Open Ended Wind Energy

Final Report

Michele Tsosie
Abdulrahman Alossaimi
Ahmad Saeed
Fahad Almutairi
Besongnsi Ntoung

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Instructor: David Willy

DISCLAIMER

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1.0 Background

1.1 Introduction

Our project is focusing on open ended wind energy. The major aim of our project is to design and build a wind turbine that will be used to generate wind energy in an efficient manner. We are limited to build our design within 45 by 45 by 45cm, and we are using the Qblades for our design.

1.2 Project Description

Our client is David Willy, and our design will be used at NAU campus. The guidelines we are following is based on the Collegiate Wind Energy Competition. Description for our project is designing a more effective turbine qblade and a productive yaw system with a hub, and a base flange with a tower and a nacelle with a shaft and bearings.

1.3 Original System

The rotor is attached with the main shaft which rotates the generator for producing electricity. The extracted power is kept at a value more than the operating speed of theoretical power. There are three basic components of the horizontal axis wind turbine.

- Rotor
- Generator
- Structural Support

The rotor is responsible for supporting the blades of the wind turbine and move under the influence of air. As the air strikes the blades of the rotor it starts to move. The generator is driven by the rotor of the turbine. The structural support is responsible for supporting the overall system.

2 REQUIREMENTS

This section describes all the the customer's requirements for the project. The client requires that we 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's requirements will then be translated into measurable quantifiable engineering requirement from which the goals of the project will be met.

2.1 Customer Requirements (CRs)

Here, all the customer requirements as asked by our client professor David Willy is refined and listed below as required. The table follows a format listing the 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.

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 need to create an effective mechanical, electrical, aerodynamic wind turbine
2	Turbine can produce energy with wind at 20m/s	5	The Collegiate completion rules specifies that the turbine design should be able to continuously withstand winds speeds at 20m/s.
3	Durable	5	The customer requires that the design must be durable in order 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 requires 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 specifies 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 will be 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 specifies 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 requires 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 requires that the wind turbine performance should constantly be in good quality
10	Proper wiring	5	Competition rules specifies 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 requires that we are able to 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) must be 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 is mounted, will be subjected to yaw rates of up to 180° per second with a maximum of two full rotations from the initially installed position.

2.2 Engineering Requirements (ERs)

ERs are measurable physical quantities that a designer uses to meet the objective of the of the project. The engineer translates the CRs into ERs in order to solve the problem presented by the constraints set up by the stakeholders. It also specifies 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/□^{2}	To be able to achieve maximum power over the turbine face surface area.
Operating Voltage	5 volts	Competition rules requires 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 needs 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 should be 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 parts needs to be able to meet a combine efficiency greater than 60%

2.3 Testing Procedures (TPs)

The testing procedures for this report was performed on two prominent components of the wind turbine. The first includes FEA analysis on the blades and the second testing on the tower.
Stress Concentration FEA analysis of composite wind turbine Blade:
Although the max wind speed for the project is 20 miles per second, but we tested the blades to operate at optimum operating wind speed that is 12.64 miles per seconds. Figure A below shows the vector field of the wind flow.

