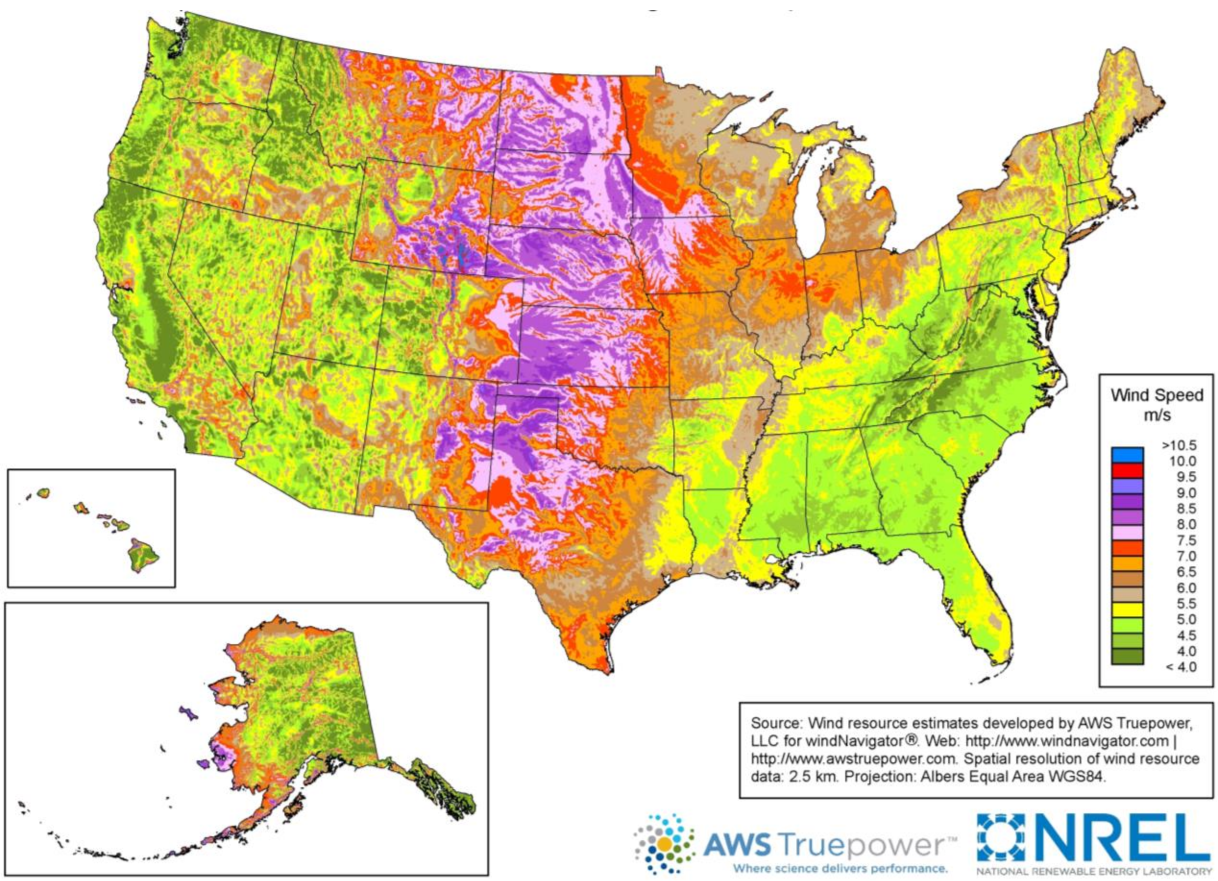


Figure 1. United States: Annual average wind speed at 80m[3]

If there was a wind turbine that could operate effectively at lower wind speeds a huge market, roughly two-thirds of the country, would develop for wind turbine producers. The question then becomes how to make wind turbines work in areas where the wind speed is too low for current turbines to operate effectively. The solution proposed by the sponsor is to make the wind turbine taller so it can utilize faster wind speeds at higher altitudes. The higher wind speed at higher altitudes can be explained by looking at wind flow like water flowing through a pipe with a boundary layer being developed. The velocity vectors will increase with distance from the ground. An example of this wind gradient is shown below in Figure 2.

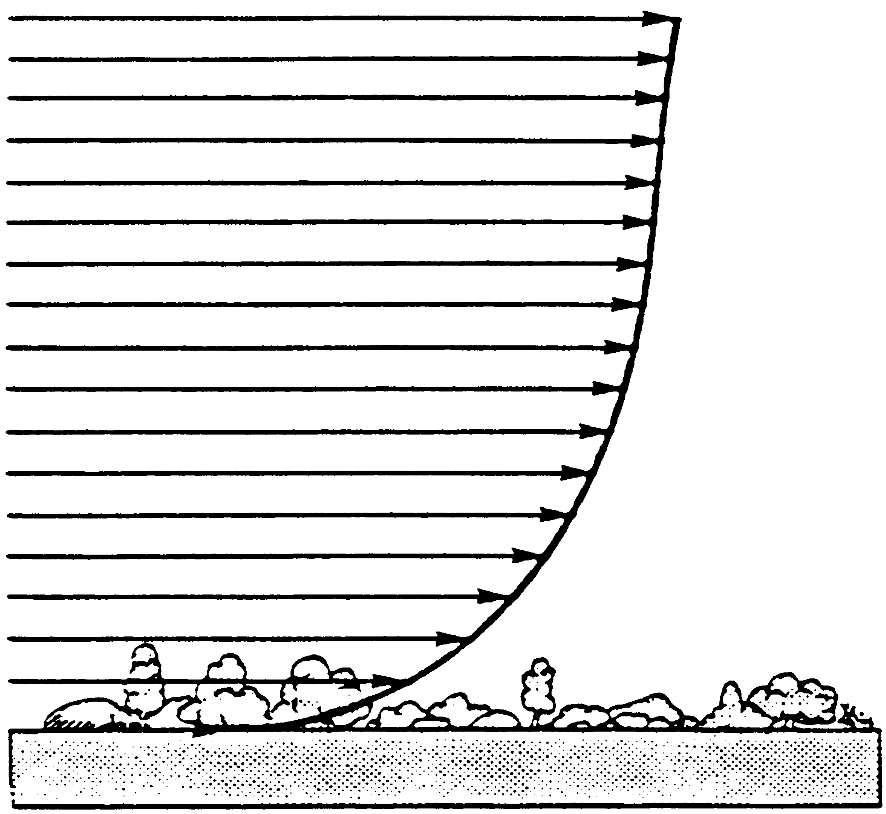


Figure 2. Development of wind gradient with increasing altitude[4]

In order to generate electricity, there must be some sort of input energy. In the case of wind turbines, the input kinetic energy is the wind. This wind causes the blades on a turbine to rotate. These blades are attached to a rotor that spins the generator producing electricity. Currently there are two types of wind turbines used to generate electricity. These include horizontal axis turbines and vertical axis turbines.[5] The issue our senior design team is faced with is the lack of input kinetic energy in the wind in low wind speed regions such as Florida. As a result of these low wind speeds, current wind turbines cannot generate sufficient energy. This leaves our senior design group with the task of overcoming the uncontrollable obstacle of low wind speeds and designing a turbine that can generate sufficient energy in low wind speed regions.

The speed of the wind on the wind turbine is critical to generating enough power to be cost-effective. Wind turbines have a “Cut-in Speed” which is the minimum wind speed needed to generate useable power.[6] For most wind turbines this speed is typically 3 to 4.5 m/s. From Figure 1 it can been seen that Florida wind speeds barely make this cut at 80 meters. The most common wind turbine used in the United States is 80 meters tall. This project would like to design a wind turbine 150 to 200% larger to utilize the higher wind speeds at higher altitudes.

Just this month (September, 2014) the Energy Department announced that they would be putting $2 million in funding towards two companies in Iowa and Boston focused on producing taller wind turbines in a cost-effective manner.[7] This commitment to taller wind turbines by the government shows that there is a strong incentive to develop this technology for the private and public sector.

