Open Ended Wind Energy

Midpoint Report

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1 Background

1.1 Introduction

Our project was focused on open ended wind energy. The major aim of our project was to design and build a wind turbine that was used to generate wind energy in an efficient manner. We were limited to build our design within 45 by 45 by 45cm, and we were using the Q-blades for our design.

1.2 Project Description

Our client was David Willy, and our design was used at NAU campus. The guidelines we followed were based on the Collegiate Wind Energy Competition. The description for our project was to design a more effective turbine Q-blade, a productive yaw system with a hub, a base flange with a tower, and a nacelle with a shaft and bearings.

1.3 Original system

The wind turbine enabled us to build bigger turbines, which enabled us to produce energy sufficient to supply to local houses. This could be great source of income and could enable other further research on wind turbines for better energy production.

2 REQUIREMENTS

This section describes all the customer's requirements for the project. The client required the team to go to the U.S. Department of energy website and search for the 2018 collegiate wind competition follow the competition rules to generate the customer needs and build a wind turbine. These customer requirements were translated into measurable quantifiable engineering requirements from which the goals of the project were met.

2.1 Customer Requirements (CRs)

The customer requirements (CRs), as asked by our client professor David Willy, are refined and listed, see Table 1 in Appendix. The table followed the following format: customer requirements, number of needs, importance weighted score and the justification for each requirement. These CR's were generated from competition rules and design requirements provided on the collegiate competition website.

2.2 Engineering Requirements (ERs)

Engineering requirements (ERs) were the measurable physical quantities that a designer used to meet the objective of the of the project. The engineer translated the CRs into ERs to solve the problems presented by the constraints and set up by the stakeholders. It also specified a standard system from which the project can be developed and properly managed. Table 2, below, lists the engineering requirements, targets and the rational reasoning.

Table 2 ERs, Targets, and Rationale

Engineering Requirements	Targets	Rationale
Power density	0 - 700 W/ m^2	To be able to achieve maximum power over the turbine face surface area.
Operating Voltage	5 volts	Competition rules required a constant voltage of 5 volts to be running
Lift Coefficient	1.75	Needs to meet this requirement to be able to initiate the turbine spin.
Stability	30.0 kPa	Turbine pillar and rotor parts needed to be able to withstand a tensile stress 30.0 kPa
Product Dimension (Size)	≤ 45X45X45cm	Project dimension set up by competition rules
Drag Coefficient	≤ 1.00	The maximum drag coefficient should be lower than 1.00
Max Voltage Limit	120 VAC	Project dimension set up by competition rules
Earth wire (ground)	≤100kΩ	Load material was able to contain a load power of 40W
Torque capacity	2 kN-m	To achieve an efficiency greater than 70 percent
Efficiency	>60%	Rotor and non-rotor were able to meet a combine efficiency greater than 60%

Max stress is 108.65 MPa and min stress is -7.84 MPa. The resultant deflections generated from the stresses at the tip of the blades are (X Axis Tip Defy.: -0.000502126 [m] & Z Axis Tip Defy.: 0.0175825 [m]). The force applied to the blades was loaded normally at eleven different radial positions from 0 m to 1 m with variable forces ranging from (0-5 N) as shown in the figure above.

2.3 Testing Procedures (TPs) ########Testing finished design. Does it actually meet the ERs. Future tense.######

Based on the HoQ, the most important ERs were the product dimensions, while the least is the max voltage limit. This is accurate as it was important that the team created a design with a product dimension size that will readily fit through the competition testing site to qualify the design and the team to begin the process of the competition. On the other hand, the team would not necessarily get a penalty if maximum voltage limit is surpassed. In which case, the design power efficiency reevaluated to limit its maximum voltage or certain design targets will be added or changed to meet up with the competition setup standards. All other importance rating scores can be seen below the HoQ as they met the needs of the client.

2.4 Design Links (DLs) – Theoretical design. Engineering calculations, CAD (is it the right size and weight?), FEA, Qblade, etc.

[Use this section to describe how your design meets each ER. Provide a meaningful description, but limit the amount of text to one paragraph per engineering requirement. Number each DL for reference in the HoQ]

2.5 House of Quality (HoQ)

This section presents a matrix format system called the House of Quality that translates the CRs into a suitable number of engineering targets (ERs) necessary to meet the expectations of the new design product. The matrix system relates all customer requirements as requested by the client and from benchmarking data collected to the newly established ERs. ERs and the technical difficulty shown on the HoQ are appropriately weighted on a scale of 1-5 relative to the degree of the constraints presented by the problem. Also, the relationship area is rated from 1-9 with 1 being the least important and 9 very important whereby the CRs meets the engineering set up target. This is the area where the performance is measured in attempt to better the design product. Once all ERs are ranked their total cumulative weights (importance rating) will identify what customer needs is very important to the design, the ones that needs improvement and those that needs to be changed. Table 1 below shows the HoQ and all its representative components in an interrelationship matrix format.

3 EXISTING DESIGNS

In this section, the team worked hard researching similar designs that will be providing us with more information about our project. This section will have three different existing designs that will be related to our project. The information we got will lead us to more creative thinking and settle down on the best design.

3.1 Design Research

To obtain details and more information about the best features and the ideas to implement in our model, we conducted a wide research, consulting both written and non-written sources. We searched for details on various already existing models and their respective weak points and strong points. This was necessary to come up with a model free of flaws and that is cost effective to come up with than the existing ones. We also conducted a historical background check on the harnessing of the wind energy through the wind turbines and the gradual development and improvements that have been conceived over time in the same sector. This also entailed the research on application of wind energy in other aspects of life, this was necessary in realizing the strength and the potential of the wind energy. Some of the sources we did consult in the event of looking for information relevant to the project were academic databases, resourceful and experienced people in the renewable energy sector and field work we conducted on the available wind farms to gain an insight on the already available models.

American settlers used windmills in grinding corns and wheat, at sawmills in wood cutting and water pumping. Wind power was now employed in building lightening due to development of electric power. Wind electric turbine continued till the 1950s, but the existence of low energy prices and cheap oil sidelined it [2]. The oil deficiencies of the 1970s changed the vitality picture for the world. It made an enthusiasm for elective vitality sources, making ready for the reentry of the breeze turbine to produce power [2]. The turbines, bunched in substantial breeze asset territories, for example, Altamont Pass, would be viewed as little and uneconomical by present-day wind cultivate improvement models. Today, wind-controlled generators work in each size range, from low turbines for battery charging at separated living arrangements to vast, close gigawatt-measure seaward breeze cultivates that give power to national electric transmission frameworks. This is as researched and found by our team members.

3.2 System Level

After researching, the team found the three different designs that related to our project. For sections 3.2.1 to 3.2.2 existing designs will be provided with a brief description of each.

3.2.1 Existing Design #1: 6 MW and 3 MW models (Gearless models).

Gearless breeze turbines completely haf no gearbox. Preferably, the rotor shaft was installed straight to the generator where the blades move the same speed it spins. Lagerwey and Enercon have discovered gearless breeze turbines with independently electrically energized generators for a long time, and Siemens created a gearless "upset generator"3 MW model while building up a 6 MW model. To compensate for a direct drive generator slower turning rate, the measurement of the generator's rotor was expanded so it can contain more magnets to make the required recurrence and power. Gearless breeze turbines are frequently heavier than equip based breeze turbines. An examination by the EU was known as "Reliawind" given the most prominent example size of turbines has demonstrated that the consistent quality of gearboxes isn't the primary issue in wind turbines. The dependability of direct drive turbines seaward is yet not known since the example estimate is so little.

Gearless turbines have a lower cost of maintenance since there is no replacement of gearbox. Figure 2, below, show a detailed image of the wind turbine implemented without the gear box.

Figure 1 - Gearless wind turbine [3]

3.2.2 Existing Design #2: Planetary Geared Wind Turbine

Geared wind turbines are known to multiply the wind speed by a constant, thus transmitting more power to the energy generator. Planetary gears are epicyclic gears aimed to improve the efficiency of the wind turbines. They are known to be advantageous over the other kinds of gear systems. The internal gear, the smaller gear was made as an idler to a counter gear. The purpose of the idler gear is to transmit energy which is kinetic to the middle gear, the middle and the outer gears have interlocked shafts to facilitate energy transmission.

In traditional breeze turbines, the sharp edges turn a pole that is associated with a gearbox to the generator. For the generator to generate electricity speed of the blades is converted into gearbox by increasing the turning rate for example 14 to 18 to rotations each minute [4]. The utilization of attractive gearboxes has additionally been investigated as a method for decreasing breeze turbine cost for maintenance. They produce more energy but have a high cost of maintenance in the replacement of gearbox when it breaks down. The figure 2 below is a representation of a wind turbine with gears.

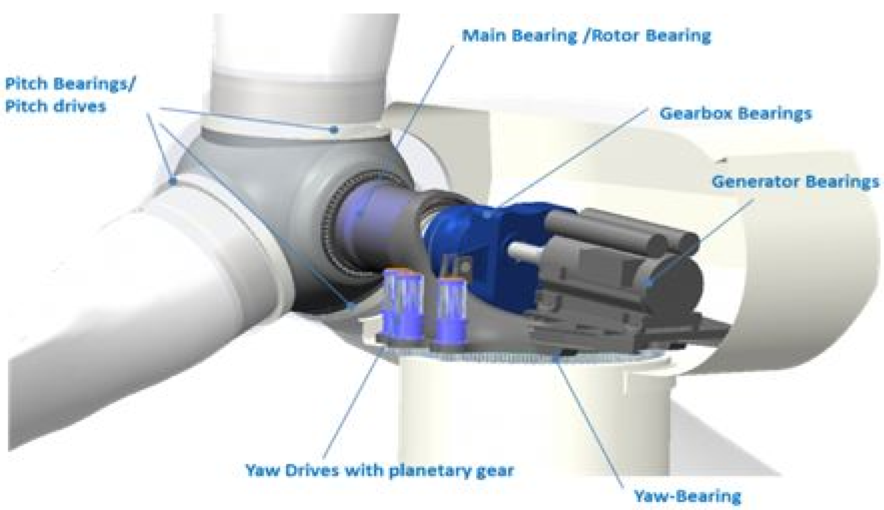

Figure 2 – Wind Turbine with Gears [4]

3.3 Functional Decomposition

The functional decomposition is one of the best way to describe our project precisely. Firstly, there will be a black box to describe the system and the output and input for out project. Secondly, there will be a functional model to describe the black box model in detailed for the output and input. So, the sections below will demonstrate the system of turbine.

3.3.1 Black Box Model

Black Box model was very significant to use for our project. To illustrate, we saw that the basic purpose of the block was to convert the wind energy to electricity. The input to the block is wind which produced the kinetic energy and velocity in the turbines. The output from the block was electricity, mechanical energy and Blade/turns Noise. The conversion from the input parameters to output parameters was brought by rotor and generator. Once the generator starts rotating the kinetic energy gets converted into electrical energy. This was the way wind turbine is performing the inter conversion. Figure – 3 below will show the black box model.

