MENG411-CAPSTONE TEAM PROJECT

Eastern Mediterranean University

Faculty of Engineering

Department of Mechanical Engineering

Design and Fabrication of a Giromill Vertical Axis Wind Turbine

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ABSTRACT

In this project we deal with the design and fabrication of three blades Giromill vertical wind turbine. The Giromill wind turbine is a type of vertical axis wind turbine which is used to produce power. The turbine consists of three straight blades which are represented by airfoils that are connected to the rotating main shaft. In this project the components required for this wind turbine like airfoil, main shaft and bearing are designed properly. The power calculations with respect to the velocity of wind are included. The components are fabricated from steel, aluminum and wood then all parts are assembled together after manufacturing of blades. Finally, the performance of the Giromill was tested and was found that it performs correctly.

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Chapter 1

Introduction

1.1 Wind Energy History

Since the 7th Century, people have been using the wind to make their life easier. The main idea of the windmills was originally put to use by Persians. Persians have been used the wind energy to quench farm-lands, crushing grains and milling applications, therefore the origin of the term “windmill” comes from these processes [1].

After the spread of windmills in Europe and starting using them during the 12th Century, many countries as Netherlands have succeeded to produce large wind farms. Although, the first rotating sails windmills were not reliable or efficient sources, but they were useful for producing torque using slow speed and tip speed ratio.

Since the creation of windmills, there has been many tries to improve the concept, as a result of tests, number of blades in the windmill has decreased. Modern windmills have 5-6 blades while in the past it had 4-8 blades. Also, past windmills had to be manually pointed into the wind direction, while the modern model can be turned into the wind automatically. In addition to this, the sail design and its materials of construction have been changed over the years.

1.2 Wind Energy

As a resource which is globally existed, wind can satisfy many of human’s energy requirements if it used effectively on a large scale. Vertical axis wind turbine which is working around the vertical axis and perpendicular to the ground can be efficient as the horizontal axis wind turbine that is working by rotating in a parallel axis to the ground.Therefore,it has many advantages over the lastly mentioned. It can be a practical, simpler and a cheaper choice to construct and maintain than the horizontal axis wind turbine. They also have other included advantages, such as they are always facing the wind motion which can achieve our main aim in building a cheaper, cleaner and renewable source of electricity that can perform in an easier way. The main concept of VAWT that it works by converting the wind power to an electricity form. In particular, this model of turbines has a rotor shaft that is arranged in a vertical way. By this arrangement, many advantages can be concluded. Firstly, the generators and gearboxes can be fixed or placed close to the ground. Secondly, the VAWT do not need to be pointed into wind direction of motion.

In these days, there are many kinds of VAWT: Savonius, Darrieus and Giromill turbine which is cheaper and simpler to build than the standard Darrieus turbine, however it needs strong winds to start. Moreover, they can work well in 2 disturbed wind conditions. The main feature of this arrangement is that the turbine does not need to be placed into the wind to be efficient. The Giromill blade design is simple to construct, but it leads to a larger structure than the conventional arrangement, and needs stronger blades [2]. In order to illustrate the correlates costumer requirements and technical requirements for enhancing the quality of product table 1.1 is used. This table determines the most significant factors in weighing the system and can be converted to the form of triangles.

Table 1. 1 : QFD of wind turbine

		Engineering Metrics							
Consumer Needs	Relative Importance	Adequate Power	Size of a Nalgene bottle	Low cut-in speed	Low manufacturing cost	Modular design	Access to components	Legend	Key
Units		W	cm^3	m/s	$	sec	sec	●	Strong or Significant Relationship
Power a cell phone, gps, camera	10	●		●				○	Medium or some Relationship
Size and Portability	9		●		Δ	Δ		Δ	Small or Significant Relationship
Price of product	8	●	○	●	●	Δ	Δ	--	No Relationship
Quickness of Charge	5	○		○	●				
Resistance to Damage	5				○	●	○		
Ease of Maintenance	4					●	●		
Technical Difficulty		5	4	5	3	2	2		Rated from 1 to 5 (easy to difficult)
Target values		6	1500	2.5	150	<30	<45		

1.3 Objective of the Project

For the purpose of using the available wind resources and reduce the usage of non-renewable energy resources which has many negative effects on the environment, Wind energy is by far the fastest-growing renewable energy resource and the easier source to depend on. In particular, the wind energy has been widely used in industrial field and supported by market rewards beside considering it as a vital policy to construct a sustainable source of energy.

This project deals with the design and fabrication of a Giromill VAWT. The Giromill wind turbine will be constructed from three blades according to our work plan. In this project the components required for this VAWT design such as airfoil, main shaft and bearing will be considered in the design process. Moreover, power calculation with respect to the wind velocity will be included.

1.4 Organization of the report

In this project a brief history about the wind energy is mentioned in Chapter 1, in addition to the specified Giromill VAWT. Chapter 2 discusses a literature review of some useful information and formulae of the aerodynamics analysis of wind power. Chapter 3 will discuss the design of the Giromill Vertical Axis Wind Turbine with a detailed analysis and dimensions of this type of wind turbine.

Chapter 2

Literature Review

2.1 Straight Blades Vertical Wind Turbine-Giromill

2.1.1 Historical Background

Vertical axis wind turbines are different from traditional wind turbines that their main axis is perpendicular to the ground. Their configuration makes them ideal for both rural and urban settings and offers the owner an opportunity to offset the rising cost of electricity and to preserve the environment. Besides, they do not need the complicated head mechanisms of conventional horizontal axis turbines.