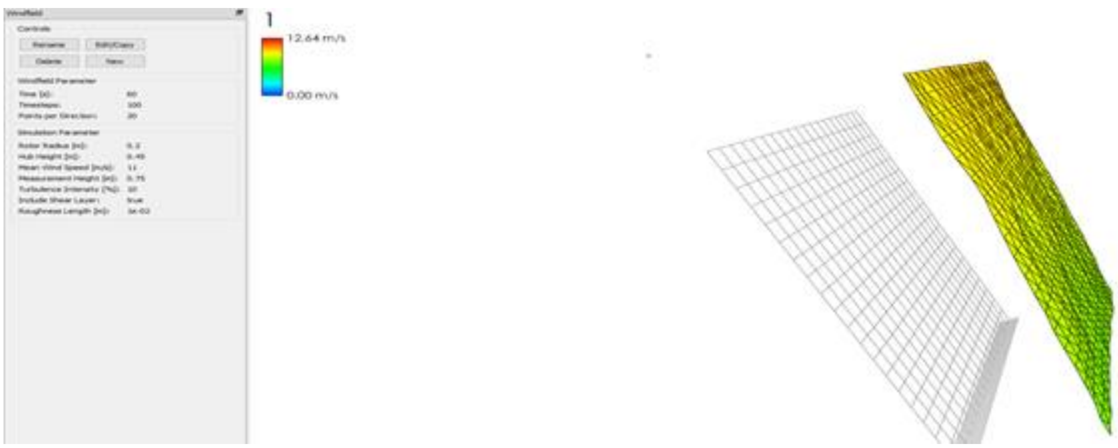


Figure A: Velocity wind field

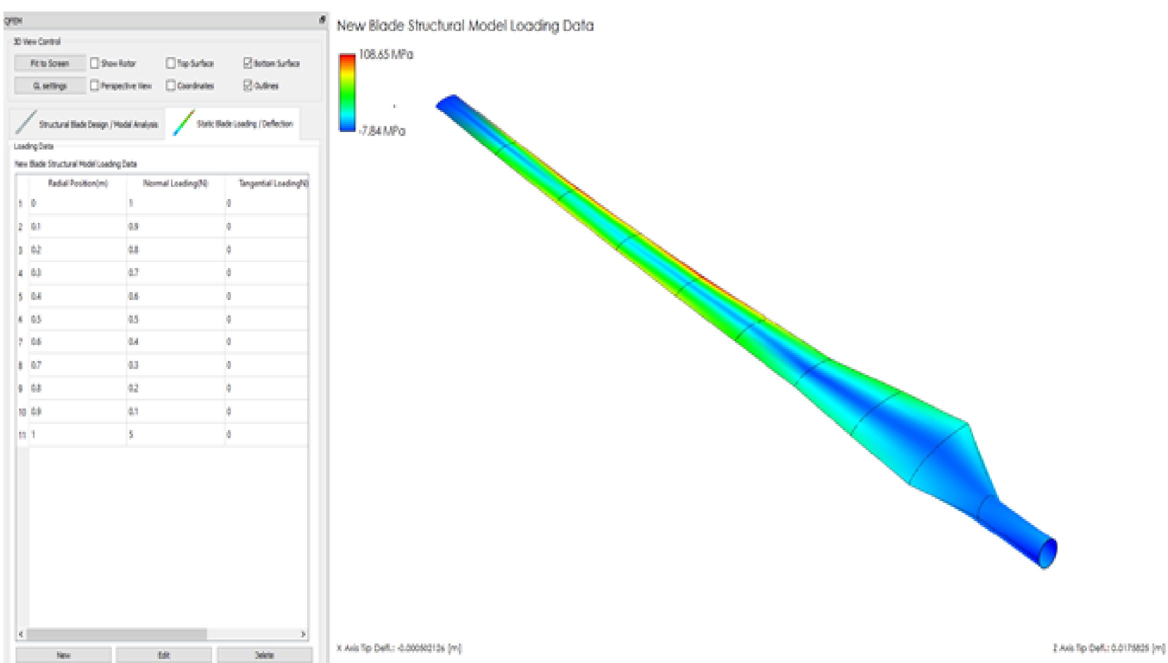


Figure B: Stress and Deflection of Blade
Max stress is 108.65 MPa and min stress is -7.84 MPa. The resultant deflections generated from the stresses at the tip of the blades are (X Axis Tip Defy.: -0.000502126 [m] & Z Axis Tip Defy.: 0.0175825 [m]). The force applied to the blades was loaded normally 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.