Figure - 3 Black Box.

3.3.2 Functional Model

The functional model showed us the steps that the system uses from the inputs and outputs. To demonstrate, from Figure – 4, we could see that the function of the wind turbine is divided among various blocks. The wind is input to the turbine block, which moves the electrical generator with the help of a gear box. There was a pitch angle controller directly attached with the electrical generator for the control of amount of electricity produced by the generator. The electrical energy produced by the generator was fed into inverter system for inter conversion of A.C and D.C quantities.

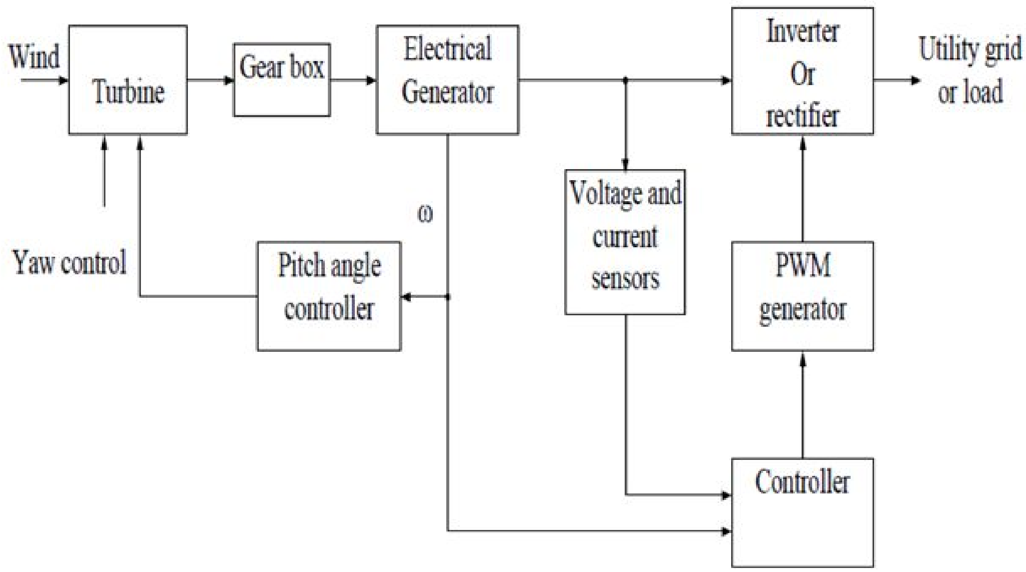

Figure - 4 Functional Model

3.4 Subsystem Level

There are some of the subsystems for this project, and for these subsystems different existing design are present so in this section few existing designs are describing for the subsystem.

3.4.1 Subsystem #1: Blade

Blade was using the fan of turbine which will rotate with the help of air, and there are different kind of blades already made.

3.4.1.1 Existing Design #1: Curved Blade

One of the most effective blade shape is curved blade which uses in wind turbines, these blades cut the air easily and these can move in the presence of low air pressure as well because of their curved design. This design could be used for our project because curved blades are good to use for rotating the turbine system.

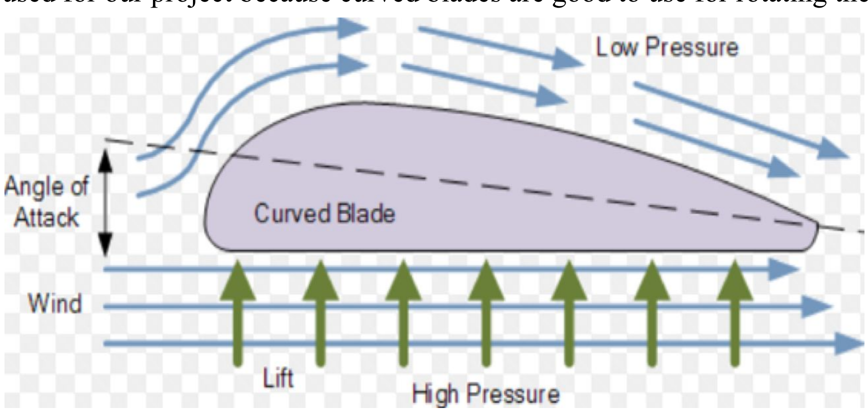

Figure [5]: Curved blade

3.4.1.2 Existing Design #2: Round Blade

Another design for the blade was round blade which has curved shape, but it had round shape from the start and it was thin in their width as well. This type of blade could be used in our project because of their better performance as the design shown in figure 6.

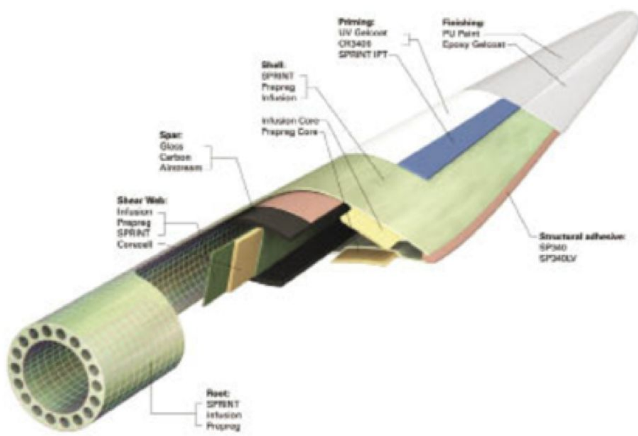

Figure [6]: Round Blade

3.4.1.3Existing Design #3: Straight Blade

This is the straight shape blade which has no curve and no round body. This blade was difficult to use because its design has less capability to cut off the air therefore need high pressure air to move the turbine. Figure 7 shows the design of straight blade.

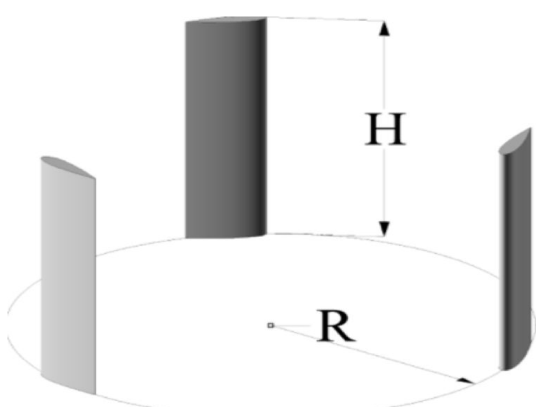

Figure [7]: Straight Blade

3.4.2 Subsystem #2: Tower

As the blade stand over the tower so tower is another important subsystem for this project and its existing designs are presenting below.

3.4.2.1 Existing Design #1: Lattice Tower

In the tower design, a zigzag body was made in the tower to make it strong and capable of bearing the high-pressure air without dangling down or topple over. This design could be used in the project when the blades are heavy and long. Design is showing in the following figure.

Figure 8: Lattice Tower

3.4.2.2 Existing Design #2: Pole Tower

A pole tower is the one which is using in regular wind turbines as it is slim and capable of bearing high pressure air as well. It could be used in our project because of the slim body. The design is shown below in figure 9.

Figure [9]: Pole Tower

3.4.2.3 Existing Design #3: Guyed Mast

Guyed mast is the design in which a straight stand uses holds with the strong wires which dig into the ground and hold the tower. This design was also useful as it had the capability to stick in strong air pressure. The design is showing below in figure 10.

Figure [10]: Guyed Mast

3.4.3 Subsystem #3: Gearbox Bearings

The wind turbine produced electricity based on speed, so variation of speed is present in the turbine using the gearbox which rotates the gears according to the air speed. Therefore, the subsystem is different bearings.

3.4.3.1 Existing Design #1: Steel Bearings

Steel bearings were strong and non-rust bearings, and these could be used for high speed shifting of gears without obstruction. The design of steel bearings is shown below in figure 11.

Figure [11]: Steel Bearings

3.4.3.2 Existing Design #2: Iron Bearings

Another bearing available in the market were iron bearings. These bearing were useful, but they get rusty when not treated properly. The iron bearings are shown in figure 12.

Figure [12]: Iron Bearings

3.4.3.3 Existing Design #3: Aluminum Bearings

Aluminum bearings were another existing design for the bearings. These are useful for light weight, but they cannot hold strong force. The advantage was that it does not get rusty. The design is shown below in figure 13.

Figure [13]: Aluminum Bearings

4.0 DESIGNS CONSIDERED

The possible designs that were considered for the final design process were carefully weighed according to the CRs and ERs. The Decision Matrix was also used in making careful consideration for the final design for the design capabilities of safety, cost, and efficiency. These were the top items that were important in the chosen designs.

The Collegiate Wind Energy Competition archives included the 2014 to 2017, which gave our team some ideas in dimensions and size constraints of the Wind turbine. Analyzing the designs in previous competitions clarified the opportunities that our design will involve during Turbine modifications. An example included a passive yaw system with a roller bearing. This is the simplest in design modification. Blade design is the basis of criteria selection because our design will need to be efficient and cost effective.

The vertical Axis Wind Turbine was also considered because the system does not need a yaw system included in the design. Horizontal Axis Wind Turbine with several blades designs. From 3 to 12 blades were considered. Calculations of power will need to be implemented to understand the effects of the number of blades of the system.

4.1 Design #1: Vertical Axis Wind Turbine

The vertical axis wind turbine was a design that was considered. The vertical axis was a significant idea because the apparatus did not need the yaw system to the direct the blades towards the wind. The other characteristic is that there are fewer components that need to control yaw and pitch [6]. The disadvantages to this design were the stability of the design. The wind turbine would need to fasten in many angles and from all sides of the turbine for stability. The forces that are acting on the vertical axis wind turbine are more turbulent. [6] This design was found in urban locations and on roof tops.

4.2 Design #2: Vertical Axis Wind Turbine (flat blade)

This vertical axis wind turbine consists of the same components that are consistent with the typical VAWT. The vertical wind turbine design in this category had blades that are flat in design selection. The flat blades were placed at an angle that will catch the wind from any direction. The advantages and disadvantages are like the previous design. The only drawback to the design was that it is less efficient than the typical vertical wind turbine. The VAWT did not have the blades that are contoured from bottom to top about the attachments. The blades simply attached to a middle beam and stand 90 degrees to the base. The team considered parts of this design and saw the functionality in simple geometry. This design would be inefficient for large production of energy because of the instability of the blades and tower. The VAWT is only used in urban locations that have less volatile wind speeds. [9]

4.3 Design #3: Horizontal Axis Wind Turbine

The horizontal axis wind turbine (HAWT) was a design that was most successful, based on the CRs and ERs. The design solution we considered was to incorporate a recharging station to the wind turbine. NAU students could attach their USB to the base of the wind turbine to recharge their small electronic devices. Incorporating our design on campus will provide clean energy for electronics.