The Giromill VAWT which has a straight blades or an H-rotor shape, is a kind of VAWT's which developed by G.Darrieus in 1927.This type of VAWT has been studied in the United Kingdom during the 80's by Musgrove researches team.

In this type of turbines, the blades that look like the egg beater machine are changed with straight blades that are connected vertically to the main tower with a horizontal axis supports. Giromill turbines generally have 2 or 3 vertical airfoils. The Giromill blade design is simpler to construct than the other types of VAWT, but has a greater structure than the conventional order and needs a tougher blade. The Giromill turbines has a generator that is located at the bottom of the shaft and as a result, it may have a larger and heavier structure than the horizontal axis turbines generators that has a lighter structure.

Although the Giromill turbines are easier and cheaper than the standard Darrieus turbines, it is less functional and needs a motor to start. However, it can work well in turbulent wind conditions. Also, it demonstrates a good choice in areas where the horizontal axis wind turbines are inappropriate [3].Table 2.1 illustrates a comparison between the different types of vertical wind turbine.

Table 2. 1 : Comparison of VAWT Models

	Darrieus 	**Giromill** 	**Savonius** 
Blades	Airfoils	Straight blades	Curved scoops
Force component	Lift	Lift	Drag
Blade profile	complex	complex	Simple
Blade Area	Moderate	Large	Moderate
Generation Site	Ground	Ground	Top of a tower
Structure	Simple	Simple	Simpler
Blade weight	Large	Large	Moderate
Self-starting	No	No	No

Furthermore, each wind turbine type has different specifications. These specifications include the power output, area, dimensions, materials used and mechanism. Table 2.2 gives an inclusive comparison of some important variables of different wind turbine models.

Table 2. 2 : Comparison of wind turbines specifications [2]

	H-rotor 1	H-rotor 2	Darrieus	HAWT (scaled)	HAWT
Rated power (kW)	500	500	500	500	600
Swept area (m^2)	850	850	955	1370	1520
Rated wind speed (m/s)	~13.5	~13.5	12.5	15	15
No. of blades	2	2	2	3	3
Tower height (m)	30	30	50	47	50
Turbine diameter (m)	35	35	34	42	44
Blade length (m)	24.3	24.3	54.5	18	19
Blade material	GRP	GRP	Aluminium	GRP	GRP
Yaw mechanism	No	No	No	Yes	Yes
Pitch or active stall mechanism	No	No	No	Yes	Yes
Gear box	Yes	No	Yes	Yes	Yes
Guy wires	No	No	Yes	No	No
Generator position	In tower	On ground	On ground	In nacelle	In nacelle
Rotation speed (rpm)	Constant, 13.6/20.4	Variable	Semi-variable, 28–38	Constant, 19/ 28	Constant, 18/ 27
Overall structure	Simple	Simple	Moderate	Complicated	Complicated
Mass blades only (t)	6	6	-	13	15
Mass turbine (t)	~24	~24	72.2	13	15
Mass nacelle (t)	~20	No nacelle	No nacelle	20	23
Mass tower (t)	153	32.8	No tower	36	42
Total weight above ground level (t)	197	56.8	72.2	68	80

There are actually many reasons behind this decision is made. Therefore, there are some advantages and disadvantages that come with the use of Giromill wind turbine as shown in table 2.2.

While the many advantages are certainly great, it is imperative that you are aware of the disadvantages. Before deciding which type of wind turbine is best for you it is a good idea to take a look at both the pros and the cons. What is right for one person may not be right for other, although it is safe to say that a VAWT is great for almost any residential setting.

Table 2. 3 : Advantages and disadvantages of VAWT

Advantages	Disadvantages
Low production cost	Vibration due the turbulent air flow
Low maintenance cost	Low torque, requiring energy to start spinning
Easy to install	Need to be pointed toward wind
No need for tower	More stress and fatigue on blades due to fast twisting
Producing electricity in any wind direction	Can create noise pollution
Blades can spin at low velocity	May requires guy wires

2.1.2 Rotor Components

Giromill rotors can be divided into three parts:

Figure 2. 1 : Rotor Parts

1) Axis of rotation: It is defined as the central mast. It lies in the center of the rotor surrounded by the other components. In general, it is metallic and has a circular section.

2) Blades: Giromill rotor has a vertical airfoils blades like the Darrieus type. However, the Giromill rotor blades are straight. The blades major function is to spin by the wind action. These blades are installed and fixed to the rotor shaft, that is connected to them and rotates at the same time. Blades numbers is an important issue. In general, it is considered as two or three blades, however these are not the only choice. These turbines may face an efficiency loss, but increasing the number of blades results that the turbine is dealing with more drag. The wind turbines that have a large number of blades, has a relatively low speed of rotation. The torque vibration can be decreased by using 3 or more blades, which leads to a greater solidity for the Darrieus rotor wind turbine, while the negative point of increasing blades number is cost.Figure 2.2 shows different types of NACA airfoils.Each type has different properties such as coordinates and chord length.