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

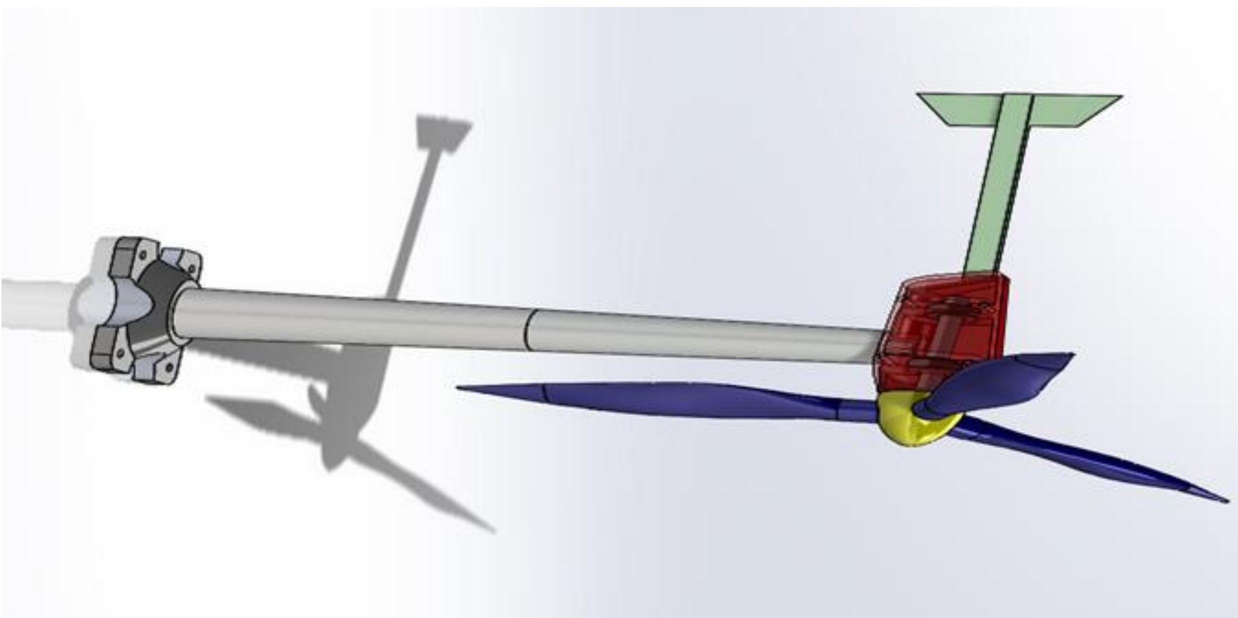


Figure C: Wind turbine

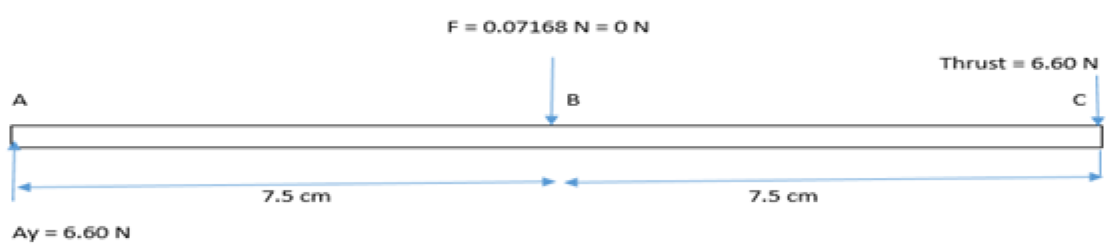


Figure D: Remodeling wind turbine

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

MA = 0.99 N-m

Figure E: Shear force diagram

Figure F: Shear force diagram

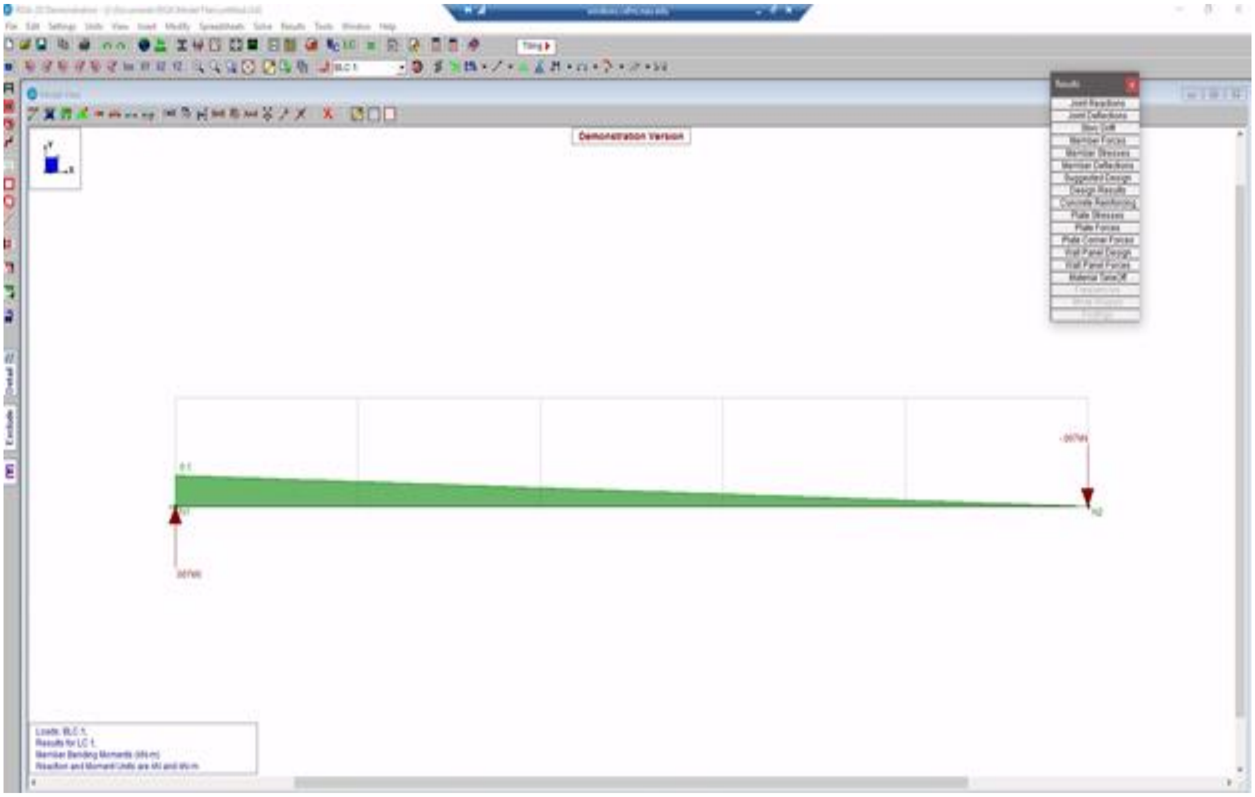


Figure G: Moment Diagram

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.

Results Using RISA-2D:

In order 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-04

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

2.4 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.

Table 3 House of Quality (HoQ) [8]

Technical Requirements											
Customer Needs	Customer need rank	Power density	Operating Voltage	Lift Coefficient	Stability	Product Dimension (Size)	Drag Coefficient	Max Voltage Limit	Load material	Torque capacity	Efficiency
Working wind turbine	5	5		8	7	7	6			9	9
Turbine can withstand continuous winds at 20m/s	4.5			5	7	8		2			
Turbine can fit via a 61cmX122cm door	4					9					
All turbine parts must be contained in a 45X45X45cm cube	5				1	9					
An electrical control system	2		2								6
An electrical ground of ≤100kΩ	1										5
Proper wiring	1								9		3
Load design	2	7	3		2				9		
Safe	5		5							8	
Reliable	3			4	6				7	7	8
Durable	3.7	6							7		
Software testable	2			1			1				5
Specification Value		[W/m^2]	Volts [V]	Dimensionless	Strength [kPa]	meters [m]	Dimensionless	Volts[V]	[H],[kΩ],[C]	Newton-meter [N-m]	Performance [%]
Technical Difficulty (1-Low, 5-High)		5	3	1	2	1	1	5	4	3	5
Importance Rating		61.2	35	76.5	93.5	152	32	9	73.9	106	99

Based on the HoQ, the most important ERs is the product dimensions while the least is the max voltage limit. This is however accurate as it is very important that the team creates 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 will not necessarily get a penalty if maximum voltage limit is surpassed. In which case, the design power efficiency will be 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 meets the needs of the client.