The HAWT was a design that was capable of withstanding high wind shears that incorporate higher efficiencies. The high towers are placed in strong winds which could increase the speed of the blades by 20% and power output of 34%. Figure 10 in the appendices show the several designs that were considered for the final project. The design C was the design that could be incorporated in our final design. [11]

4.4 Design #4 - 10: Additional Designs

The additional designs that were considered are listed in the below. The designs that are in this section were possibilities from the CR and ER constraints. The designs range from vertical wind turbine designs to the horizontal wind turbine. There designs that were developed from existing designs. An example would be the design from Northern Arizona University. In 2016, a HAWT design was created and then components were added to enhance the capabilities of the design.
The components that were added are the yaw control, electronics control, and stopping mechanism. These were added to create a more efficient design that will capture the effectively through yaw controls.

5 DESIGN SELECTED – First Semester

This chapter will explain the reasons behind what made the team choose design C. After doing more research about the projects on the collegiate wind competition website, and the research process led us to settling on design C.

5.1 Rationale for Design Selection

This is our selected design for our project, where as shown in table 3 in the Appendix A, design C is a complex design with a simple working, blade design and a good yaw to help the turbine to rotate. Even though it cost a lot, but it has a good reliability and efficiency and this is why we have chosen it as our selected design. We are thinking to use electric plug or USB to power up the turbine in order to generate electricity as you can see in figure 6.

Figure - 6 Selected Design C

Table - 3 - Pugh Chart

TOTAL	Efficiency	Manufacturability	Reliability	Cost	Blade Design	Yaw	Working	Complexity	Design Concepts
-3	S	-	+	-	-	S	S	-	Design F
-5	S	-	-	-	-	S	S	-	Design E
-4	S	-	S	-	-	S	S	-	Design D
+1	+	S	+	-	S	+	S	-	Design C
0	S	S	S	S	S	S	S	S	Design B (Datum)
-6	-	+	-	-	-	-	-	-	Design A

Pugh Chart

Table 4 - Decision Matrix

Criterion Weight		Design A		Design B		Design C		Design D		Design E		Design F	
		Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted score
Complexity	0.10	100	10.0	90	9.00	80	8.00	40	4.00	60	6.00	50	5.00
Working	0.10	0	0.00	80	8.00	90	9.00	70	7.00	70	7.00	70	7.00
Yaw	0.15	0	0.00	0	0.00	100	15.0	0	0.00	0	0.00	0	0.00
Blade Design	0.10	50	5.00	100	10.0	100	10.0	40	4.00	70	7.00	40	4.00
Cost	0.15	100	15.0	90	13.5	80	12.0	50	7.50	70	10.5	70	10.5
Reliability	0.15	0	0.00	50	7.50	100	15.0	60	9.00	70	10.5	60	9.00
Manufactura bility	0.10	60	6.00	80	8.00	70	7.00	60	6.00	80	8.00	70	7.00
Efficiency	0.15	0	0.00	60	9.00	95	14.25	60	9.00	70	10.5	60	9.00
Totals	1.00		36.0		65.0		90.25		46.5		59.5		51.5
Relative Rank			6		2		1		5		3		4

Decision Matrix

5.2 Design Description

The selected design had complex shape blades and a yaw to rotate the turbine. A CAD model of final design was developed, in which all the subparts have developed separately to visualize the complete product from inside and outside. All the subparts have presented below:

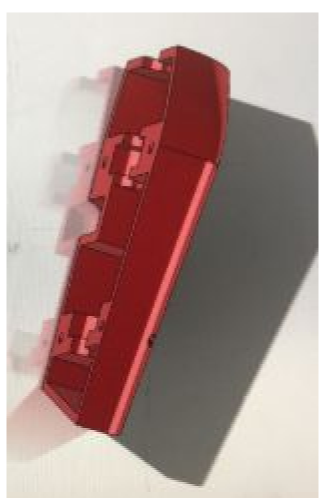

Figure 16 Center Casing

Center casing covers the complete electronic part. All the processing of wind turbine occurred in the center; therefore, it was important to cover that part and figure 16 is showing the center casing of the wind turbine to cover the parts.

Figure 17 Rotating shafts

Figure 17 shows the rotating shaft which connected the blades and generator. When the blades rotated because of wind, it would eventually rotate the rotor of generator and that would produce the electricity.

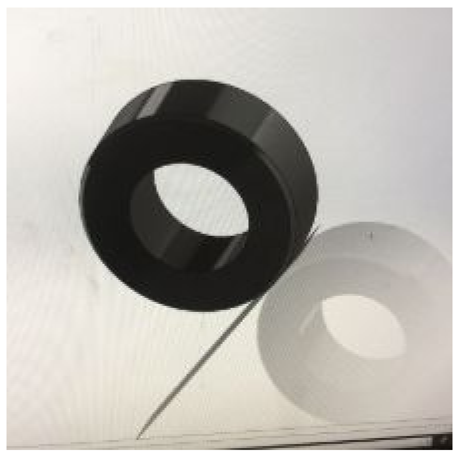

Figure 18 Bal bearing

Ball bearing uses along with the shaft and blades to provide smooth rotating. Ball bearing has the capability to rotate with high speed and provide the support in rotating. When the wind pressure is less even at that time shaft will rotate because of ball bearings.

Figure 19 Holder

Figure 19 has shown holder of the stand in which the stand will fix and this holder will fix with the ground to provide the strong contact and will not allow the body to vibrate or go here and there during the high speed wind.

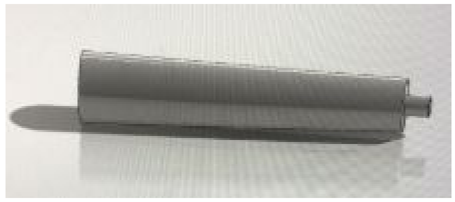

Figure 20 Nozzle

This part provides the relation between shaft and the blades for making the strong connection without getting any trouble. Because of high speed wind, there are chance of breakdown between the connections so this part provides proper strength to the connection.

Figure 21 Blade

Blades were the major part of wind turbine system. Blades provide the rotation when the air blows. Figure 21 has shown the shape of blade which is curved form to provide the maximum pressure different between the top side and down side of blade so that more speed can get in lower wind speed.

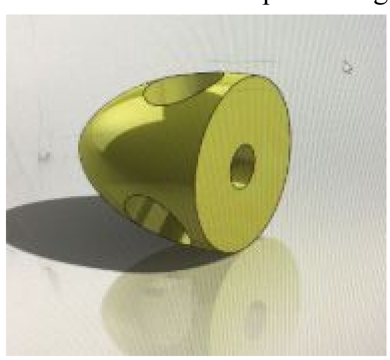

Figure 22 Back socket

This device basically provides the support to the complete set up by the reverse weight. Purpose of this part is to carry the blades easily and don't allow the turbine to bend on front side. Also it holds the shaft firmly and the structure of body remains in equilibrium and balanced because of this back holder socket.

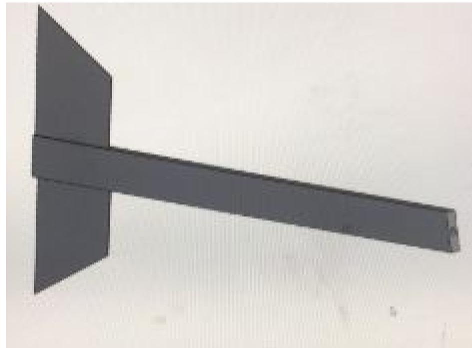

Figure 23 Standing base

Figure 23 had shown the stand on which the complete system will stand. This stand provides enough height to the blades that blades can easily rotate and feel the air pressure as well.

Figure 24 Rod

This rod provides the complete support to the wind turbine system. It gives the height and the strength during the high speed air. So this was the complete detail for our final design.