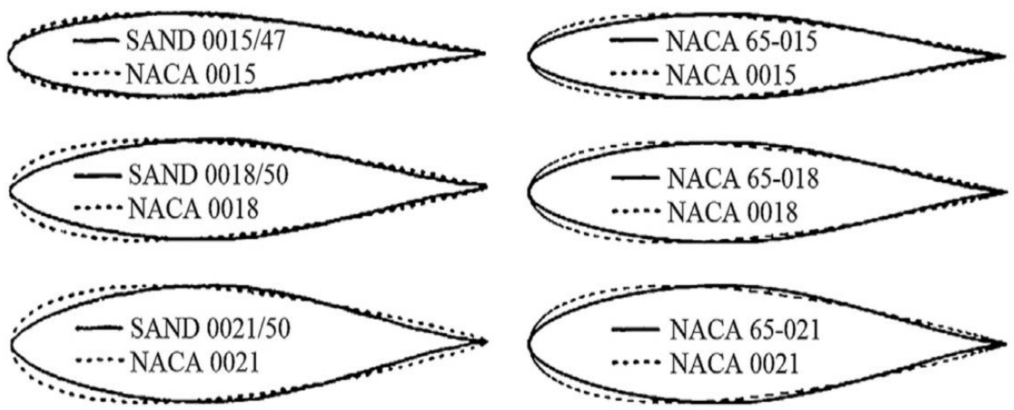


Figure 2. 2 : NACA 65-series airfoils standards [3]

3) Radial arms: These parts are horizontal supports that connecting the blades to the central axis of rotation. It can be connected to the blades and central mast by threaded union or welding process.

4) Pulley: The duty of this part is to transmit the torque and rotation from the rotor shaft to the generator. The pulley is made from aluminum and was taken from a washing machine. However,it can be used for our design due to its shape and size.

2.1.3 Darrieus Rotor Mechanism of Action

Darrieus rotor method of work can be simplified as below. Firstly, the disturbed wind that faces the rotor keeps straight. At the same, the blades tips are spinning faster than the main undisturbed wind speed. For example the tip ratio of blade speed due to free wind speed is larger than 3. When the TSR is high, the airfoils will cut along the wind with a small angle of attack. As a result, the lift force constantly helps the rotor rotating when the drag force resists the rotating. As the lift has a zero degree at the left side and the right side has 180 degrees, where the uniform airfoil moves with parallel to the wind, the torque alternate to negative around this location. Close to front with a 90 degree, and far back with 270-degree site, the lift component is higher than the drag component. As a result, a positive torque is produced. This total torque per revolution will be positive with an adjust of airfoils, causes the rotor to accelerate at the correct direction.

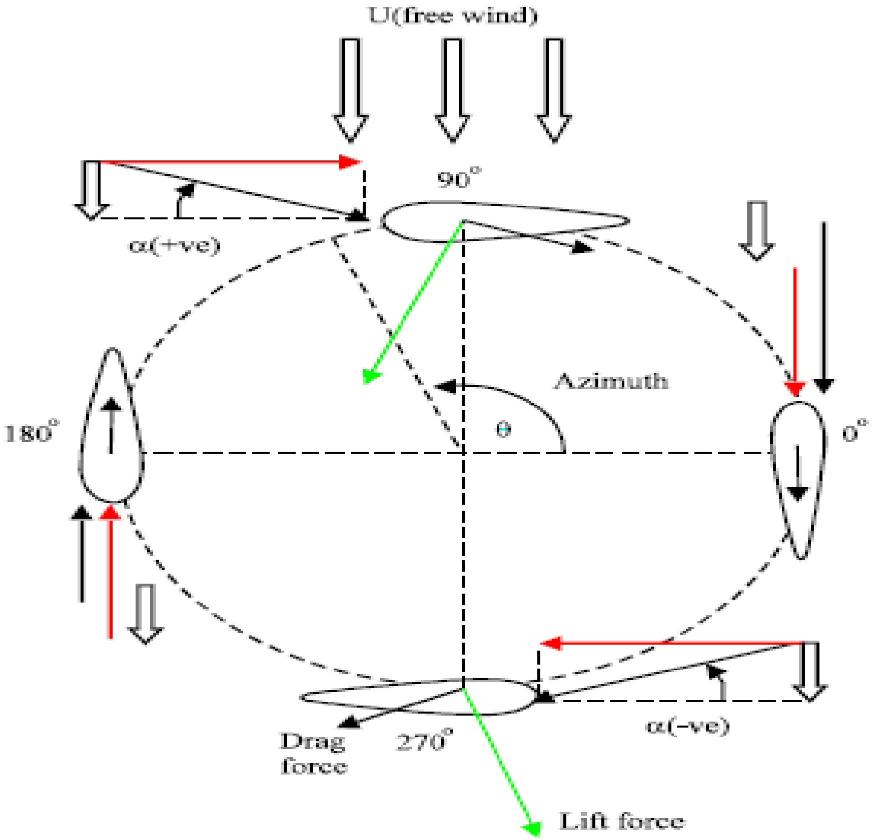


Figure 2. 3 : Principle of Darrieus Rotor [16]

While the rotor is starting to rotate, the initial torque will depend on the angular speed of the rotor according to wind direction. The rotor may rotate at the right direction immediately or sway a little before initiating. As normal, the rotor requires some support to achieve greater number of revolutions before beginning the self-rotating. Due to this, Darrieus rotors have a very low torque at low Tip Speed Ratio which has a negative effect by the friction in the system [4].

As a summary, work method of Giromill VAWT is the same as the widespread Darrieus turbine. The blades are spin by wind and its velocity is divided into lift and drag forces. As a result, the resultant of the two velocity components causes the turbine to rotate. The sweeping area of the Giromill VAWT is represented by the length of blades multiplied by the rotor diameter. Fig 2.3 below represent the principle of the Darrieus Rotor.