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

In the attempt to obtain details and more information about the best features and the ideas to implement in our model, we conducted a wide research, these is through consulting both written and non-written sources. We searched for details on the various already existing models and their respective weak points and strong points, this was necessary in order 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 so as 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. The oil deficiencies of the 1970s changed the vitality picture for the U.S. also, the world. It made an enthusiasm for elective vitality sources, making ready for the reentry of the breeze turbine to produce power (Lewis2007) [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 got no gearbox. Preferably, the rotor shaft is 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 creates 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 is 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 as 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 3 below show a detailed image of the wind turbine implemented without the gear box.

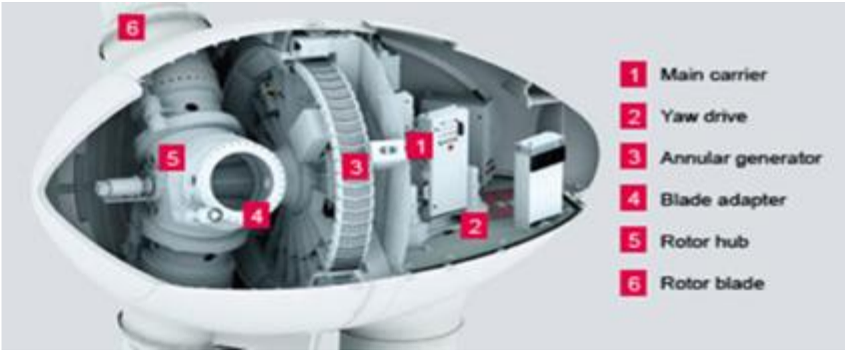


Figure 2 - Gearless wind turbine [3]

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 is made us of 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 (Jonkman and Scott 2009)[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 3 below is a representation of a wind turbine with gears.

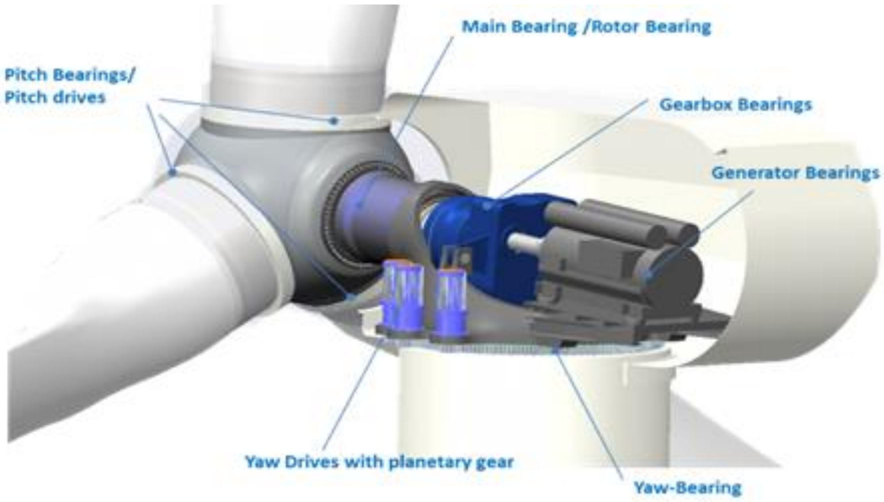


Figure 3 – Wind Turbine with Gears [4]

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 is very significant to use for our project. To illustrate, we can see that the basic purpose of the block is to convert the wind energy to electricity. The input to the block is wind which produces the kinetic energy and velocity in the turbines. The output from the block is electricity, mechanical energy and Blade/turns Noise. The conversion from the input parameters to output parameters is brought by rotor and generator. Once the generator starts rotating the kinetic energy gets converted into electrical energy. This is the way wind turbine is performing the inter conversion. Figure – 5 below will show the black box model.

Figure - 4 Black Box.

3.3.2 Functional Model

The functional model is actually show us the steps uses the system from the inputs and outputs. To demonstrate, From Figure – 6, we can 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 is 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 is fed into inverter system for inter conversion of A.C and D.C quantities.