Figure A: Velocity wind field

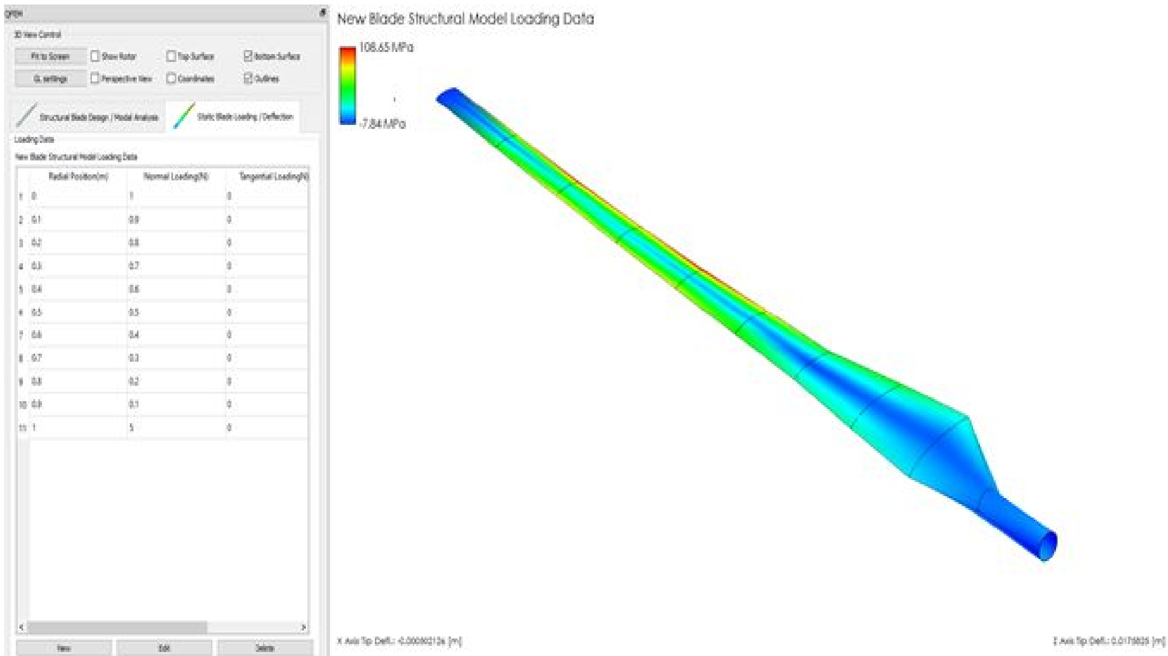

Figure B: Stress and Deflection of Blade

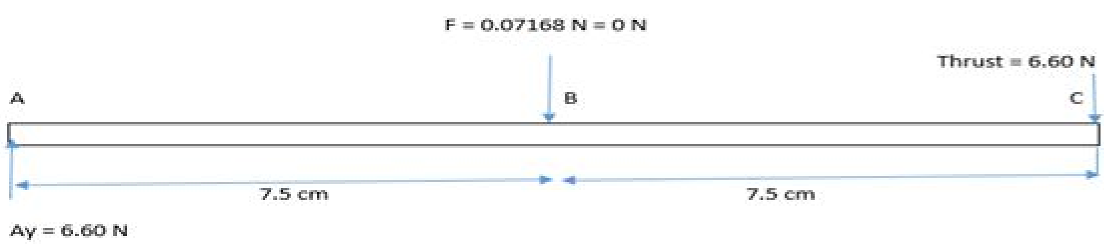

Figure D: Remodeling wind turbine

Force in y – direction

$$\sum Fy = 0$$

Ay = 6.60 N

$$\sum MA = 0\ (7.5\ cm) + 6.60\ (\ 15\ cm\ )$$

MA= 6.60 N * 0.15 m

<u>MA = 0.99 N-m</u>

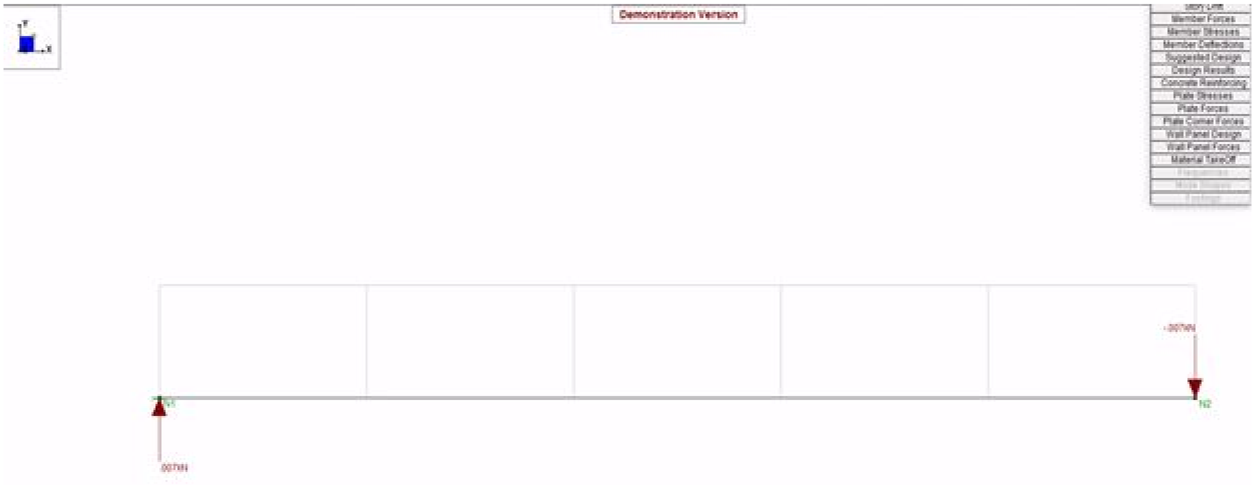

Figure E: Shear force diagram

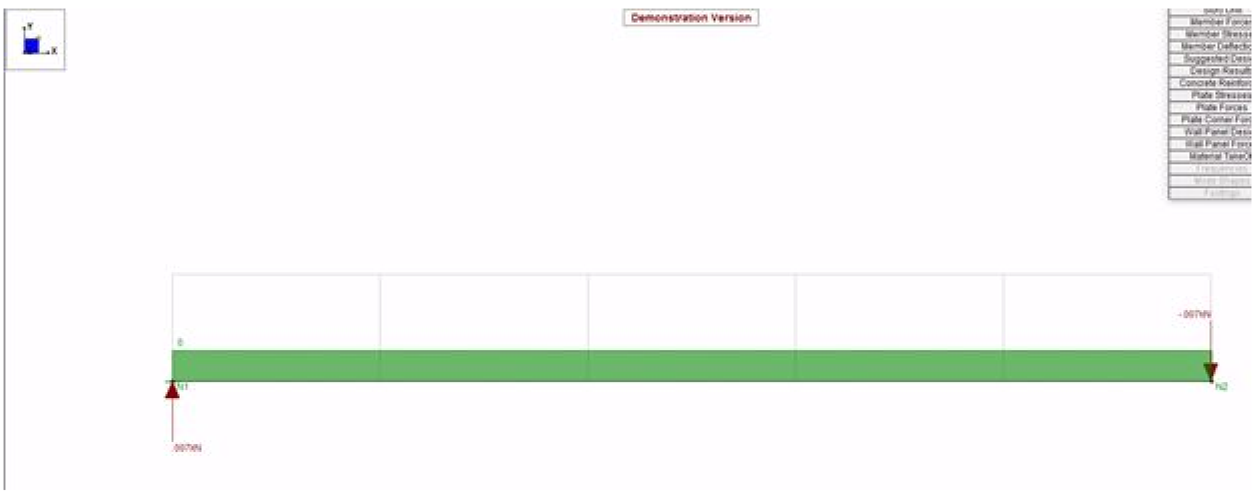

Figure F: Shear force diagram

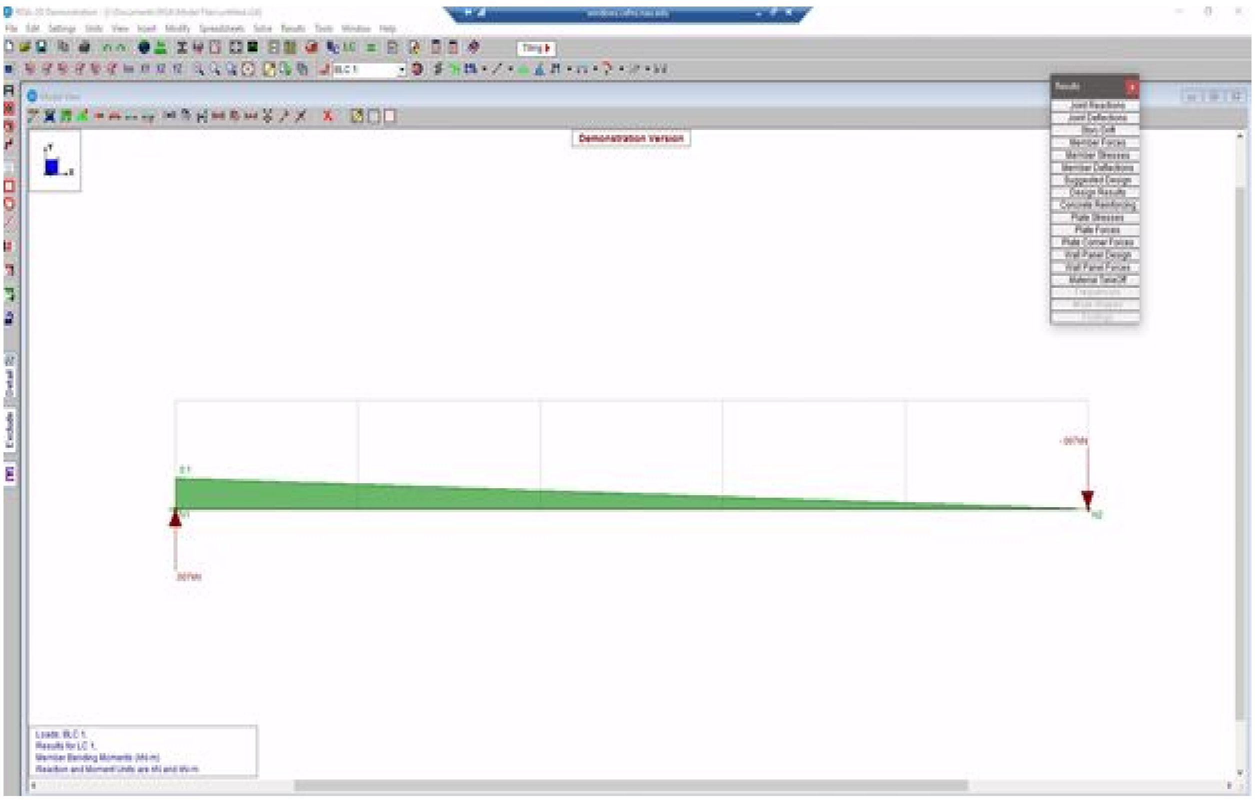

Figure G: Moment Diagram

Starting with the calculations for force of the wind on the tower surface to know all the resistance forces that have arisen due to the wind action on the turbine. It turns out the most significant force was the thrust force at the tip of the tower which is 6.60 N. Since the thrust was very high, we made the assumption to neglect the force of the wind action on the tower itself because it was too small (0.07168 N). This is because the effect caused by the 0.07168 N force was minimal to the stability of the design as compared to that of the thrust force.

Tower Analysis using RISA-2D:
Raw data:
D=3.5 cm = 0.035 m
l=0.15 m
V= 12 m/s
A = PI/4 * D^2 = PI/4 * (0.035 m)^2 = 9.621*10^-4
Cp= 0.79
ρ=1.31 kg/m^3
P = Cp A 0.5 ρ V^3 = 0.8602
P = F*V
F = P/V = 0.07168 N
Thrust = 6.60 N
w = F/0.15 =0.07168 / 0.15 = 0.4778 N-m

Results Using RISA-2D:
To visually and analytically get a good understanding of the situation of shear and bending moment of the tower RISA 2D was used to analyze the design. The full-length tower was section into five sections (1-5). Point 1 is the base flange that is fixed to the ground while position 5 is the tip of the tower. The shear forces and bending moments for the tower are measured in units of kilo-Newton (kN).

The shear force generated is 0.007 kN and is constant throughout the entire beam (tower). The maximum bending moment of 0.066 kN-m was concentrated at the base of the tower as shown in figure G. The maximum deflection obtained is -1.074 mm due to the action of the thrust force on the tip of the tower.

Table A below shows the results of the analysis performed at different sections of the tower. Figure E, F and G shows the loaded beam (tower), the shear force diagram and the bending moment diagram using the software.

Table A: Result of Analysis

Member Section Forces (By Combination)

Sections | Maximums | End Reactions

	L...	Member Label	S...	Axial[kN]	Shear[...	Mome...
1	1	M1	1	0	.007	.066
2			2	0	.007	.05
3			3	0	.007	.033
4			4	0	.007	.016
5			5	0	.007	0

Member Section Stresses (By Combination)

	L...	Member Label	S...	Axial[M...	Shear[...	Top Be...	Bot Be...
1	1	M1	1	0	.008	-.516	.516
2			2	0	.008	-.387	.387
3			3	0	.008	-.258	.258
4			4	0	.008	-.129	.129
5			5	0	.008	0	0

Joint Deflections (By Combination)

	L...	Joint Label	X [mm]	Y [mm]	Rotatio...
1	1	N1	0	0	0
2	1	N2	0	-1.074	-1.609e-0

Member Section Deflections (By Combination)

	L...	Member Label	S...	x [mm]	y [mm]	(n) L/y ...
1	1	M1	1	0	0	NC
2			2	0	-.092	NC
3			3	0	-.336	NC
4			4	0	-.68	NC
5			5	0	-1.074	9312.059

6.0 Proposed Design
The proposed design consists of using the engineering design process. The Wind Energy team initially analyzed the details of the Collegiate Wind Energy Competition website. The rules and regulations guided

our design constraints. The client, David Willy, also provided objectives to the design about the testing wind tunnel located off campus. These deliverables provided the design with the CRs. The CR was compared with our Engineering Requirements which were numerically evaluated by importance to the project design.