The main problem faced with this design is that the AOA varies while the turbine rotates, so that each of the blades produces the maximum torque at two points on the cycle. Second negative point is that most of the mass of the rotating motion is located at the boundary instead of the center like the fan structure. This issue, causes a high centrifugal stresses on the technique of work, that must be heavier and stronger so it can resist these stresses. Usually the shape looks like an egg-beater machine, which used to avoid this problem, because the mass is rotating away from the rotation axis. Fig 2.4 shows the direction of rotor rotating [5].It can be noted that the resultant force due to wind speed determines the angle of attack at which the blade has the maximum wind effect on its area.Therefore,having a greater resultant force will increase the lift force and the speed of rotor which causes the turbine structure to rotate faster. For this reason installing a wind turbine in a high wind speed areas can be more efficient and functional resulting in a better utput of energy production.

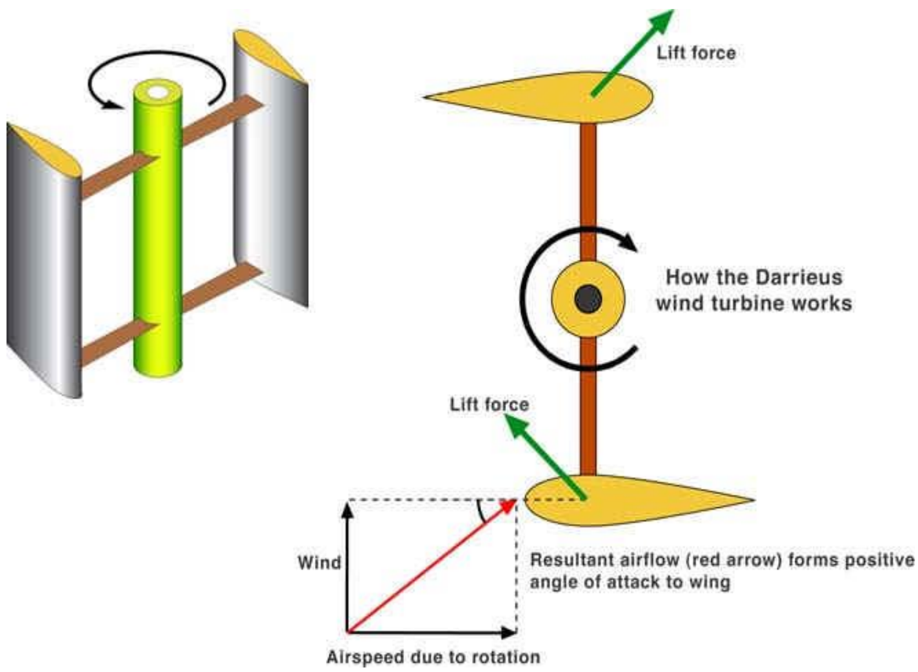


Figure 2. 4 : Rotor rotation direction [17]

2.2 Placing Conditions

The available wind power increases in a fast rate with respect to the speed, as a result, the conversion of wind energy should be sited in an appropriate area, where winds have high speed. While selecting the wind energy site these points should studied [6]:

1) Velocity curve availability at a specific site:

Velocity curve with respect to time, demonstrates the maximum output of energy wind, so it can be considered as the initial principle of controlling factor for finding the electrical O/P, so that the yield returns to the wind conversion system machine. As a result, it is common to have an average wind speed of V such as:

V≥12-16 km/hr., For example (3.5-4.5 m/sec)

2) Average annual wind speed:

Wind velocity is a critical value when dealing with wind energy. Wind power through a specific x-section area for a constant wind velocity can be expressed as:

$P_w = KV^3$ (K=Constant)

From the previous equations it is obvious that the cubic relation is dependent on wind velocity which affects the wind power output value. For example, doubling the velocity increases wind power with an 8 factor.

3) Height of the planned location:

Air density is affected by the height of site. As a result, wind power,machine conversion system and electric power are affected. When the location height increases, the wind velocity increases.

4) Ground quality:

Wind energy conversion systems should be secured in addition to having a stable ground surface.

5) Distance between site and local users:

A visible standard can minimize the length of transmission line, resulting in decreasing the cost.

6) Structure of wind at a specific site:

Near the ground, wind is turbulent and disturbed, so the direction of velocity varies rapidly. This caused by the symmetric flow that is collected and defined as the wind structure.

2.3 Solidity Effect

Solidity which represents the state or quality of being strong in structure, affects the Giromill VAWT rotor. The rotor has to achieve an initial velocity ratio between 3-3.3 value before producing a power output as shown in Fig 2.5 below. For this reason, the rotor has to start by an external force and initial velocity ratio. Moreover, Fig 2.5 shows that the maximum power coefficient which is 0.59 and velocity ratio are the functions of solidity ratio.