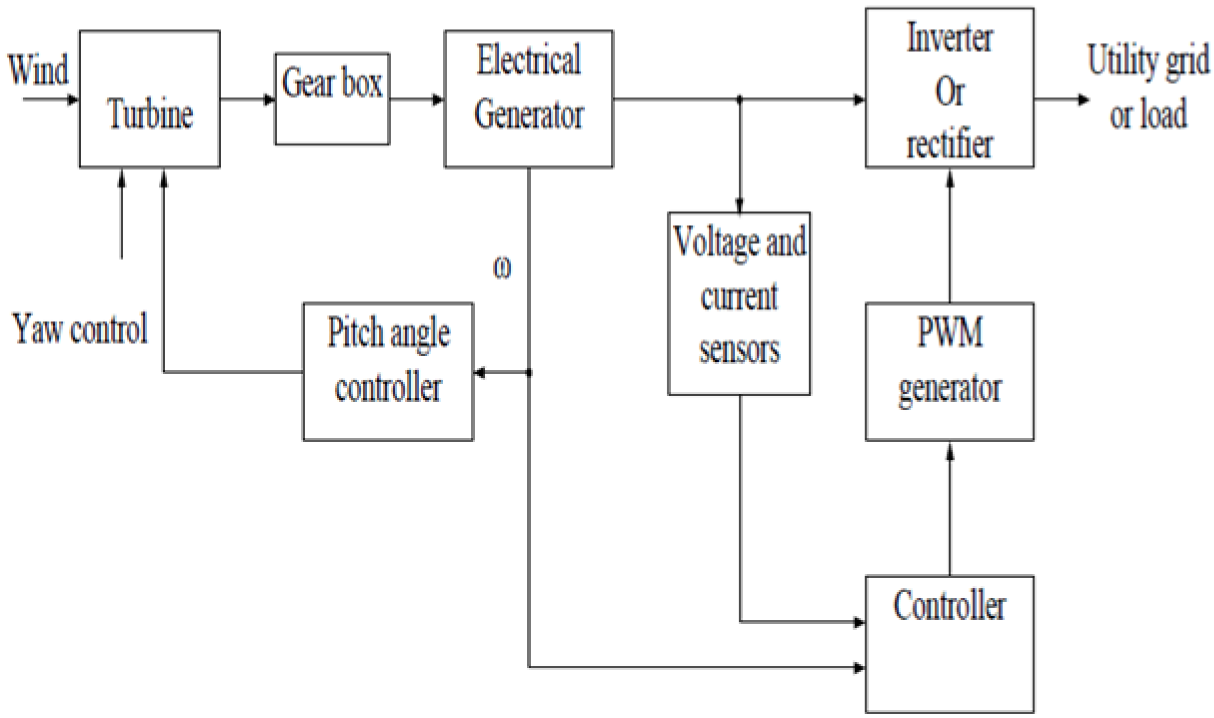


Figure - 5 Functional Model

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 is 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 can use for our project because curved blades are good to use for rotating the turbine system.

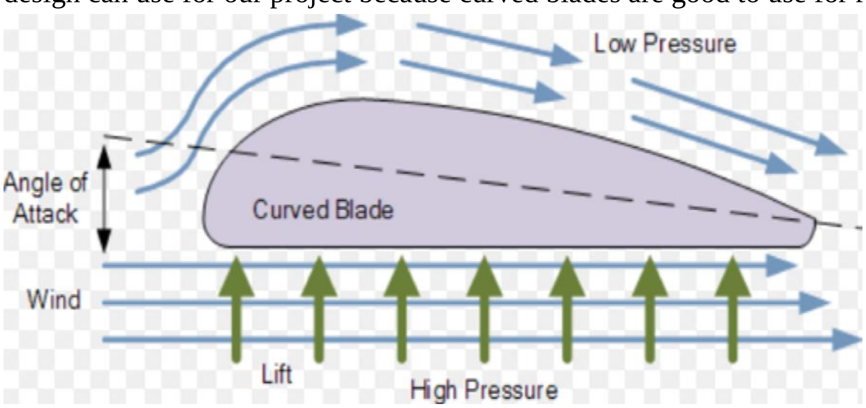


Figure [6]: Curved blade

3.4.1.2 Existing Design #2: Round Blade

Another design for the blade is round blade which has curved shape as well but it has round shape from the start and it is thin in their width as well. This type of blade can also use in our project because of their better performance as the design is showing in the following figure.

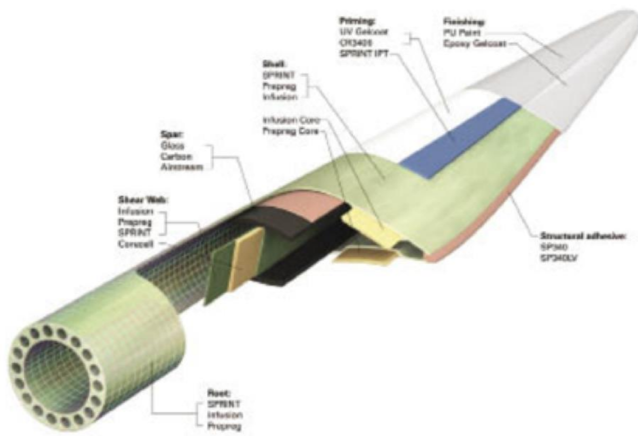


Figure [7]: Round Blade

3.4.1.3 Existing Design #3: Straight Blade

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

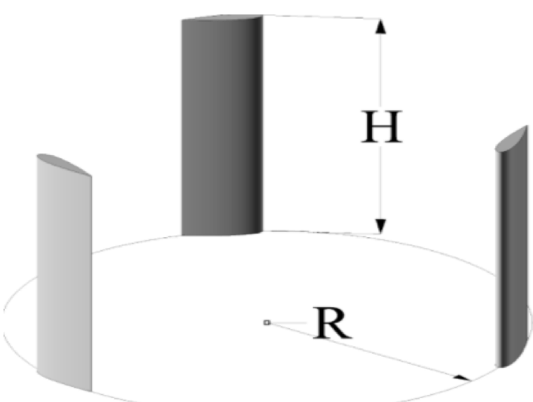


Figure [8]: Straight Blade

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 this design of tower a zigzag body has made in the tower to make it strong and capable of bearing the high pressure air without dangling down or topple over. This design can use in the project when the blades are heavy and long. Design is showing in the following figure.