Using Qblade software, blade analysis and design was completed with a prototype that will be sent to the 3D Maker Lab. The blades were developed by using the Qblade software and Airfoil Tools. Both resources were used to develop our blade for printing. The following figure 14 is our prototype design. The CAD design was developed, and modifications were implemented to incorporate the blade dimensions. Figure 18, in the appendices, was our CAD design which is our proposed design.

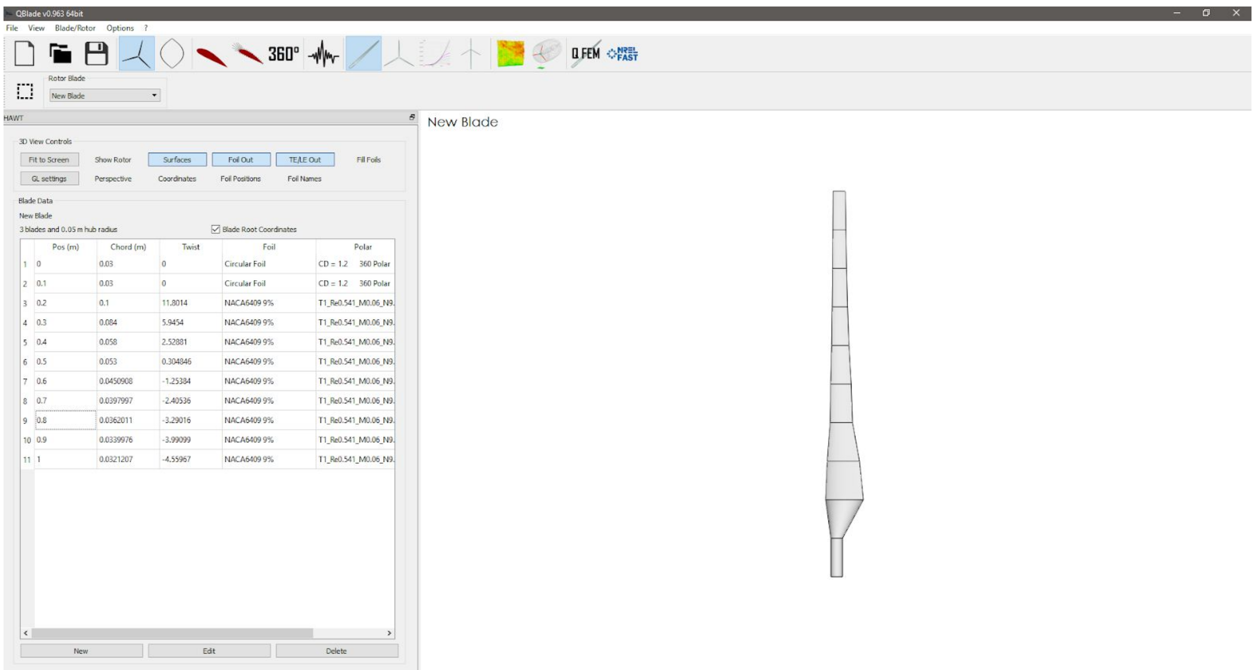

Figure 14: Blade design in Qblade

Note: BOM is in Appendix A.

6.1 Resources Needed

The resources needed in the final validation of our design will be access to our client and professionals that can give insight to our design process and procedures. As students, we will need experienced professionals that are willing and capable in providing insight and direction to our design modifications.

The machine shop will be a tool that we will need in response to material modification Material modification occurs when a part is not available for purchase. The maker lab will also be a resource that needs to be available to our project to our blade design. The modifications of our blades will be conducted in Qblade and sent to the library as a stl - file. The 3D print modification will be an iterative process that consists of size and shape reevaluations.

The parts that are needed for our electronic components will need to be purchased as a complete and working part. These types of components will need to be purchased because of our limitations in using the machine shop for the summer. The Bill of Materials located in the appendix will give more insight to the parts selection of the design build.

7 IMPLEMENTATION – Second Semester

This section documents the changes that were made from the previous design into the current one. The base flange, tower, were to be made out of PLA. After testing the prototype for strength and factor of safety the team decided to use 1023 carbon steel to replace the plastic component. In addition, another new part was added to the new design called the nacelle yaw case. This part is added to enable the nacelle to yaw about 360 degrees as needed. Moreover, an electrical system disk brakes will be implemented to replace the previous hydraulics braking system. The hydraulic braking system consists of fluids that will take up a large amount of space within the nacelle design. The electrical system involving little mechanical parts that are control electronically has wires that can bend and fit through the hollow tower which increases the factor of safety and takes less space.

Implementations of the manufacturing process will involve severals resources that will drive the completion of the wind turbine project. We will need to utilize the Maker Lab and the Rapid Lab for 3D printing the blades and nacelle. The next resource in manufacturing is the Fabrication Lab. The Fab Lab will be used for material manipulation to the specifications of the components of the Wind Turbine through Solidworks (CAD). We will develop a CAD package through Solidworks and evaluate for the calculated requirements of the design. Some online ordering will also need to be utilize because of the limitations of summer hours in the Fab Lab. Welding of parts through companies will be a possible source to determine in reference to bonding parts together.

7.1 Manufacturing

This section discusses the methods of manufacturing that will be used to completely design the wind turbine system. The methods of manufacturing can be divided into to subcategories that includes off the shelf components and those that would be manufactured by the team at the NAU machine shop. Also featured are the bill of materials including the costs, source, budgeting and the schedules of all tasks that would be implemented. The BOM can be referenced in table 2 of appendix B

7.1.1 Base flange and Bolts

The tower assembly, shown in Figure 26, consists of the tower beam (part XXXXX in the BOM, Table 2), base flange (part XXXX), and three M10 x 1.5 studs hex head bolts (part XXXX). The base flange is will be made out of 1023 carbon steel, and will be milled, while the bolts holes in the the base flange will be drilled at the NAU machine shop. The three bolts will be bought off the shelf, and will be inserted into the base flange to secure the tower to the testing site. Then, the tower beam and base flange will be welded together as shown in Figure 26.

7.1.2 Tower beam and the Nacelle yaw case

The tower beam and the nacelle yaw case will be constructed from 1023 Carbon Steel (SS), and machined on a lathe in the NAU machine shop. In addition, we were able to get the raw material needed for the tower beam donated to us for free by Dr. Willy. Similarly the raw material to design the nacelle yaw casing would be obtained from the copper state company based here in Flagstaff. Manufacturing the the tower beam will involve hard turning to cut to the length needed for the tower assembly. The tower beam will be attached to the nacelle yaw case by way of threading to lock firm the two parts together.

7.1.3 Brake

The brakes design is made up of materials that will be bought entirely from off the shelf. Already approved and bought are the braking disk and the friction pads. The manufacturing will be mostly electrical to control and move the braking pads back and forth to stop the shaft from rotating as well as allowing rotation to occur.

7.1.4 Nacelle

The nacelle was first designed on Solidworks after determining the dimensions of the other components. I used the solidworks software to design the nacelle by adding the maximum dimensions of the components and made the nacelle larger in size to accommodate the components attached. Solidworks played an important role in figuring out the final dimensions of the nacelle, which helps aid the manufacturing process.

The nacelle is part of the wind turbine that has a flat surface and holds other parts, such as the generator, break, shaft and bearing support. We need to buy carbon steel plates which will be cut to create the plate. The Nacelle calculations will be used to cut the plate for the right dimensions which will be 15.24 cm for the length , 5.08 cm for width , with 0.45 cm thick.

7.1.5 Fin

The fin design was incorporated into this design for the mechanical capabilities of the direct yaw system. The direct yaw system involves using the wind as the adjustment to the entire mainframe. When the wind approaches the fin the yaw system then directs the blades to the wind. The blades are to be perpendicular to the wind. The yaw system consists of the fin and the bearings that are placed over the top of the tower. The bearings are then able to turn that are attached to the mainframe. The bearing system that we selected will be the bearing flange. The bearings will be attached to the flange. The flange will be attached to the lower part of the nacelle.

7.1.6 Shaft

7.1.7 Blade

In order to develop our blade design we will utilize the Qblade software. The software gives us the ability to input variables of Reynolds number, tip speed ratio, angle of twist, and Mach number. These variables are derived from the local air density, local velocity of the blade, and the length of the blade design. Qblade uses these values to develop simulation throughout the project. The project consists of picking an existing airfoil from airfoiltools.com. The airfoil is downloaded and then imported into Qblade. The airfoil can be manipulated by chord thickness and length. Simulations in Qblade give us the power of the turbine and the thrust force of the blade design as the apparatus is operating in a three blade design. Final blade design selection is then inserted into solidworks or 3D printed from the stl file. The blade will have an x y z plane and will need to 3D printed with the twist of the blade implemented in the final design.

IMPLEMENTATION 7.2 Design Changes

7.2.1 Base flange and Bolts Iterations

The first iteration of the base flange is shown in Figure 18. This design used plastic and was 3D printed, but the team ultimately decided that it wouldn’t work because the default dimensions were incorrect and material used had a low factor of safety. When bolted PLA can easily shear due to its low stiffness. The bolt design however did not change throughout the iterations. The final iteration for the base flange is made with 1023 carbon steel (SS).

7.2.2 Tower beam and Nacelle yaw case

The first iteration for the tower beam can be seen in figure 18. This design is made up of plastic which have a low factor of safety and stiffness. The team rejected it and elects that we use a more stiffer material. The next iteration feature a galvanized steel material that is coded with several unknown alloys that was not manufacturable due to the high risk of manufacturing as gases of the alloy are very dangerous for a safe manufacturing. We used FEA to justify that it exceeded our design F.S., but due to the high risk involved, it couldn't be manufactured. The nacelle yaw case is a newly designed component and is manufactured with the same material as the tower beam. Since both of the designs are created at the same time they would be manufactured with a similar type material together as the final iteration. The final iteration as shown in (Figure 22-23) used 1023 Carbon Steel (SS), which met the strength requirement and was safe for manufacturing. This exceeded our our design factor of safety as well and we decided to settle with it as our final design. FEA done on tower was done for normal stresses (figure 27), shear stresses (figure 28) and factor of safety (figure 29). The F.S. for the tower assembly and with the nacelle attachment is 59. This is however lower than that of the calculation for just the tower assembly alone because the nacelle is composed of a thin hollow tube that is now attached into the tower without the bearings.

7.2.3 Brake

The brakes design first featured a hydraulic braking system that will need some fluid through a pipe to apply pressure that will produce a clamping force unto the brake disk to stop the rotation of the shaft. This however is a complex design and require that we have large pipes which takes a lot of space. The team rejected this design after consulting with the client who suggested that we use a different approach such as an electrical system. He proposed using a solenoid to control the braking pads. Moreover, after some researching on using the solenoid for this purpose, we were able to learn that wasn't very effective. The team later consulted the client again for other better approaches and he later suggested that we do a research on the linear actuator. After several studies on using the linear actuator to move the braking pads, the team concluded that it works best and finalized it as the final iteration for the braking system. The linear actuator is still undergoing research on sourcing, cost and budgeting, while the disk brake and the friction part assembly can be seen in figure 21 of appendix B.