2.2 Need Statement

Our project is sponsored by the FAMU-FSU College of Engineering. The project leader/sponsor is Dr. Sungmoon Jung and he wants the group to focus on using new turbine blade and structural materials that will allow for a new, cost-effective wind turbine to be built in Florida. Currently there are no major wind farms in Florida due to low wind speeds at 80 meters. By introducing a wind turbine that is effective in Florida a new market could exist. There is a need to develop and produce a new type of wind turbine that is larger to utilize wind power in areas like Florida.

"Current 80 meter wind turbines are not cost-effective for use in the Southeastern U.S."

2.3 Goal Statement & Objectives

Due to the fact that current wind turbines do not exist that can be effectively used in the southeastern united states, this team was presented with the following idea

"Design a new wind turbine that can be used in low wind speed regions to generate electricity"

Objectives:

The goal of the project has several important objectives that the team needs to meet to be successful. They are as follows:

- Incorporate innovative technologies into the wind turbine design
- Design wind turbine blades for tower 150-200% larger than current wind turbines
- Design a turbine tower that is structurally sound at higher altitudes
- Construct a scaled prototype of turbine design for testing

2.4 Constraints

The sponsor wants the students to utilize new technologies and ideas in their design of the wind turbine. The new structural/mechanical designs have to be structurally sound at the height of 150 to 200 meters. In order for the turbine to be a realistic option for the southeast the design must be cost competitive with current wind turbines in the market today. Along with being financially competitive, the turbine must be able to generate at least the same electrical power as current turbines. All of these initial designs and prototyping by the team must be accomplished before the end of the spring semester within a budget of $2,000. The design and performance specifications for the project are below.

2.4.1 Design Specifications

The design specifications for this project are as follows

- The wind turbine will be 150-200% taller than current wind turbines
- Must withstand stress of wind at 150m in SE United States
- The structure must support its own weight
- Blades will lighter than average current turbines
- Wind Turbine will be innovative into the wind energy field

2.4.2 Performance Specification

The performance specifications for this project are as follows

- It will use a 5 MW turbine motor
- Operating in all weather conditions with exception of winds >20 m/s
- There will be no energy used or fuel consumed
- The efficiency will be within a range of 30-35%

3 Design and Analysis:

3.1 Functional Analysis

The components of the wind turbine that the team is working on are the blades of the wind turbine and the tower. There will be three blades with a length of 60 meters each and the tower will be 140 meters in height. The blades will be attached to a rotor that spins a 5 MW generator that will be used to generate electricity. A series of cables will transfer the generated power from the top of the wind turbine to the ground

3.2 Design Concepts

All designs can be seen in Appendix B.

Blade Designs

After researching, the group decided to use the standard airfoil blade shell design. The airfoil is the optimum shape for gaining lift which will be essential for generating the most power. The material of the blades are still to be determined. Some of the materials considered are carbon fiber, Kevlar, and other composite fabrics. Inside the shell, a shear web is placed to strengthen the blades. The standard shear web is composed of one or two I-beams. Our team is looking into other possible designs that may reduce the overall weight of the blades which will generate more power. In the proceeding paragraphs, three of the possible designs will be discussed.

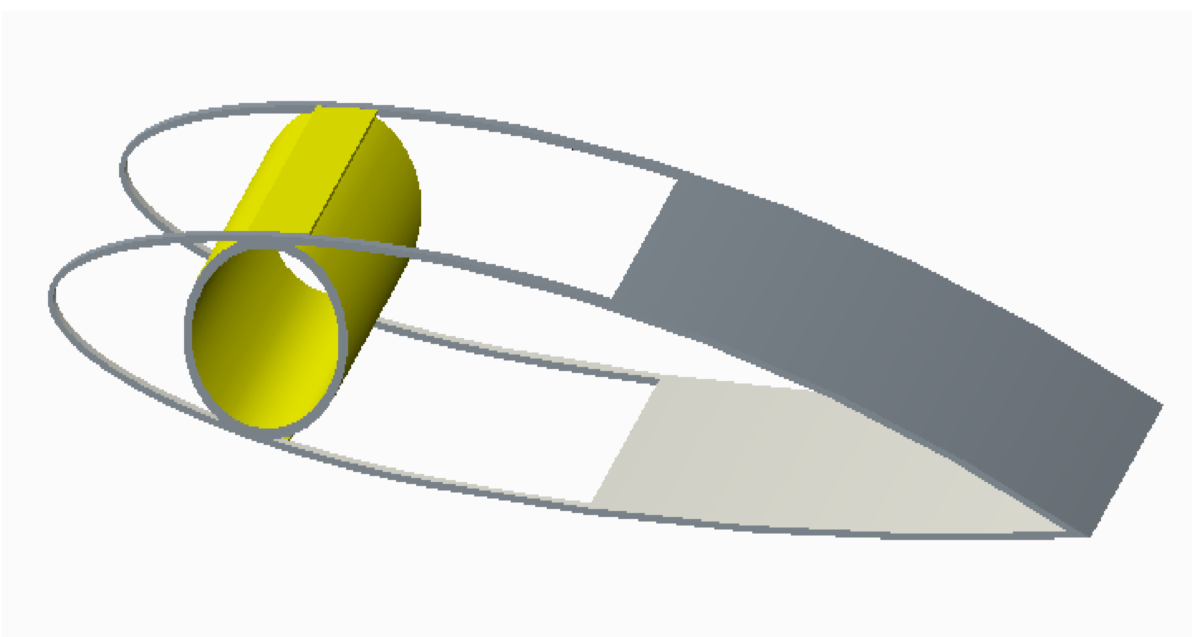


Figure 3. Blade Design Concept 1 (Internal Cylinder)

This design shown in Figure 3 consists of a standard airfoil turbine blade, internally supported by a hollow cylinder. The idea behind this design is that the hollow support will reduce the amount of material in the blade, thus reducing the overall blade weight, while still maintaining strength.

The cylinder will most likely be made from of composites. This may increase the strength of the shear web while minimizing the mass. Using a simplistic shape such as a cylinder will make this design easier to produce.

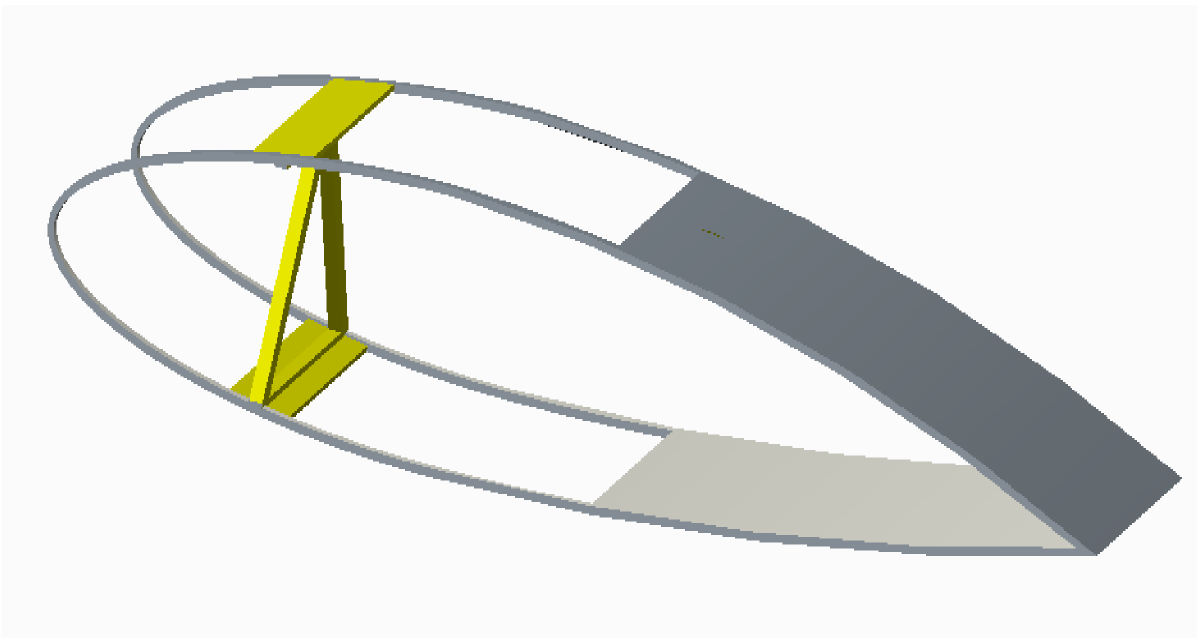


Figure 4. Blade Design Concept 2 (Internal Truss)

This turbine blade design shown in Figure 4 uses triangular trusses for the shear web. This design eliminates much of the material used. Triangles were chosen in this design because they distribute the compressive load uniformly. This deigns hopes to significantly reduce the mass while providing enough support so the blades do not bend.