Figure 9: Lattice Tower

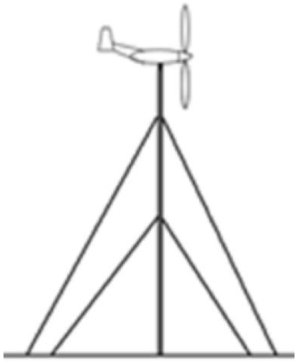
3.4.2.2 Existing Design #2: Pole Tower

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 can use in our project also because of its slim body. Design is showing below.

Figure [10]: Pole Tower

3.4.2.3 Existing Design #3: Guyed Mast

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



Figure[11]: Guyed Mast

3.4.3 Subsystem #3: Gearbox Bearings

As the turbine produces electricity on the basis of speed so variation of speed is present in the turbine using the gearbox which rotates the gears according to the air speed. So the subsystem is different bearings.

3.4.3.1 Existing Design #1: Steel Bearings

Steel bearings are strong and non-rust bearings and these can be used for high speed shifting of gears without obstruction. Design of steel bearings is shown below.

Figure [12]: Steel Bearings

3.4.3.2 Existing Design #2: Iron Bearings

Another bearings available in the market and these iron bearings, these bearing are useful but they get rusty after sometime when didn't treats properly. As showing the design in following figure.

Figure [13]: Iron Bearings

3.4.3.3 Existing Design #3: Aluminum Bearings

Aluminum bearings is another existing design for the bearings, and these are useful for light weight but they cannot hold strong force but the advantage is that it doesn’t get rusty as well. Design is showing below.

Figure [14]: Aluminum Bearings

4.0 DESIGNS CONSIDERED

The possible designs that were considered in the final design process were carefully weighed by the Customer Requirements and the Engineering Requirements. 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, includes 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 amount 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 are the stability of the design. The wind turbine will need to fastened 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 particular design is 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 has blades that are flat in design selection. The flat blades are placed at an angle that will catch the wind from any direction. The advantages and disadvantages are similar to the previous design. The only drawback to this design is that it is less efficient than the typical vertical wind turbine. The VAWT does not have the blades that are contoured from bottom to top in reference to the attachments. The blades simply attached to a middle beam and stand 90 degrees to the base. The team have considered parts of this design and see 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) is a design that was most successful in reference to the customer requirements and engineering requirements. The design solution we have considered is to incorporate a recharging station to our wind turbine. Students of NAU will be able to 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 is a design that is capable of withstanding high wind shears that incorporate higher efficiencies. The high towers are placed in strong winds which are able to increase the speed of the blades by 20% and power output of 34%. Figure 11 in the appendices show the several designs that were considered for the final project. The design C is the design that could be incorporated in our final design. [11]

4.4 Design #4 - 10: Additional Designs in Appendices

The additional designs that were considered are listed in the appendices listed as Designs Considered. The designs that are located 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

In this chapter it will show you 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 7.

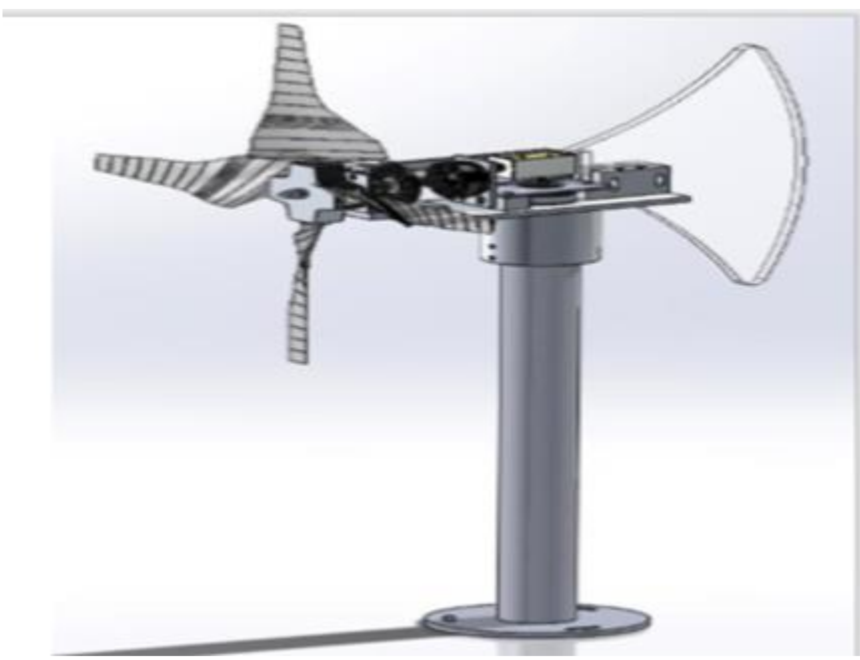


Figure - 7 Selected Design C.

5.2 Design Description

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

Figure 17 Center Casing

Center casing covers the complete electronic part. All the processing of wind turbine is occurring in the center therefore it is important to cover that part and figure 17 is showing the center casing of the wind turbine to cover the parts.

Figure 18 Rotating shafts

Figure 18 has shown the rotating shaft which connects between the blades and generator. When the blades will rotate because of wind, it will eventually rotate the rotor of generator and that will produce the electricity.