7.2.4 Nacelle

The first design of the nacelle was a covered plate. The reason for this was thinking of protecting the components placed on the surface. I changed the design to be an open surface, where it is an easier way to handle the components if something goes wrong. From beginning we decided to print out the nacelle 3D printing in cline library, but then we decide to use a flat steel that can help use make an adjustment for what component we are going to put, instead of printing it and if it does not work, through it and print again, this will cost us too much.

7.2.5 Fin

The first fin design we came up with, was too big tail fin, we thought if we can make it big this will help the turbine to move when the air hit it, but then after we showed Dr. Willy how much big fin we have, he did not accepted it, and he advise us to make it small. After we discussed with him about the fin size and after we did the fin calculation we got 15 cm for the fin length and 7 cm for the width of the tail fin.

7.2.6 Shaft

7.2.7 Blade

During the design process, we had to reiterate several airfoils to evaluate several values of the power of the turbine and the thrust force. The design process engaged our understanding of the blade design and how the airfoil choice was important to the success of the project. The airfoils we chose were NACA 6409, 2414, and circular for the first two chords of the blade. Running a simulation in Qblade, we were able to determine how many iterations the blade design needed to be tested. During the testing phase the turbine would operate correctly based on the Collegiate Wind Competition.

After several attempts at the software we were successful with the NACA 2414. The success was based on the power of the turbine of 21 Newtons and the thrust force of 24 Newtons. These were important variables to move forward in the design process. The thrust force was needed for the mainframe. The mainframe consists of the shaft, braking system, and generator of the turbine system.

3D printing involved the selection of the blade design as a 3 blade system. The blades would then be printed and pressed between two hubs. This is our latest design. We had a hub design that consists of the blades to be fastened to the hub by three metal fasteners that were bolted to the hub apparatus.

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APPENDICE

Appendix A: Customer Requirements

Table 1 No. of Needs, CR's, Importance, and Justification

No. of Needs	Customer Requirements	Importance	Justification
1	A working wind turbine	5	Per collegiate wind competition 2018 all competition participants were needing to create an effective mechanical, electrical, aerodynamic wind turbine
2	Turbine can produce energy with wind at 20m/s	5	The Collegiate completion rules specified that the turbine design should be able to continuously withstand winds speeds at 20m/s.
3	Durable	5	The customer required that the design must be durable to withstand damages or any hard-tearing from the competition testing and the through the period for which it is expected to last
4	Safe	5	Customer required that all aspect of the wind turbine and load design should be safe for testing in an on-site wind tunnel
5	Working control system	4	Customer specified that all created turbine designs must shut down when disconnected from the grid as well as manually as commanded
6	Load Design	5	A storage element device for bulk energy storage was provided to the team by the competition judges at the competition day provided it would be used in a safe and reliable manner.
7	Turbine can fit via a 61cmX122cm door	5	Competition rules specified that the Turbine should be capable fitting through a 61cm by 122cm door of the testing site.

8	Rotor and non-rotor parts must be contained in a 45X45X45cm cube	4	Competition rules required that all rotor and non-rotor turbine parts must be contained in a 45cm by 45cm by 45cm cube centered horizontally on the flange axis with its horizontal mid-plane located 60 cm ± 3 cm above the mounting flange.
9	Reliable	4	Customer required that the wind turbine performance should constantly be in good quality
10	Proper wiring	5	Competition rules specified that all components must meet safety requirements including, but not limited to, proper wiring practices, shielding of hazardous components, and proper heat rejection.
11	Software testable	3	Competition rules required that we can test design components and generates results of laboratory and/or field testing for the turbine prototypes.
12	Earth ground system (≤100kΩ)	3	To prevent overvoltage of the tunnel data acquisition system, turbine electrical system ground(s) was electrically tied to this base plate with a 100 kΩ or lower resistance connection.
13	Turbine must be able to yaw	3	The tunnel base flange, where the turbine was mounted, are subjected to yaw rates of up to 180° per second with a maximum of two full rotations from the initially installed position.

Appendix B: BOM

Bill of Materials (BOM)

Table 2: BOM

Bill of Material						
ITEM NO.	Material	Purchased	QTY.	COST PRICE	Manufacturer	website
1	Blades	X	3	$3.38	Qblade	https://nau.edu/library/
2	Brakes		1	$35.00	king motor	https://m.ebay.com/itm/NEW-KING-MOTOR-Brake-Hardware-HPI-BAJA-5B-SS-5T-5SC-Compatible-GB9-/312092464877
3	Shaft	X	1	$38.76	master carr	https://www.mcmaster.com/#precision-shafts/=1djipt2
4	Generator	X	1	$45.24	Turnigy power system	https://hobbyking.com/en_us/turnigy-hd-3508-brushless-gimbal-motor-bldc.html
5	Nacelle	X	1	$1.71	Home Depot	www.homedepot.com
6	Tower (provided)	X	1	$0	N/A	
			Total Cost	$124.09		

Appendix B: Designs Considered

Figure 16: Vertical Wind Turbine with angled blades [1]

Figure 17: Vertical Wind Turbines with 90 degree blades [6]

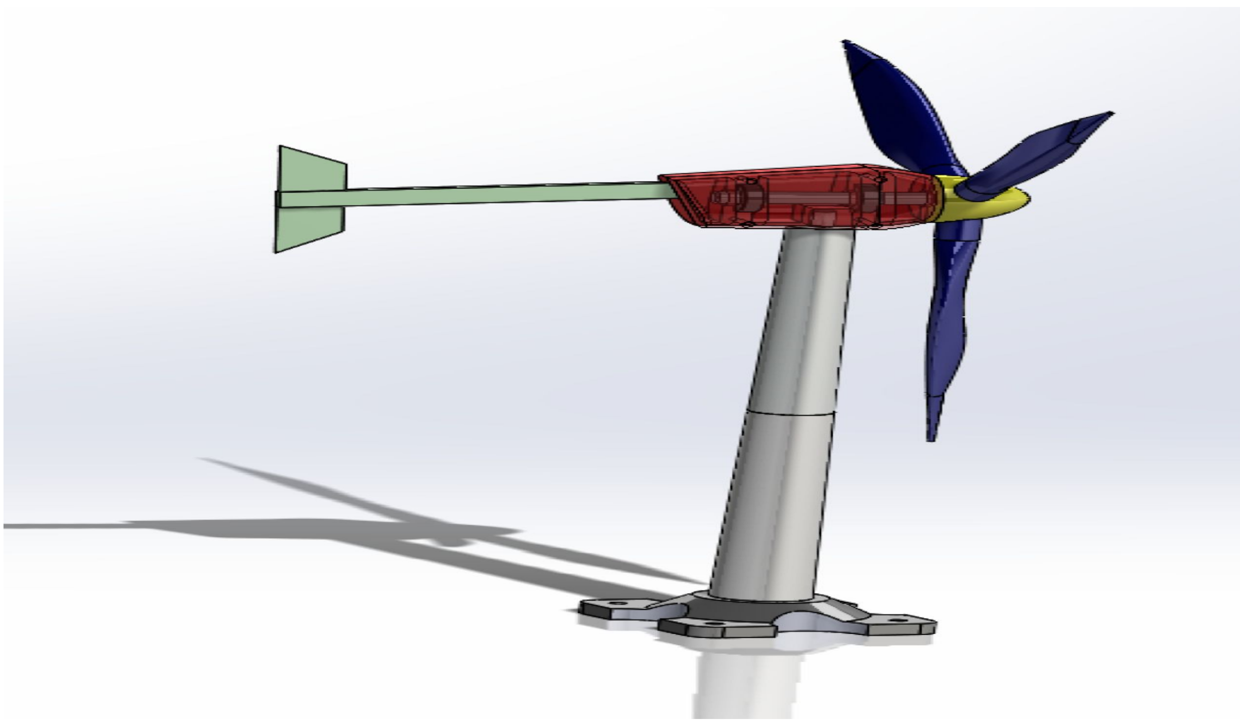

Figure 18: Design choice of wind turbine CAD

Figure 19: Primus Wind Power Turbine [10]

Figure 20: Sunforce 44444 Wind Turbine [11]