The trusses of shear web for this design could be made out of composites, wood, or a low density metal. The braces can be bonded with epoxy or welding depending on the truss material. This design will be more costly to produce.

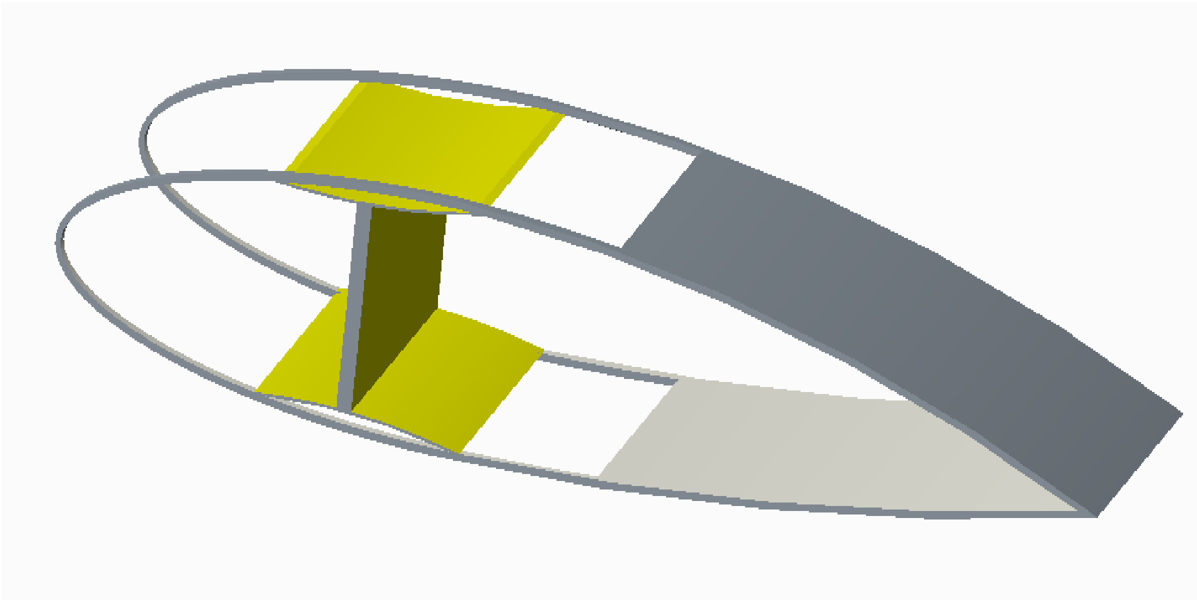


Figure 5. Blade Design Concept 3 (Single Post)

Figure 5 shows a design that uses a central I-beam placed in between two curved domes. To prevent the load from being too great on a single point in the blade, the top and bottom of the beam will sit on two curved surfaces which will attach to the top and bottom inner surface of the blade. The curved surface will take the point load from the central I-beam and distribute it over a larger area to prevent damage to the blade. As the dome size increases, the load decreases on the contact points and the shape of the dome will resist flattening out even if the load becomes too large.

The central post and domes can be made out of composites or certain woods. The material chosen should be as light as possible as long as the post can withstand the compressive load from the beam bending. It is possible that the one central beam will not be able to withstand the torque that the wind turbine blade will face, but this will be tested by the team.

Structure Designs

This project requires designing a structure that is between 120-160m tall. Additionally, the structure must be able to support a nacelle of a 5MW wind turbine. Some of the main design challenges will involve cost and transportation.

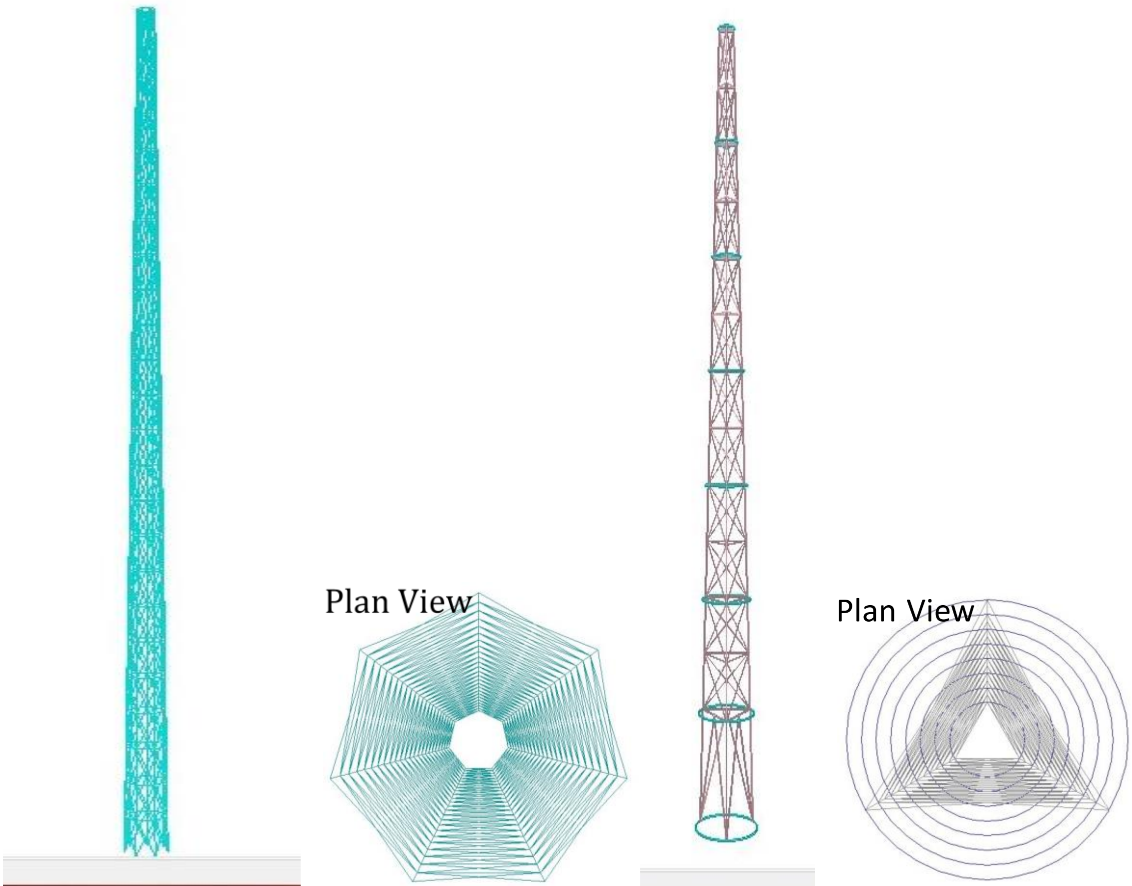


Figure 6 and 7.Tower Design Concept 1 (Heptagonal Lattice) and 2 (Triangular Lattice)

These designs rely on using a steel lattice structure that is wrapped in architectural fabric. This will result in a lighter structure and reduce the overall cost of materials. The tower will have either three or seven sides, shown in Figure 6 and 7 above, depending on the transportability of the sections and stability of the overall tower. A three-sided tower may require base sections that are too wide to transport without a permit. However, a seven-sided tower requires a greater number of connections and more material.