Figure 19 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 20 Holder

Figure 20 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.

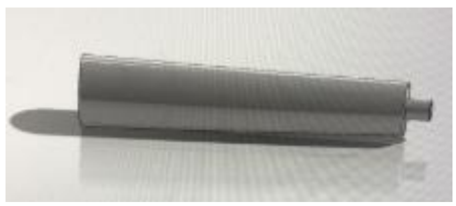


Figure 21 Nozzle

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 22 Blade

Blades are the major part of wind turbine system. Blades provide the rotation when the air blows. Figure 22 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.

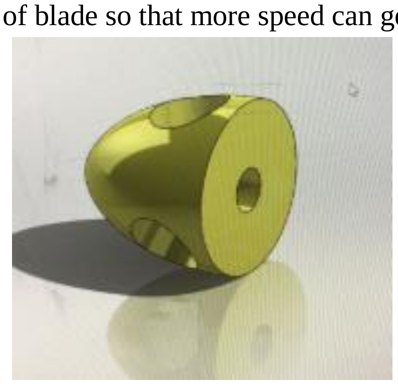


Figure 23 Back socket

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.

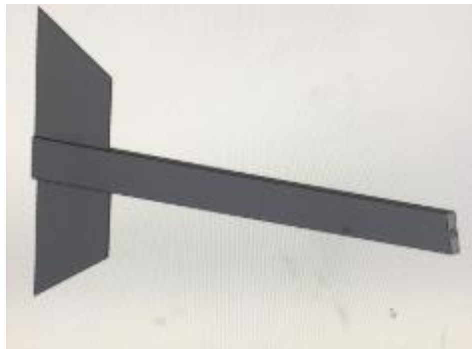


Figure 24 Standing base

Figure 24 has 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 25 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.

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 in reference to the testing wind tunnel located off campus. These deliverables provided the design with the Customer Requirements(CR). 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 15 is our prototype design. The CAD design was developed and modifications were implemented to incorporate the blade dimensions. Figure 19 in the appendices is our CAD design which is our proposed design.

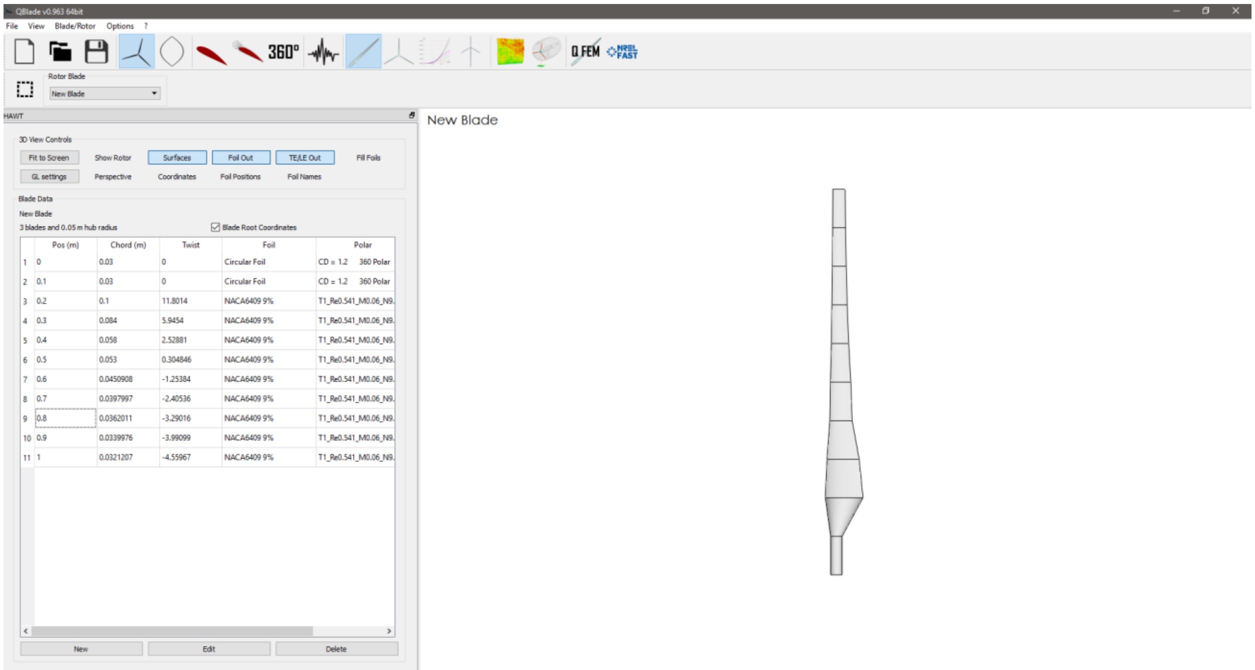


Figure 15: Blade design in Qblade

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 for the purpose of 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.