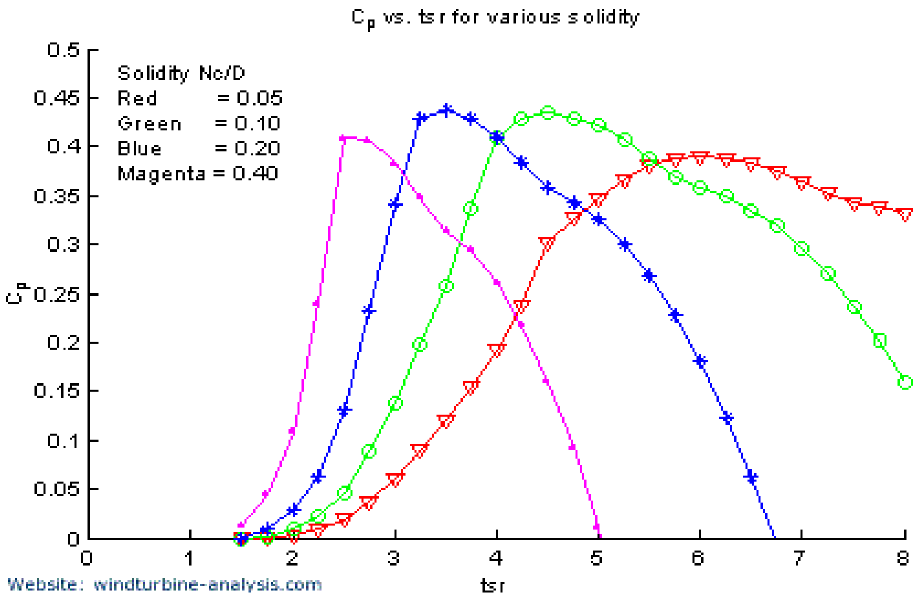


Figure 2. 5 : Effect of Solidity Ratio on the rotor performance [18]

2.4 Tip-speed ratio:

It is the speed ratio of the rotating blade to the wind speed. There will be an angle of attack that produces the highest lift to drag ratio. As the angle of attack depends on wind speed, there will be an ideal tip speed ratio.

2.5 Aerodynamics of VAWT:

Vertical axis wind turbine has many common aspects that is different from the horizontal axis model. VAWT blades has a spinning surface which its plane lies at the right angle of wind direction. Angle of attack of the blades changes continually while it rotates. Furthermore, the blade moves down the wind side of the other blade, in a degree of 180 to 360 of a rotational angle, causing the wind speed to reduce due to extraction of energy by the upper wind blade. For this reason, power produced is smaller at the lower wind section of rotation. According to the flow velocity considerations and the aerodynamics forces, its shown that the produced torque occurs after its affected by lift forces. By comparing the two forces components it shows that the drag force is lower than the lift force.

Rotor blade produces a positive torque in addition to some points that have a negative torque. Change of the total torque represent the decreasing in positive torque on the lower side of wind. Moreover, balancing the torque with revolution variation can be achieved by using three rotor blades, so that the change increases and decreases with a positive torque. In the other hand, torque can be used with a vertical axis rotor in case of having a peripheral speed ,knowing that the vertical axis is not self-starting. By flow conditions analysis for the vertical axis rotor, it shown that the calculations might be more complex than the fan type. In other words, the physical and mathematical calculations of the power generation is also more advanced [7].

2.5.1 Wind Power:

Calculating the wind power of the blades is an important point using Eqn 2.1

$$P = GAV^3 \quad \textbf{(2.1)}$$

Where, P= Wind power (watts)

G=Air density **(** Kg/m^3 **)**

A=Area perpendicular to the wind direction (m^2)

V= Wind speed (m/s)

For calculating the power input of the shaft Eqn 2.2 can be used:

$$\text{Pin}= \frac{1}{2} GAV^3 C_p \quad \textbf{(2.2)}$$

The term Cp represents the power coefficient which depends on the machine type and relation between the wind speed and circumferential speed of blades [8]. In order to calculate the wind speed Eqn 2.3 used:

$$V = V_o \left(\frac{h}{h_0} \right)^n \quad \textbf{(2.3)}$$

Where, V= Wind speed at a specific height (m/s)

V_0 = Given wind speed at height h=0 (m/s)

h= Height at which the wind speed is calculated (m)

h_0 = The initial height (m)

n= A value that depends on the ground roughness

Roughness due to ground nature:

- Smooth such as snow, sand: 0.10 -0.13

- Moderate: 0.13-0.20

- Rough: 0.20-0.27

- Very rough: 0.27-0.40

2.5.2 Power Coefficient:

Wind turbine rotor power output varies with every round. Due to this, the rotor performance will be expressed by the power coefficient divided by the tip to wind speed ratio. As a result, for a Darrieus wind turbine Eqn 2.4 calculates the power coefficient: $C_p = \frac{P}{\frac{1}{2}\rho U^2 A}$ **..(2.4)**

Where, P = Power of rotor

Moreover, the tip to wind speed ratio TSR is calculated by Eqn 2.5:

$$\lambda = \frac{wR}{U} \qquad \textbf{(2.5)}$$

Where, R = Maximum radius of the rotor

w = Rotor rpm

Torque coefficient is defined by the Eqn 2.6:

$$C_t = \frac{T}{\frac{1}{2}\rho U^2 A} \qquad \textbf{(2.6)}$$

Where,

T= Rotor torque

These two coefficients have a relation by the Eqn 2.7 as:

$$C_t = \frac{c_p}{\lambda} \quad \textbf{..(2.7)}$$

2.5.3 Betz's Law:

For finding the maximum power produced by wind, Bets law is used, knowing that it does not depend on the design of the wind turbine in an open flow. The law which has been founded by the physicist Albert Betz in in Germany, is differentiated from the mass-momentum conversion principle of air that flowing through the blade that produced by the wind. Maximum power produced by wind is calculated using Eqn 2.8:

$$\frac{P}{P_0} = \frac{1}{2}(1-(\frac{v_2}{v_1})^2(1+(\frac{v_2}{v_1})) \quad \textbf{.................................(2.8)}$$