Figure 21: Disk brake

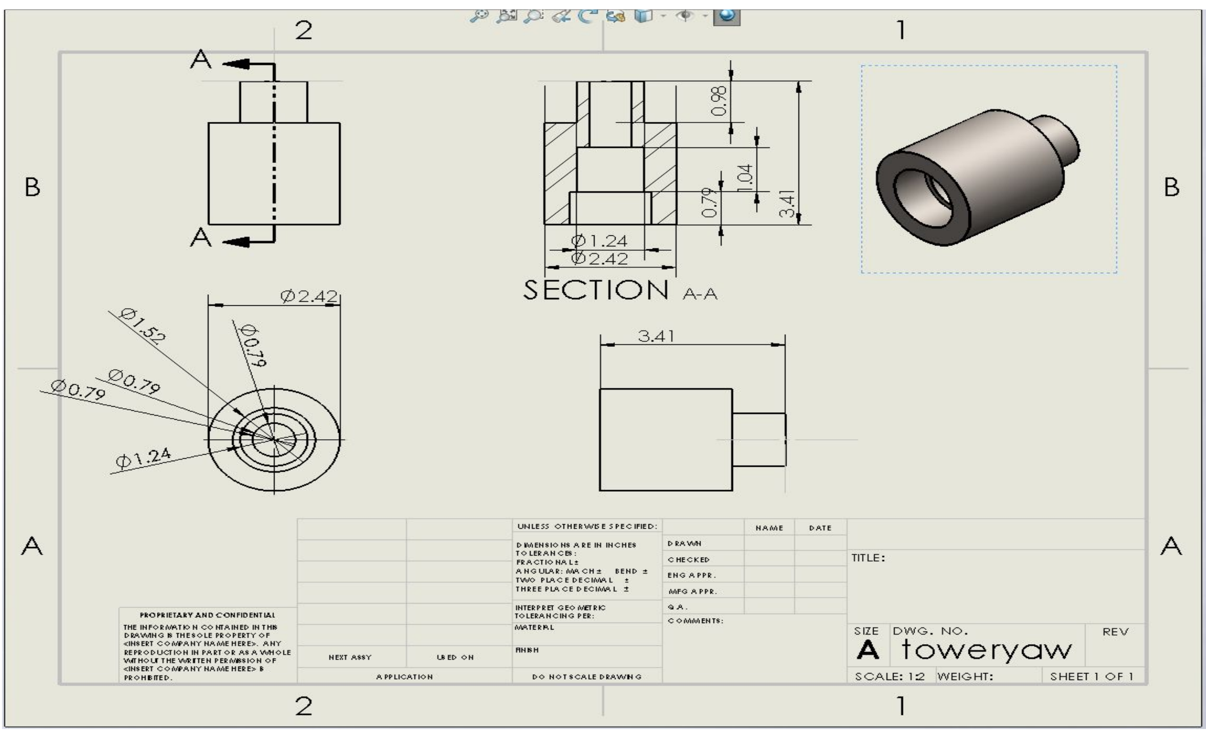

Figure 22: Tower yaw case

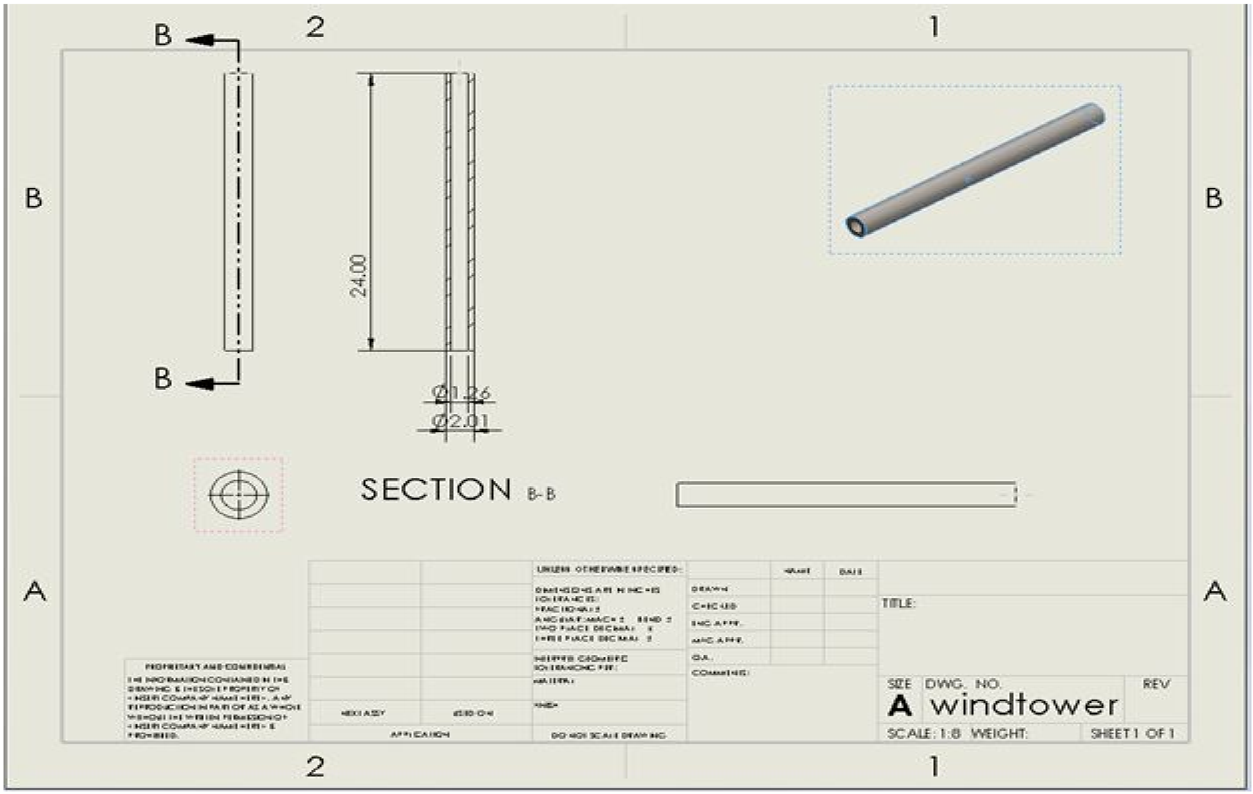

Figure 23: Tower beam

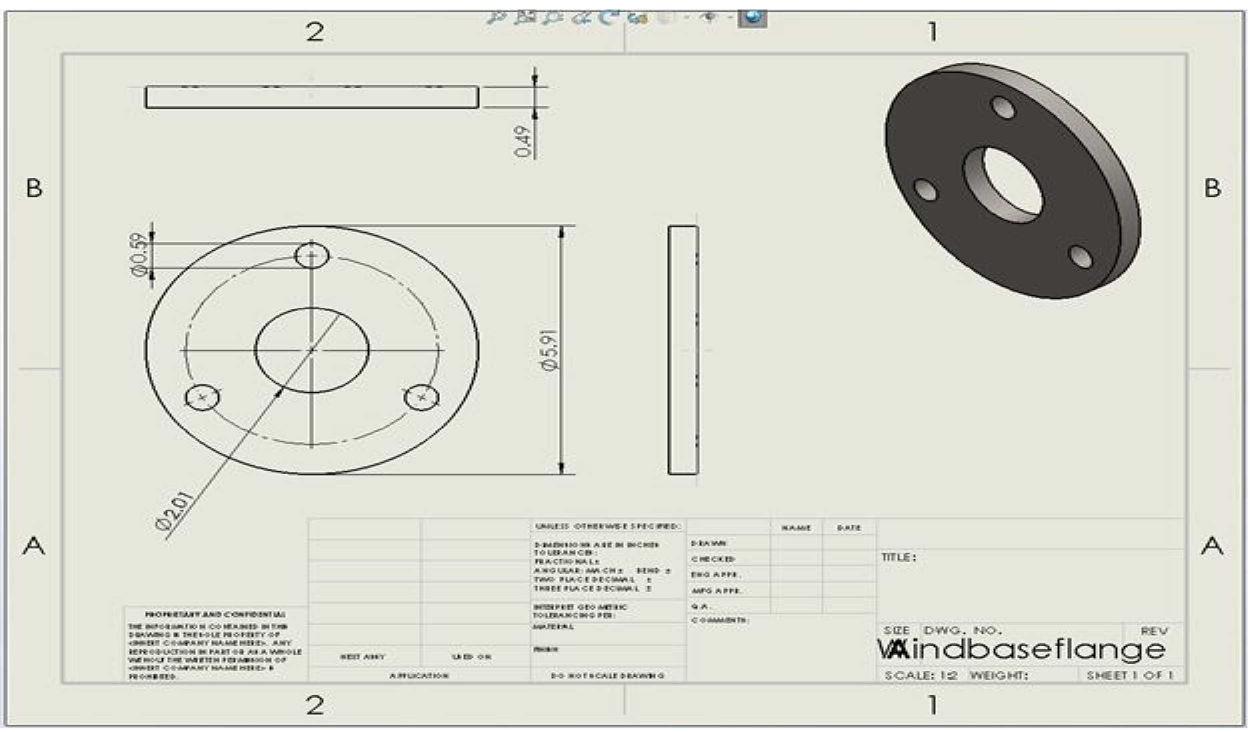

Figure 24: Base flange

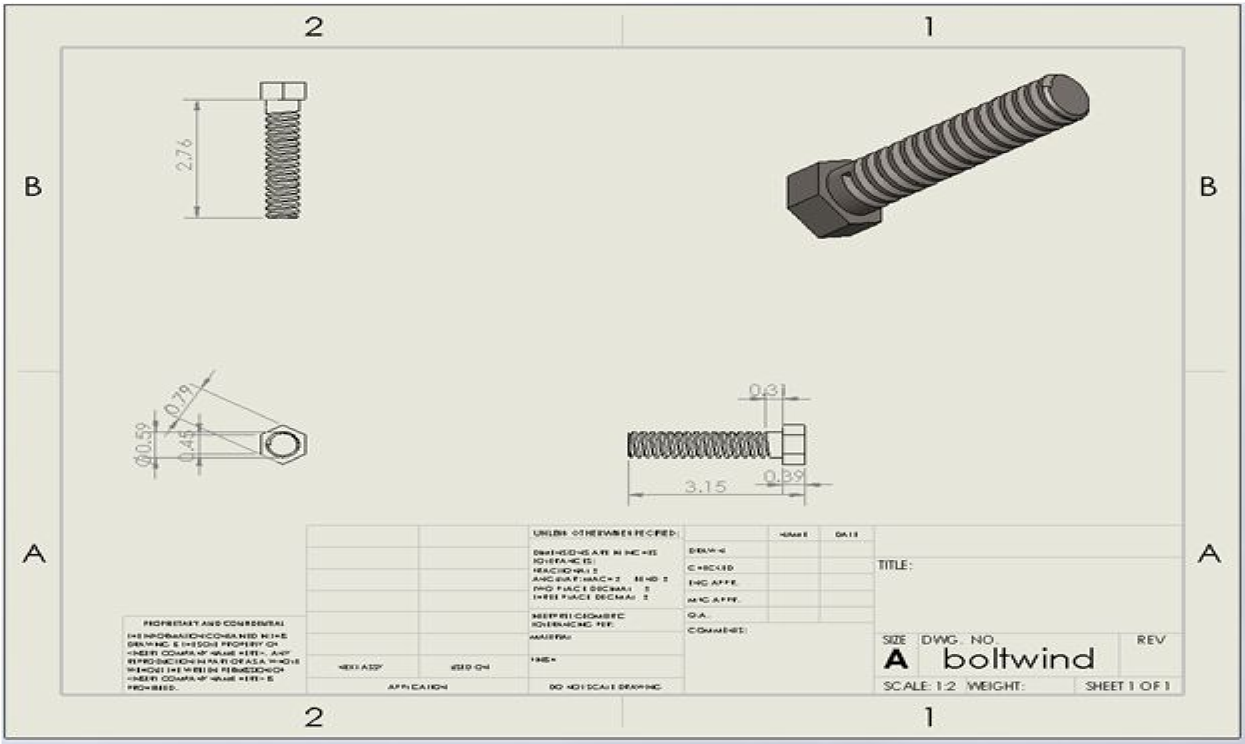

Figure 25: Bolt