The tower must be assembled on site due to the height and restrictions on transportation. The construction time is likely to increase due to the greater number of connections compared to the typical wind turbine tower. Therefore, in order to reduce the construction time, the connections will consist of male to female joints. Despite the potential benefits of this design, complications may arise due to the increased height of the tower. Also, the vibration of the modular steel design may increase noise levels. At this point, knowledge of applying the space frame to wind turbines is very limited since it is still in the research phase.

Figure 8 shows the most common design used for 80 meter wind turbine towers. It is a steel tubular structure that is built by stacking multiple cylindrical cross sections on top of each other. The tower has a larger diameter at the base to improve stability. This tower is effective for use at 80 meters and below but it becomes less cost effective if built to taller heights. If this design is made for the project constraint of 120-160 meters the base will have to be larger and this could affect the transportability of the cylindrical sections. This tower is useful as a good baseline that the team's designs will be measured against. This type of tower design obviously uses more

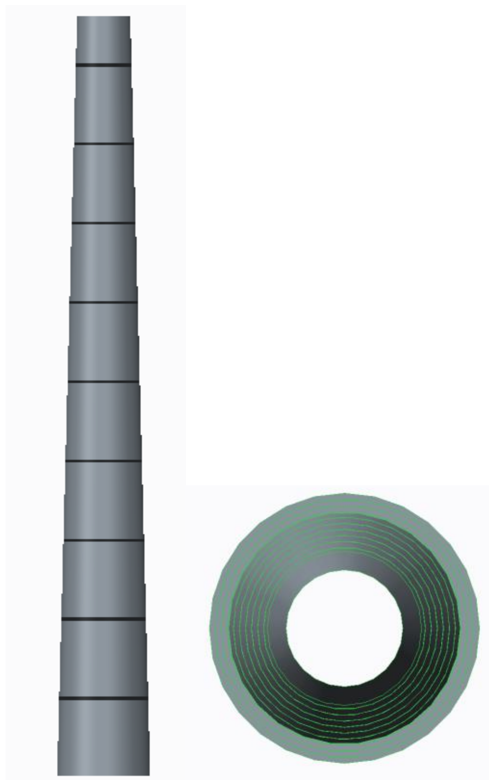


Figure 8. Tower Design Concept 3 (Steel Tube)

material than the lattice structures, but we have to test to see if the tube design is also more stable.

3.3 Evaluation of Designs

Decision matrices were utilized in order to select the optimal design for the turbine blades and tower. These decision matrices can be seen below in Tables 1 and 2. Five criteria were considered for each design. Each criterion was given a weight based on a scale from one to four. Each design was then analyzed for each criterion and also given a rating from one to four. The total rating for each design was determined, and the design with the largest total rating was selected. Although the decision matrices select optimal designs, the project sponsor must approve all final design decisions.

Table 1 displays the decision matrix used to determine the optimal blade design for the wind turbine. After rating each design, blade design 1 (Internal Cylinder) was selected as the optimal design for the wind turbine.

Table 2. Decision Matrix for Blade Design Selection

Criterion	Weight	Blade Design 1 (Internal Cylinder)	Blade Design 2 (Internal Truss)	Blade Design 3 (Single Post)
Cost	2	4	3	2
Weight	4	4	3	2
Manufacturability	2	3	2	3
Durability	3	2	1	3
Strength	4	3	4	2
Total Rating		**50**	41	35

Table 2 displays the decision matrix used to determine the optimal tower design for the wind turbine. After rating each design, tower design 1 (Heptagonal Lattice) was selected as the optimal design for the wind turbine.

Table 3. Decision Matrix for Tower Design Selection

Criterion	Weight	Tower Design 1 (Heptagonal Lattice)	Tower Design 2 (Triangular Lattice)	Tower Design 3 (Steel Tube)
Cost	2	3	4	2
Portability	4	4	2	2
Weight	4	3	4	2
Manufacturability	2	4	4	1
Durability	3	4	2	4
Total Rating		**54**	46	34

3.3.1 Criteria, Method

For the selection of the blade cost, weight, manufacturability, durability, and strength were considered. The weight and strength of the design were considered to be the most important criteria in the selection process with a weight factor of four. The weight was considered important since the team is designing a taller, lighter wind turbine and strength is important because the design cannot fail when wind loads are imposed upon it. The durability was given a weight factor of three because it is important that the blades do not degrade quickly in order for the design to be cost-effective. The cost and manufacturability were given a weight factor of two because they still play an important role in the design of the blades, but their impact on the final design is not as large.

The structural selection criteria were cost, portability, weight, manufacturability, and durability. Portability and weight were both given a weight factor of four because it is essential that the structure can be delivered to the site and the taller tower means that weight induced forces will be larger so reducing weight is of extreme importance. The durability was given a weight factor of three because it is important that the tower have an extended life to reduce replacement and maintenance costs. The cost and manufacturability were given a weight factor of two because the designs need to be cost competitive with current turbine towers and it is important that they can be produced easily.

3.3.2 Selection of optimum ones

It can be seen from Table 1 above that blade design 1 (internal cylinder) is the optimal design for the wind turbine. Table 2 shows that tower design 1 (heptagonal lattice) is the best option for the turbine tower. All designs will be analyzed by the team with FAST and presented to the sponsor for approval. If force analysis shows that the chosen designs do not withstand loads placed upon them the team will reevaluate and modify the decision matrices.

4 Methodology

The general strategy of the team is to split up the various tasks into distinct sections to make the workload more manageable. Although everyone has individual tasks the team will still meet weekly to ensure that progress is being maintained throughout the semester. The team will also meet every other week with the sponsor and faculty advisor to keep them updated and inquire about any issues encountered. The following schedule describes how the project will be broken down.

4.1 Schedule

The Gantt chart in the Appendix shows a complete breakdown of the tasks that the team plans to accomplish this semester. The first thing the team completed was research into wind turbines to make sure that team members were informed about the project and its requirements. Several different research topics were focused on including current wind turbine construction techniques, cost of wind turbine production, new materials being developed for turbine blades, and the types of forces and loads imposed on a wind turbine during operation. More extensive research will be done throughout the semester as the needs of the project expand.

Having completed initial background research the team created several different designs for the wind turbine. The mechanical engineering students created three possible designs for the wind turbine blades, while the civil engineering students created three possible designs for the wind turbine tower. New technologies were incorporated into all prospective designs for both the blades and the tower. After the team developed these new designs, they were constructed in CAD software.

The team is currently working on force analysis of the possible designs. The team is utilizing a program called FAST which is created by the National Renewable Energy Laboratory to perform this analysis.

After simulation of the designs is complete the team will select the best design using a decision matrix. By the end of the fall semester the team should have at least two viable designs that can be taken into the spring semester for further analysis and possible prototyping.

4.2 Resource Allocation

Every member of the team was responsible for background research on wind turbines. More research will be done if needed. The first three weeks of the project were spent on research about the project and wind turbines in general. The team is finishing the design development phase of the project, three weeks were given for initial designs to be created. The mechanical students focused on design of the blades while the civil students designed the structure. The team is now working on force calculations of the blades and structure which will take place over two weeks. Then one week will be spent on cost analysis of the possible designs. Finally, there will be a design selection process at the end of the semester lasting two weeks. The entire team will participate in the design selection process. Table 3, located below provides information on the main tasks that each team member will focus on.