Where,

P = Power extracted by wind

P_0 = Power under undisturbed wind flow

CHAPTER 3

DESIGN OF GIROMILL VERTICAL AXIS WIND TURBINE

3.1 Introduction

The figure.3.1 below shows the components and dimensions of Giromill vertical wind turbine:

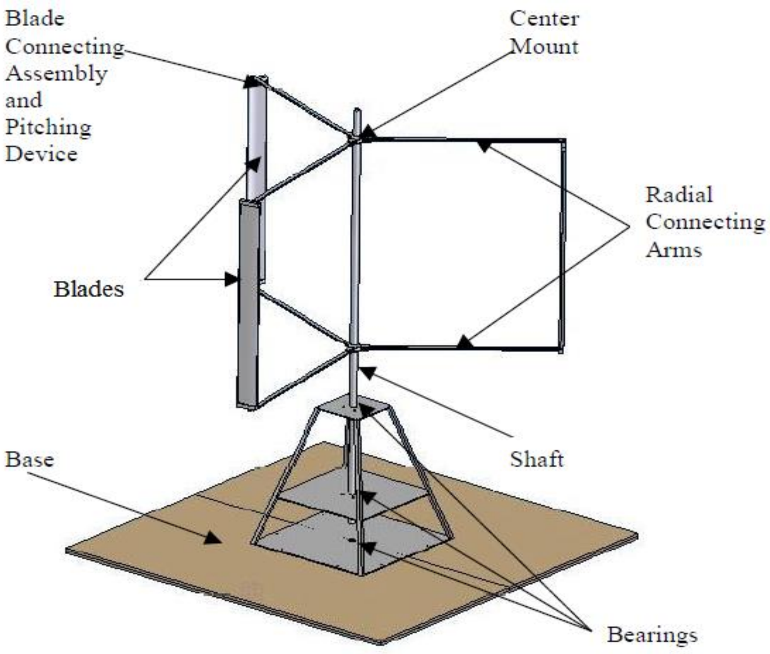


Figure 3. 1 : SolidWorks Sketch of Setup

Giromill wind turbine have the following components:

1. Airfoil

2. Radial arms

3. Shaft

4. Bearings

5. Screws

6. Support

7.Generator

3.2 Materials Used for Giromill VAWT

Many materials are used in manufacturing of wind turbines. These materials varies depending on the size of the wind turbine. Moreover, materials are provided by the marketing that estimated due to manufacturing and type of wind turbine. Generally, materials used in wind turbines manufacturing are Steel, Copper, Wood, Plastic and Aluminum.

3.3 Materials Properties

- Hooke's Law:

Stress is proportional to strain considering an elastic limit as shown is Eqn.3.1:

$$\sigma = E\varepsilon \quad \textbf{(3.1)}$$

Where, E= Young Modulus (GPa)

σ = Stress (MPa)

ε = Strain

- Young's Modulus:

The rate of stress due to strain. The unit is N/mm^2

- Yield Stress:

The material keeps deforming at this value of stress at a constant force of load. For example, it is 250Mpa for steel.

- Ultimate Stress:

Represents the maximum value of stress stimulated on the material. It takes place in the plastic range. For example, it is 40Mpa for wood.

- Hardness:

It is defined as the resistance ability to abrasion and penetration. It occurs due to a stress that leads to a failure at a specific point.

- Toughness:

Material ability to absorb energy at the plastic range. When toughness is expressed per volume it is called modulus of toughness.

- Fracture Stress:

When the cross sectional area decreases, the bearing of load over the material decreases respectively. This process continues until the sectional area becomes too small so it cannot bear the load so it breaks. Fracture stress is the stress at which the specimen breaks. Usually it is lower than the ultimate stress for a ductile material.

- Poisson's ratio:

The lateral strain divided by the longitudinal strain. For Copper it is 0.33

3.4 Airfoil of Giromill VAWT

The type of airfoils that have been studied for our Giromill wind turbine design is a 4 digit NACA wing sector. In this kind of NACA airfoil (The NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics),the shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties.The initial number represents the larger hunch of tension. The second number represents the distance of largest tension caused by the airfoil resulted by edge in 10 % of the tension. Last two numbers represent the maximum thickness of the airfoil as percent of the tension.

In particular, the NACA airfoil which have been studied in the project is a uniform four numbers NACAs airfoil. The main property of these airfoils is that it starts with two 0 numbers. The equation of NACA shape of 00xx model which replaces the xx by a thickness percentage to tension is expressed by Eqn3.2:

$$\boldsymbol{y = \frac{t}{0.2}c\left[0.2969\sqrt{\frac{x}{c}} - 0.1260\left(\frac{x}{c}\right) - 0.3516\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 + 0.1015\left(\frac{x}{c}\right)^4\right]} \quad \textbf{..... (3.2)}$$

Here:

c: Chord length

x: Position through the chord from 0 to c

y: Half of the thickness at a given position (centerline to surface)

t: Maximum thickness

The above equation is vital to draw the airfoils using a software like Gambit by the coordinates created by one sequence of points.

For analyzing these NACA airfoils in a 2D uniform form:

The main three NACA airfoils that have been chosen are: NACA 0012, NACA0015 and NACA 0020, because these airfoils gave many good results according to the past studies about the Giromill VAWT.