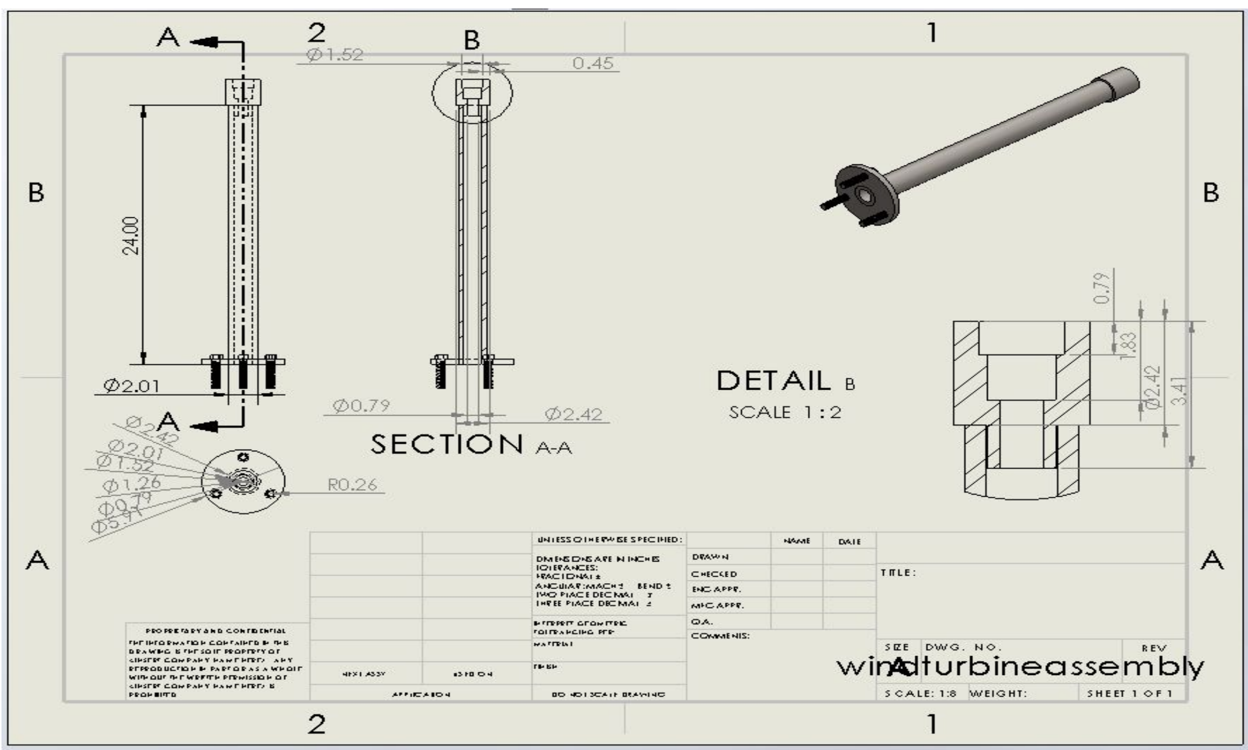

Figure 26: Tower assembly

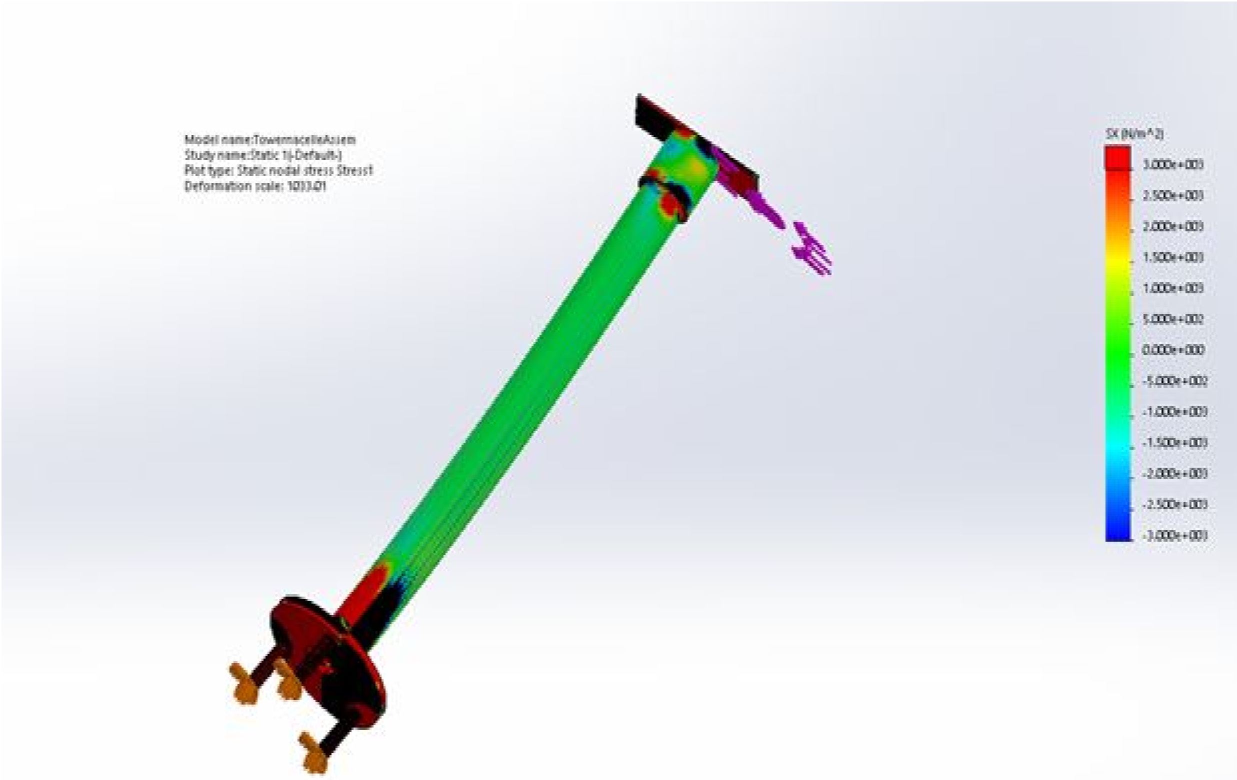

Figure 27: Tower assembly

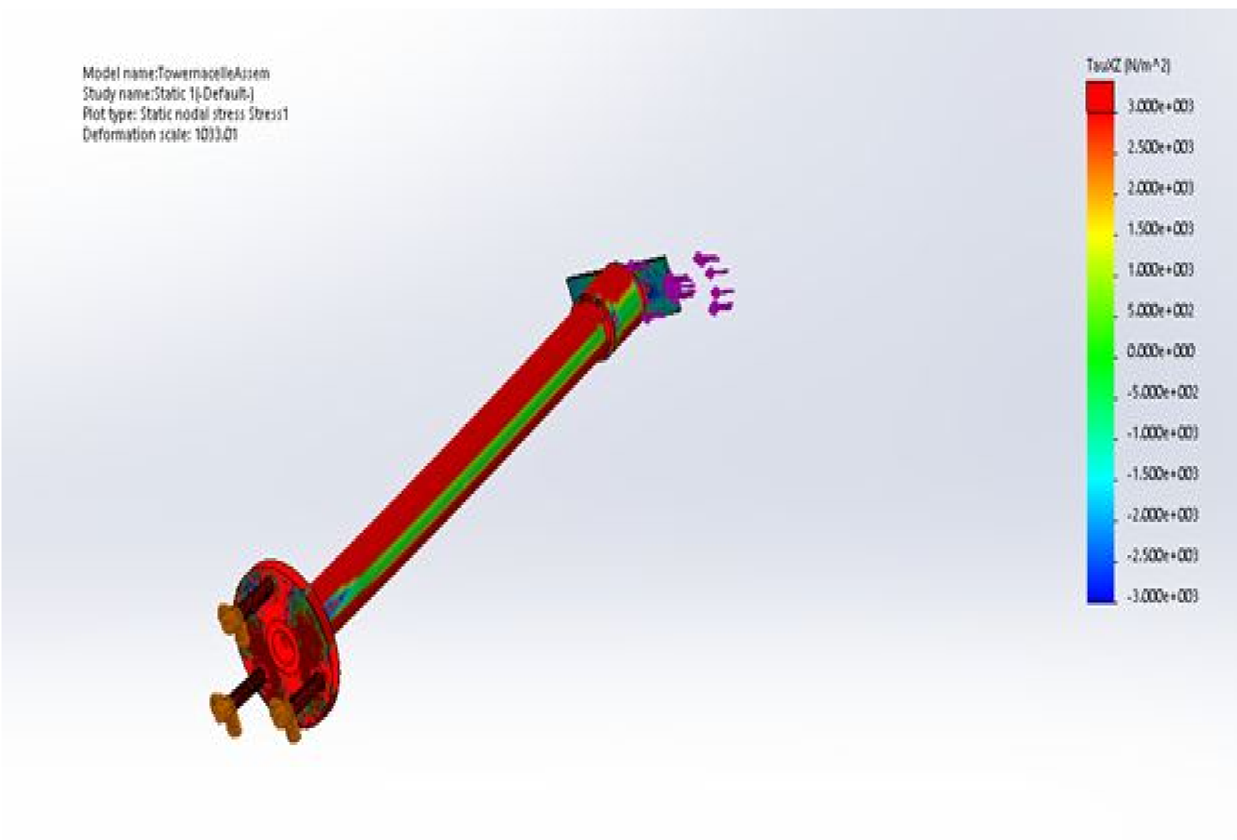

Figure 28: Tower assembly

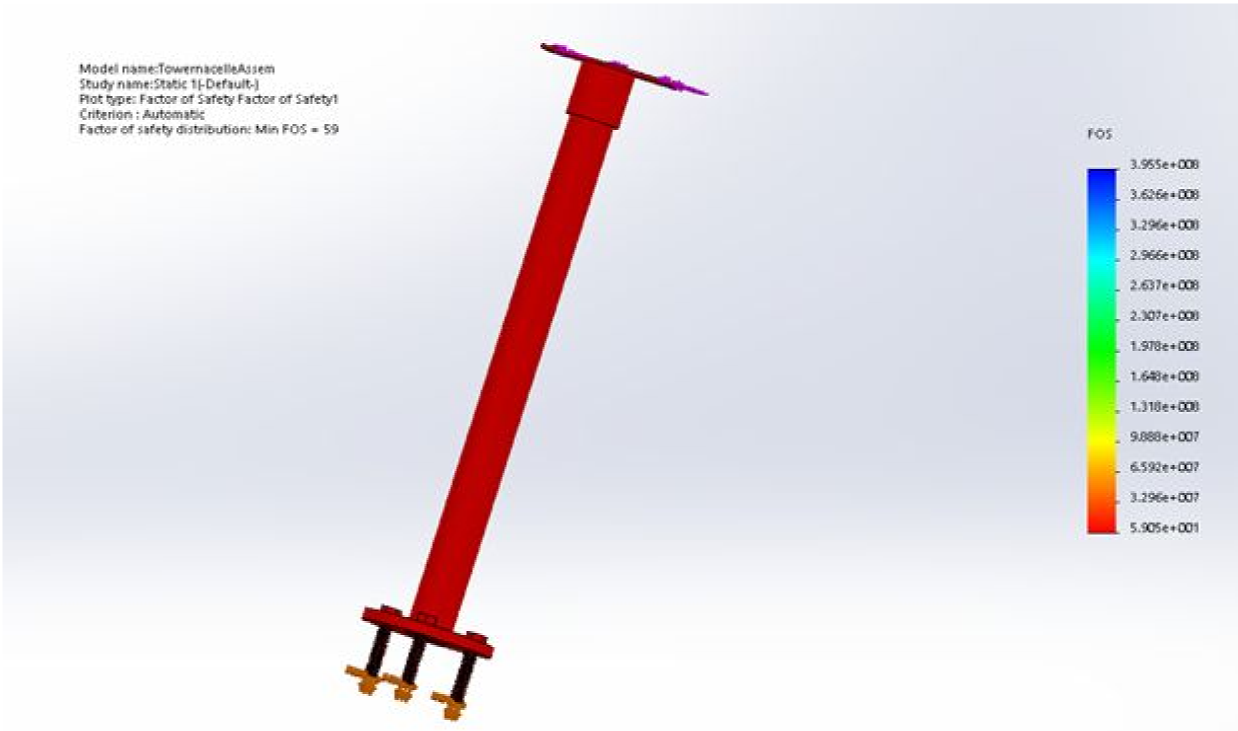

Figure 29: Tower assembly