Table 3. Allocation of resources

Task	Team Member(s) Responsible
• Background Research ○ Wind Power	• All team members
• Background Research ○ Blade Shape (Airfoil)	• Abigail McCool • Steven Blanchette
• Background Research ○ Blade Material	• Jeremiah McCallister • David Delie
• Background Research ○ Structure (Design and Material)	• Kimberly Martinson • Theodore Meros
• Preliminary Blade Designs	• Jeremiah McCallister • Abigail McCool • Steven Blanchette
• Preliminary Structure Designs	• Kimberly Martinson • Theodore Meros
• Blade CAD Drawings	• Steven Blanchette
• Structure CAD Drawings	• Kimberly Martinson • Theodore Meros
• Blade Material Selection	• Jeremiah McCallister • David Delie
• Structure Material Selection	• Kimberly Martinson • Theodore Meros
• Force Analysis (Using NREL FAST)	• Jeremiah McCallister • Abigail McCool • Theodore Meros
• Cost Analysis	• David Delie • Kimberly Martinson
• Design Selection	• All team members

5 Conclusion

The goal of this project is to design a new wind turbine that is 150-200% larger that can be used in the Southeastern United States. If a turbine that makes wind power feasible for use in Florida is developed, there will be a huge new market for turbine producers to sell to. Preliminary research has been completed for the project and three designs for both the blades and the tower have been produced. All of the prospective designs have been created in CAD software. The team is currently performing force analysis calculations on all the designs by means of the FAST simulation software given to the team by Dr. Jung. Once the simulation of the designs is completed it can be compared to current turbines and the team can proceed with the best design. For the next report the team will have calculated forces on the wind turbine designs.

6 References

1) Jung, Sungmoon. "Senior Design Project Definition." FAMU-FSU COE. Web. 20 Sept. 2014. <https://campus.fsu.edu/webapps/portal/frameset.jsp?url=/webapps/blackboard/execute/launcher?type=Course&id=_6400320_1&url=>.

2) "Renewable Energy for America: Florida." *Natural Resources Defense Council*. Natural Resources Defense Council. Web. 22 Sept. 2014. <http://www.nrdc.org/energy/renewables/florida.asp>.

3) "Wind Maps." *NREL: Dynamic Maps, GIS Data, and Analysis Tools* -. National Renewable Energy Laboratory, 10 Sept. 2014. Web. 22 Sept. 2014. <http://www.nrel.gov/gis/wind.html>.

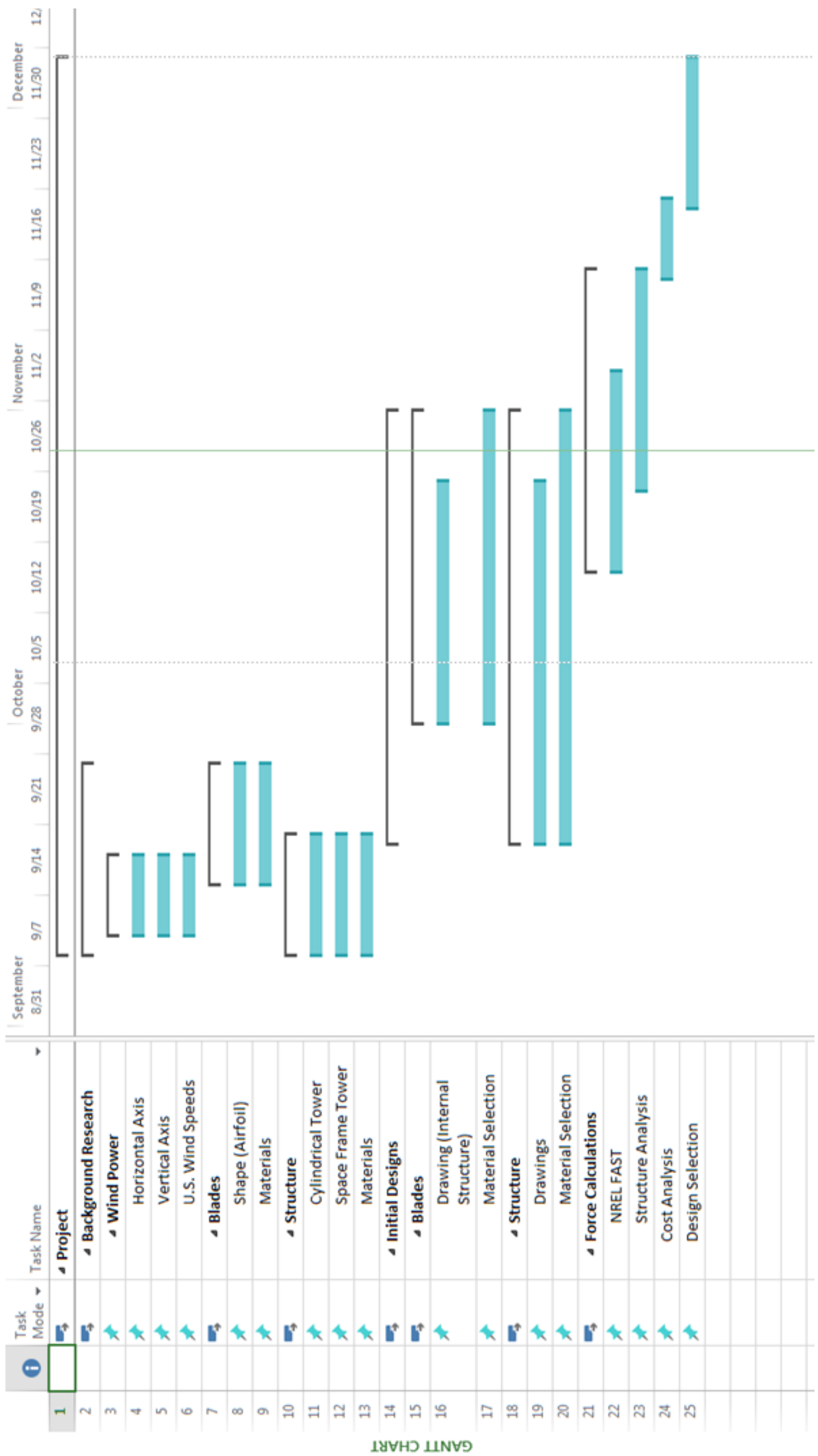
4) Lake, John. "The Wind Gradient." *CHGPA: Intermediate Study Material from USHGA for Hang Gliding*. United States Hang Gliding Association, Inc., 1 Jun. 1997. Web. 22 Sept. 2014. <http://www.chgpa.org/H3_StudyGuide/h3.study.guide.html>.

5) "How Does a Wind Turbine Work?" *Energy.gov*. U.S. Department of Energy. Web. 22 Sept. 2014. <http://energy.gov/maps/how-does-wind-turbine-work>.