10 REFERENCES

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11 APPENDICES

11.1 Appendix A: Pugh Chart

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

11.2 Bill of Materials (BOM)

Table 2: BOM

Bill of Materials							
Team				Wind Energy Open Ended 13			
Part #	Part Name	Qty	Descriptio	Material	Dimension	Cost Per Pa	Link to Cost estimate
1	Base Flange	1	Flat base material that supportsT	Cast Iron	15.0 diameter	$11.83	https://www.mcmaster.com/#flanges/=1coqq6r
2	Tower	1	Round	Steel	3.5 CM	$46.36	https://www.mcmaster.com/#precision-shafts/=1coqz33
3	Blades	3	Flat Material	PLC	20.0 CM	$28.00	3D Printer
4	Nacelle	1	Cover	PLC	4.48 in	$11.00	3D Printer
5	Shaft	1	Step Down	303 Stainl	3.5 Diameter	$31.36	https://www.mcmaster.com/#precision-shafts/=1coqis9
6	Yaw fin	1	Flat object	PLC	H 6in , W 3.5 in , L 0.5in	$22.00	3D Printer
7	Generator	1	Electrical Converted	Steel	2.0 CM	$19.75	https://www.amazon.com/Pacific-Sky-Power-Project-Generator/dp/B01KMZQT1Q/ref=sr_1_13?ie=UTF8&qid=1525393236&sr=8-13&keywords=generator+small
8	Brake disk	1	A short shoe	Carbon	5 Diameter	$25.65	https://www.mcmaster.com/#=1cor9oh
9	Brake	1	Circle	Steel	4in	$12.50	https://www.fcpeuro.com/products/audi-bmw-brake-piston-wind-back-adapter-3-pin-cta-1458?ads_cmpid=352578319&ads_adid=22976872639&ads_matchtype=&ads_network=g&ads_creative=85227587119&utm_term=&ads_targetid=pla-70936742985&utm_campaign=&utm_source=adwords&utm_medium=ppc&ttv=2&gclid=EAIaIQobChMItI3y8fbq2gIVA6rsCh0inQAYEAQYASABEgIN0vD_BwE
10	Bearing	2	Circle	Steel	22.86 MM	$12.88	https://www.mcmaster.com/#standard-ball-and-roller-bearings/=1coresq
11	hub	1	Circle	Steel	18.90 MM	$14.50	https://www.mcmaster.com/#=1coqhom
					Total Cost	$235.83	

11.3 Appendix B: Decision Matrix

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

11.3 Appendix C: Designs Considered

Figure 17: Vertical Wind Turbine with angled blades [1]

Figure 18: Vertical Wind Turbines with 90 degree blades [6]

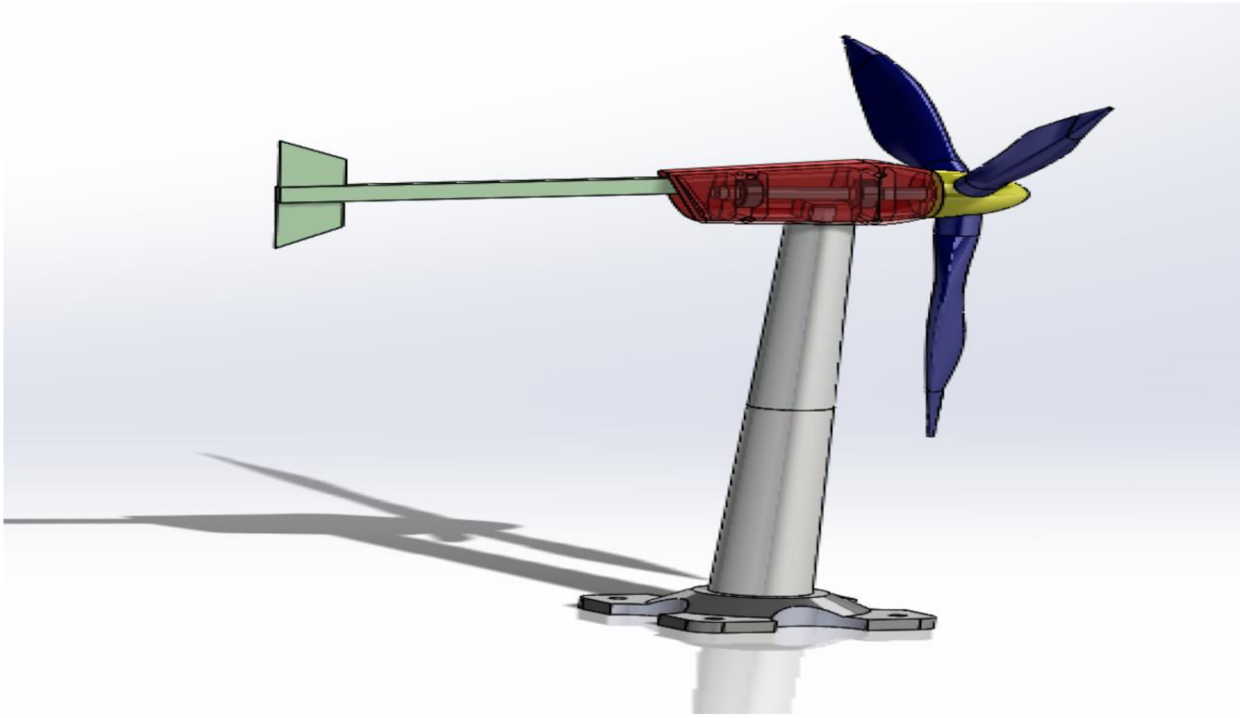

Figure 19: Design choice of wind turbine CAD

Figure 20: Primus Wind Power Turbine [10]

Figure 21: Sunforce 44444 Wind Turbine [11]