If we use NACA 0015 for this project, we have the following coordinates:

Table 3. 1 : Coordinates of NACA 0015 airfoil

X	Y(UPPER)	Y(LOWER)
1	0.00221	0.00221
0.95	0.01412	0.01412
0.9	0.02534	0.02534
0.8	0.04591	0.04591
0.7	0.06412	0.06412
0.6	0.07986	0.07986
0.5	0.09265	0.09265
0.4	0.10156	0.10156
0.3	0.10504	0.10504
0.25	0.10397	0.10397
0.2	0.1004	0.1004
0.15	0.09354	0.09354
0.1	0.08195	0.08195
0.075	0.0735	0.0735
0.05	0.06221	0.06221
0.025	0.04576	0.04576
0.0125	0.03315	0.03315
0	0	0

The Fig 3.2 shows the excel sketching of the NACA 0015 airfoil:

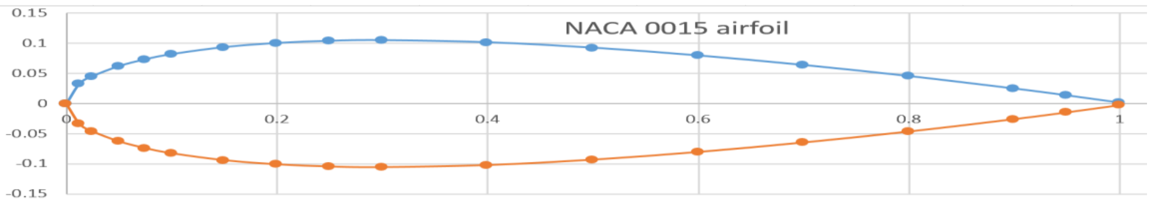


Figure 3. 2 : Excel sketching of the NACA 0015 airfoil

The airfoil has a hole at top and bottom surface to connect with the radial arms. This can be clearly seen in the Fig 3.3 which is generated using the solidWorks software. The place of the drill is determined as 40% of chord from the front end based on the previous studies of the Giromill wind turbine.

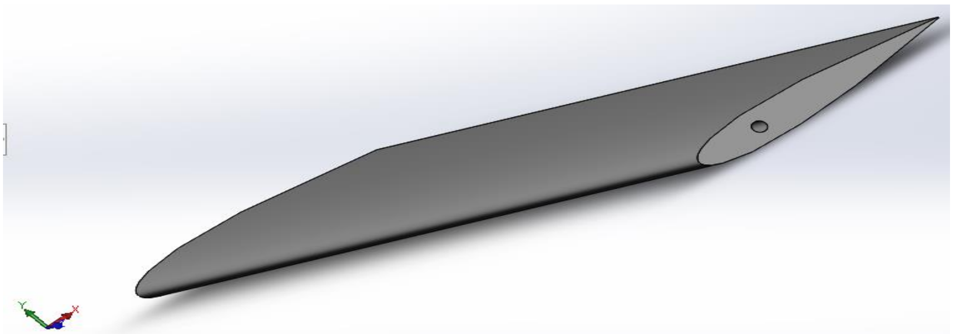


Figure 3. 3 : 3D model of the blade

3.5 Radial Arms

The distance between center shaft and the air foil is called radial arm. Specific systems are needed to be installed for easy assembling and dismantling of airfoil and shaft. The material used for fabrication of radial arms is aluminum because of its light weight and high strength.

To fasten the airfoil with the arms, 6mm screws are used . There are two types of radial arms that are designed one for the top and another for the bottom which goes through the shaft.

For our design we have assumed a 50 cm length for each arm by approximating the length to the size of the rotor and blades weight.Later, we have adjusted the length to get better wind effect over the blades area and less deformation of the arms.This deformation occurs due to arms bending in case of great force over the structure of the rotor.

In the following table dimensions of top radial arm:

Table 3. 2 : Dimensions of top radial arm

SNO.	DESCRIPTION	DIMENSION
1	Arms number	3
2	Arm length	50 cm
4	Centre drill diameter	2.5cm
5	Side holes' diameter	0.6cm
6	Position from the outer end to the center	1.5cm
7	Arm width	4cm
8	Thickness	2cm

Fig 3.4 shows the 3D model for top radial arm which is generated by using the solidWorks software:

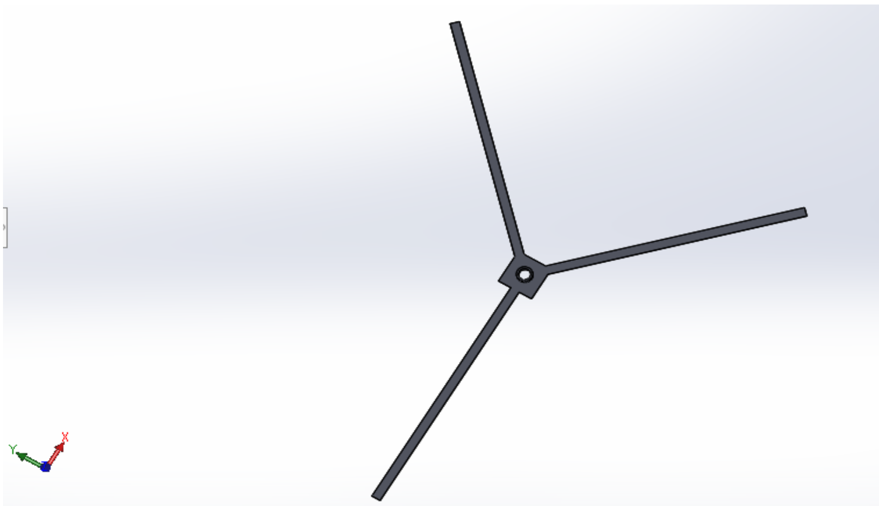


Figure 3. 4 : Top radial arm

The top and bottom radial arms has the same design and dimensions while the center hole is 16mm .