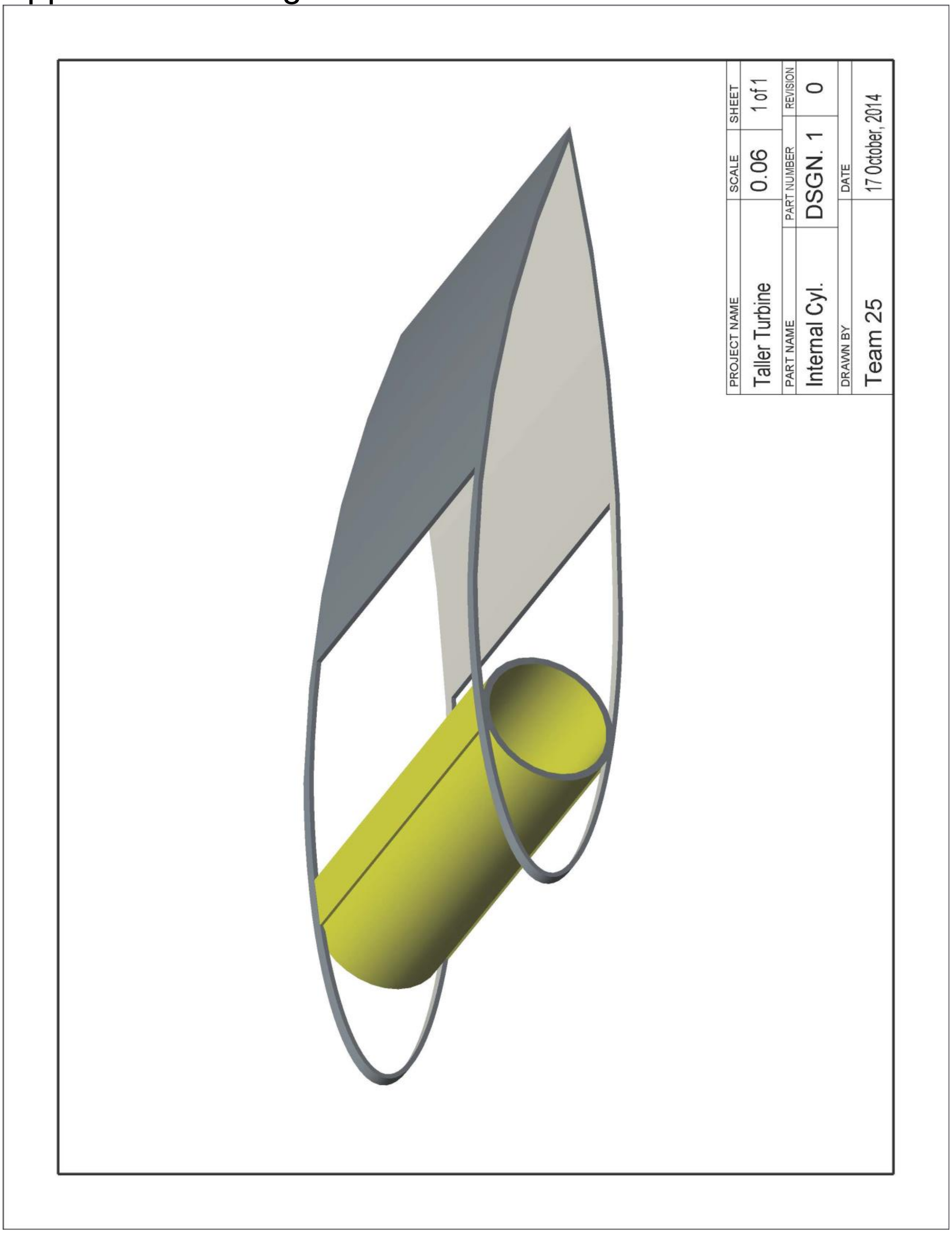
6) "Wind Speed and Wind Energy." *Wind Energy*. EnergyBible.com, 1 Jan. 2012. Web. 22 Sept. 2014. <http://energybible.com/wind_energy/wind_speed.html>.

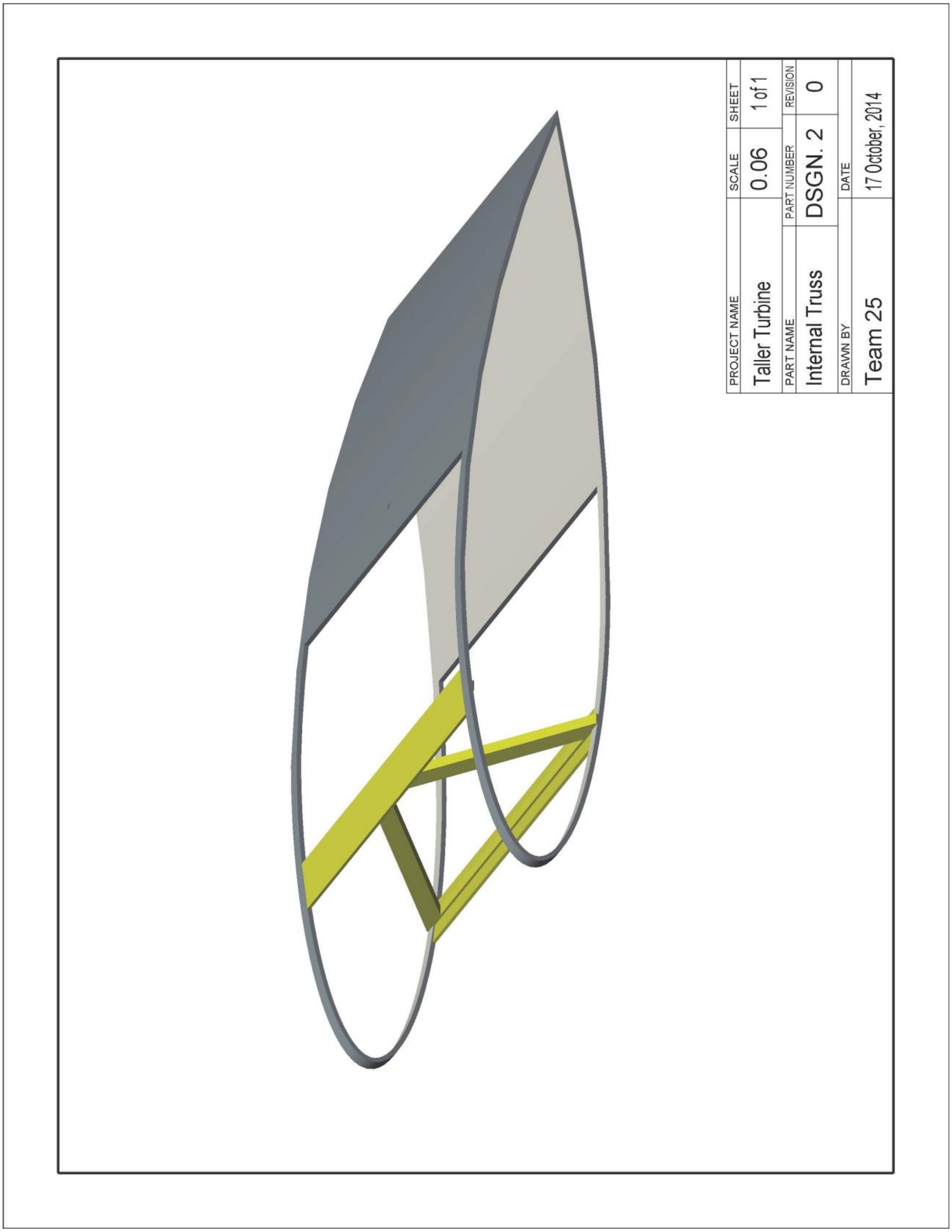
7) "Energy Department Announces $2 Million to Support Manufacturing of Taller Wind Turbine Towers." *Energy.gov*. Office of Energy Efficiency & Renewable Energy, 18 Sept. 2014. Web. 22 Sept. 2014. http://www.energy.gov/eere/articles/energy-department-announces-2-million-support-manufacturing-taller-wind-turbine-towers

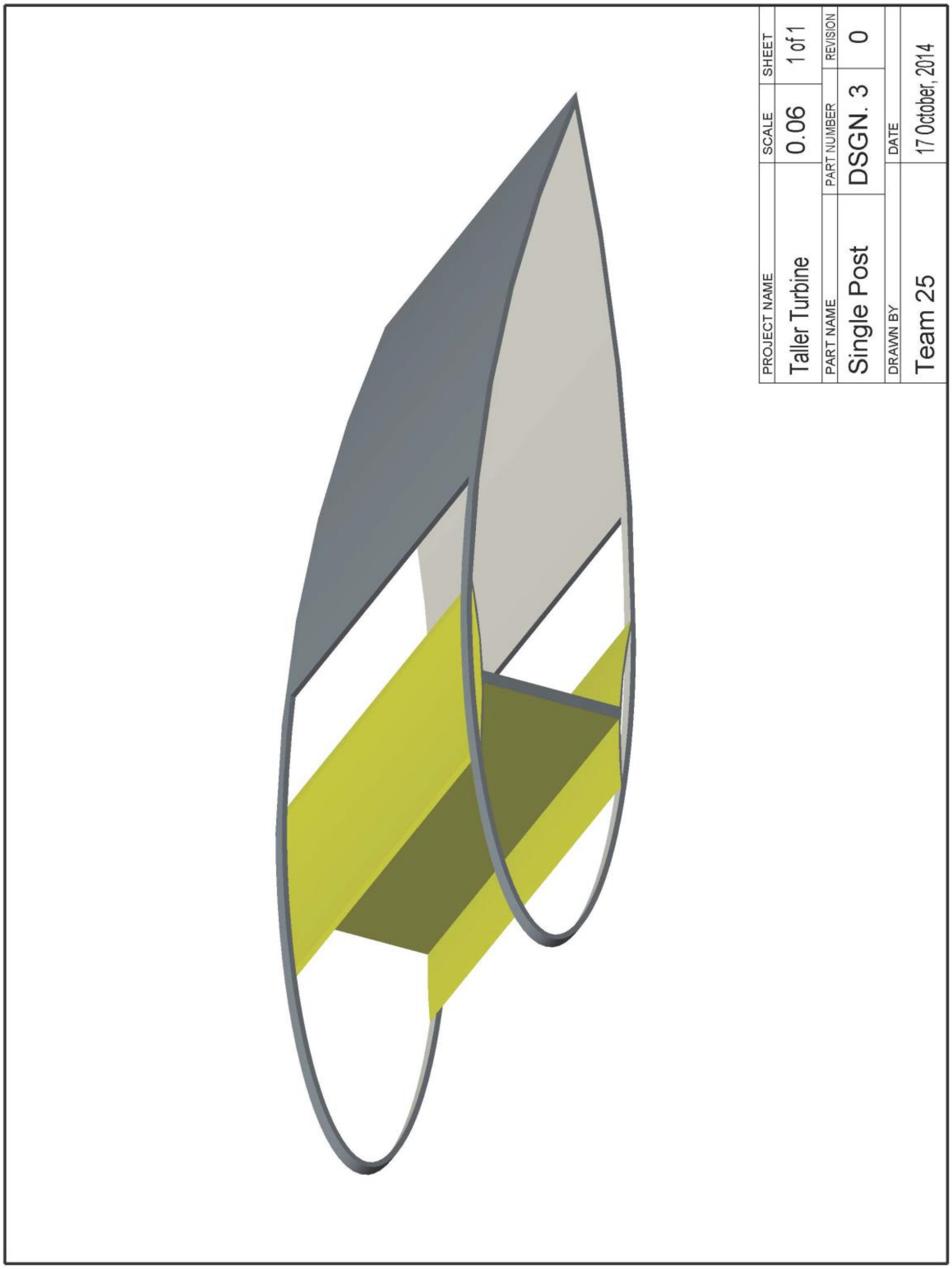
Appendix A: Gantt Chart

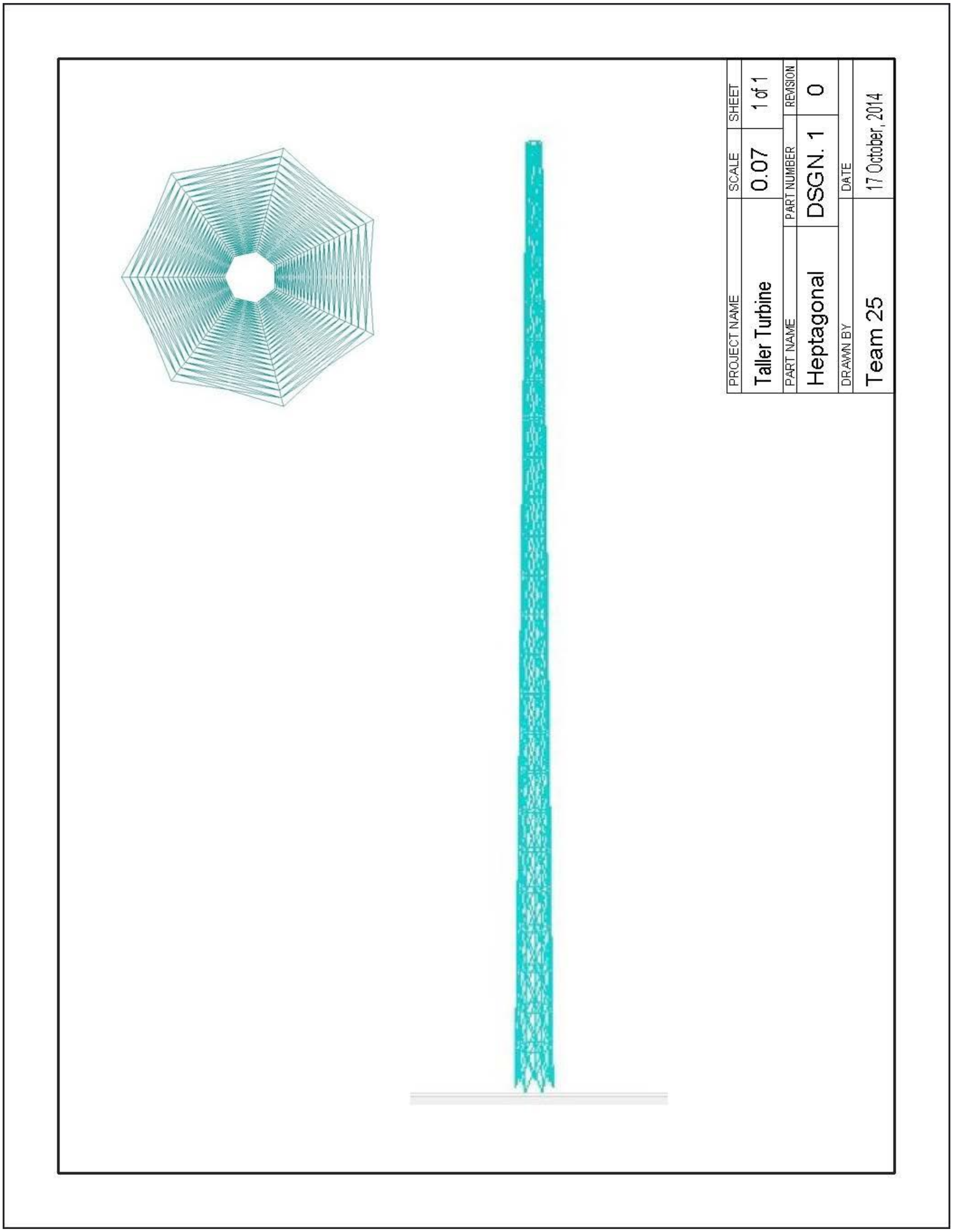


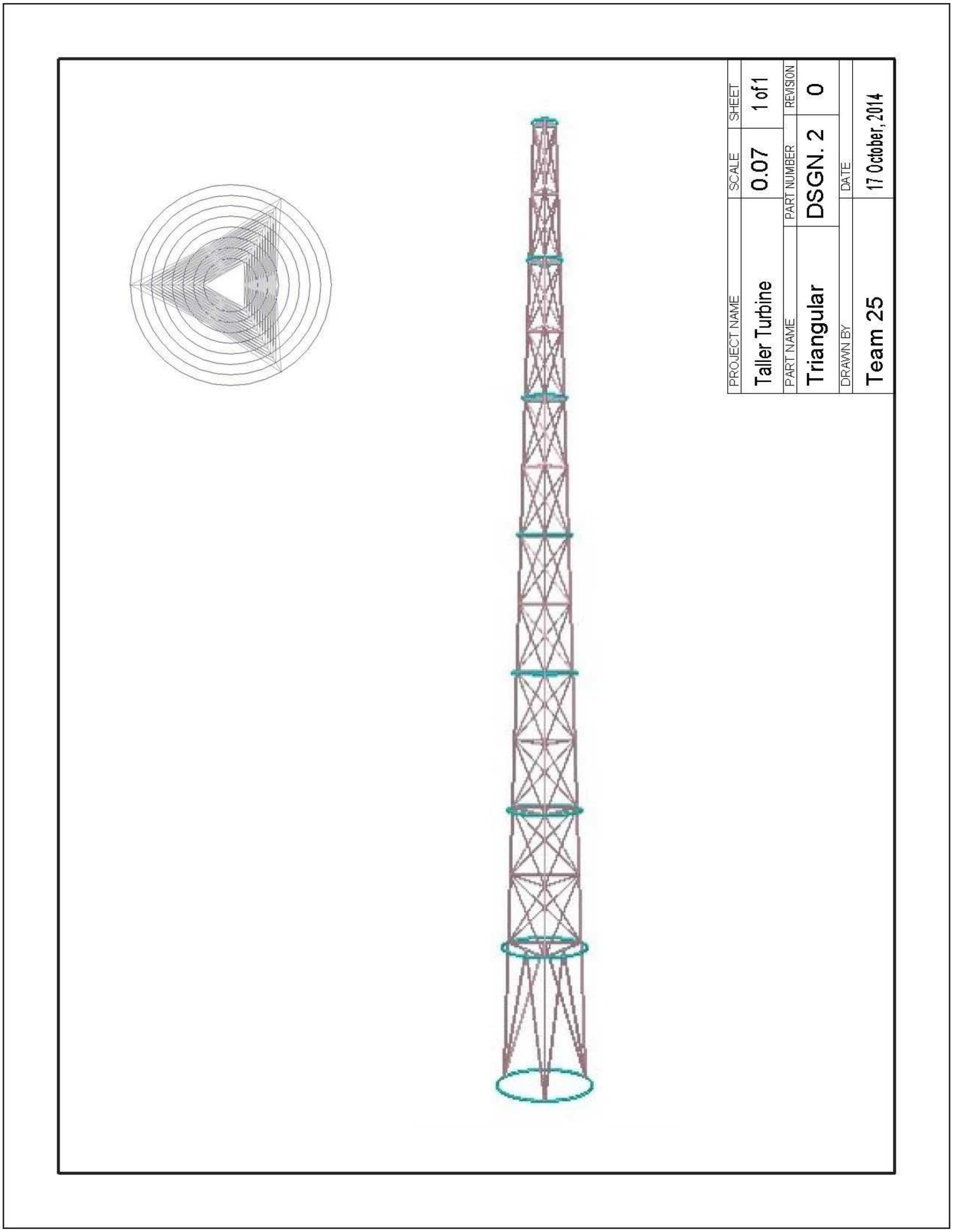
Appendix B: Design CAD

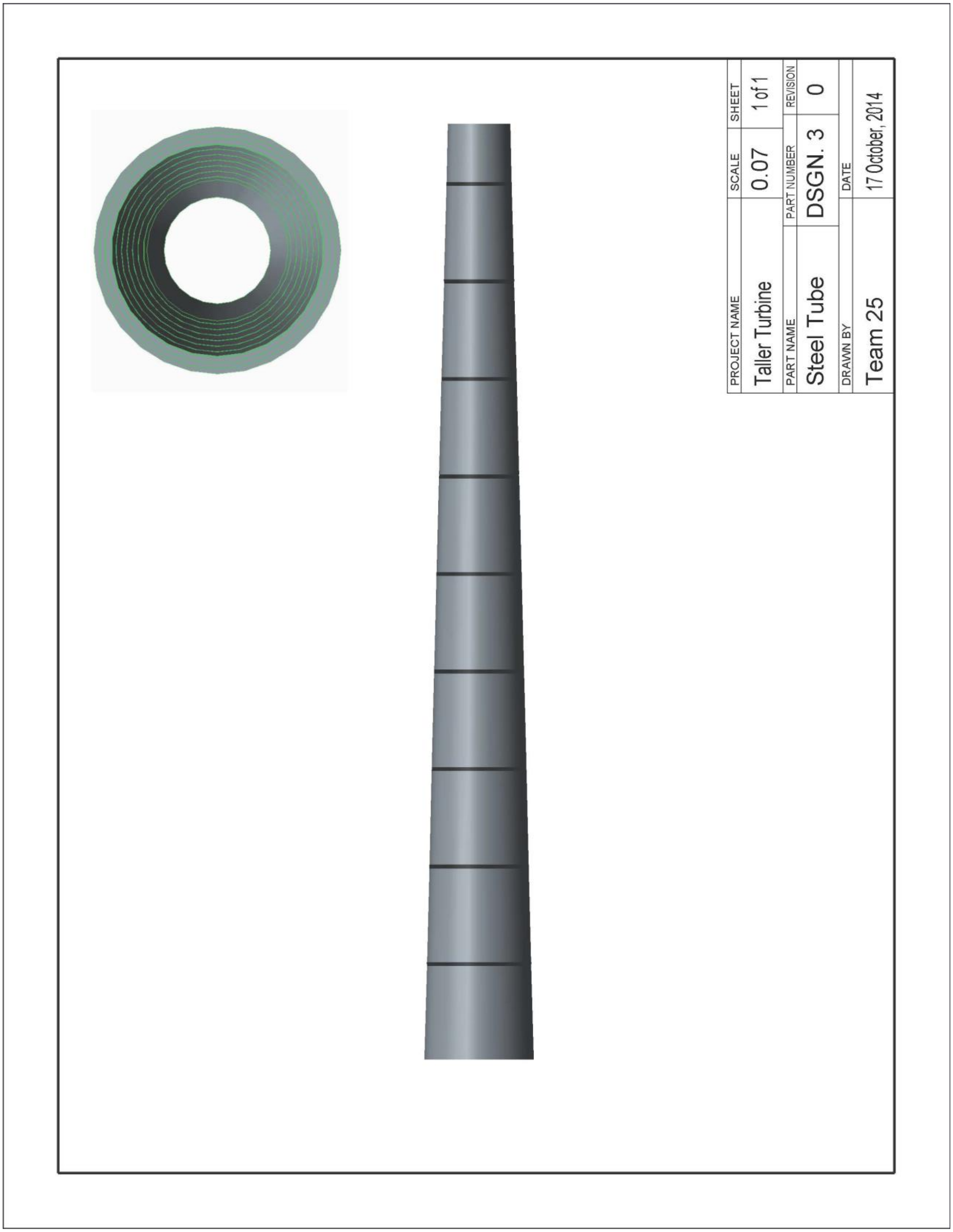



PROJECT NAME
Taller Turbine
SCALE
0.06
SHEET
1 of 1
PART NAME
Internal Truss
PART NUMBER
DSGN. 2
REVISION
0
DRAWN BY
Team 25
DATE
17 October, 2014


PROJECT NAME
Taller Turbine
PART NAME
Single Post
DRAWN BY
Team 25
SCALE
0.06
SHEET
1 of 1
PART NUMBER
DSGN. 3
REVISION
0
DATE
17 October, 2014


PROJECT NAME
Taller Turbine
SCALE
0.07
SHEET
1 of 1
PART NAME
Heptagonal
PART NUMBER
DSGN. 1
REVISION
0
DRAWN BY
Team 25
DATE
17 October, 2014


PROJECT NAME
Taller Turbine
SCALE
0.07
SHEET
1 of 1
PART NAME
Triangular
PART NUMBER
DSGN. 2
REVISION
0
DRAWN BY
Team 25
DATE
17 October, 2014


PROJECT NAME
Taller Turbine
SCALE
0.07
SHEET
1 of 1
PART NAME
Steel Tube
PART NUMBER
DSGN. 3
REVISION
0
DRAWN BY
Team 25
DATE
17 October, 2014