The following table shows the dimensions of bottom radial arm

Table 3. 3 : Dimensions of bottom radial arm

NO.	DESCRIPTION	DIMENSION
1	Arms number	3
2	Arm length	50 cm
4	Centre drill diameter	2.5cm
5	Side holes' diameter	0.6cm
6	Position from the outer end to the center	1.5cm
7	Arm width	4cm
8	Thickness	2cm

Fig. 3.5 shows the 3D model for bottom radial arms which is generated by the solidWorks software:

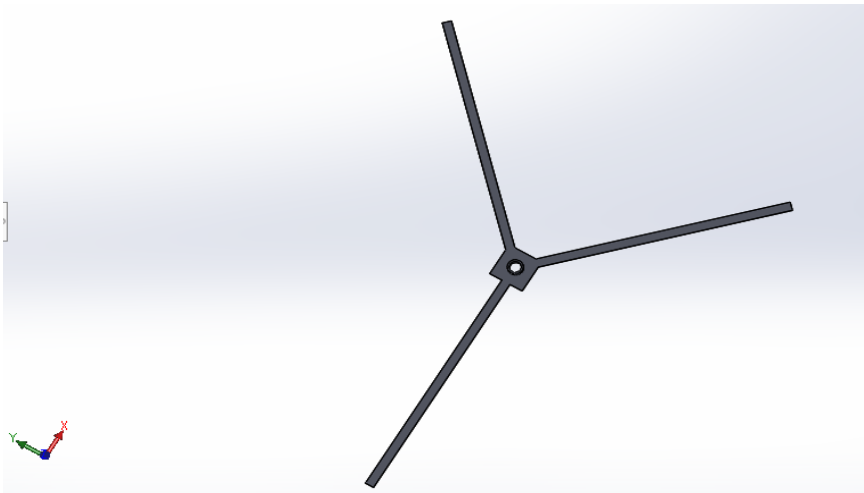


Figure 3. 5 : Bottom radial arm

3.6 Shaft

Shaft is a rotating machine element which is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque set up within the shaft permits the power to be transferred to various machines linked up to the shaft. In order to transfer the power from one shaft to another, the various members such as pulleys, gears etc. are mounted on it. These members along with the forces exerted upon them causes the shaft to rotate.In other words,the shaft is used for the transmission of torque and bending moment. The various members are mounted on the shaft by means of key or spines.

The shaft is usually cylindrical, but may be square or cross- shaped in section. They are solid in cross -section but sometimes hollow shaft is also used. An axle, though similar in shape to the shaft, is a stationary machine element and is used for the transmission of bending moment only. It simply acts as a support for some rotating body such as hoisting drum in a car wheel or a rope. A spindle is a short shaft that impacts motion.

3.6.1 Materials used for shaft

The materials that are used for shafts should have the following properties:

1. It should have high strength.

2. It should have good machinability.

3. It should have low notch sensitivity factor.

4. It should have good heat treatment properties.

5. It should have high wear resistant properties.

Based on the calculations, the shaft diameter is determined as 25mm.The material that has been chosen for shaft is steel due to its high strength properties that highly suits the requirements of the wind turbine.

The Table 3.4 shows the dimensions of the shaft:

Table 3. 4 : Dimensions of the shaft

NO.	DESCRIPTION	DIMENSION
1	Diameter of shaft	2.5cm
2	Length of shaft	130cm

The Fig 3.6 shows the 3D model of the shaft which is generated by the

SolidWorks software.

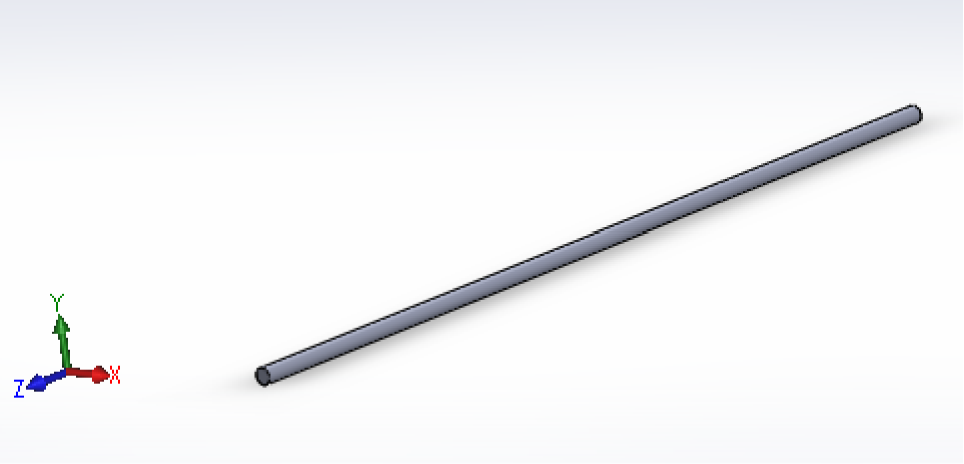


Figure 3. 6 : 3D model of the shaft

3.7 Bearings

A bearing is a device used to permit constrained relative motion between two parts, typically rotation or linear movement. In or project we will use bearing type 6005 because the diameter of the shaft is 25mm as shown in figure 3.7

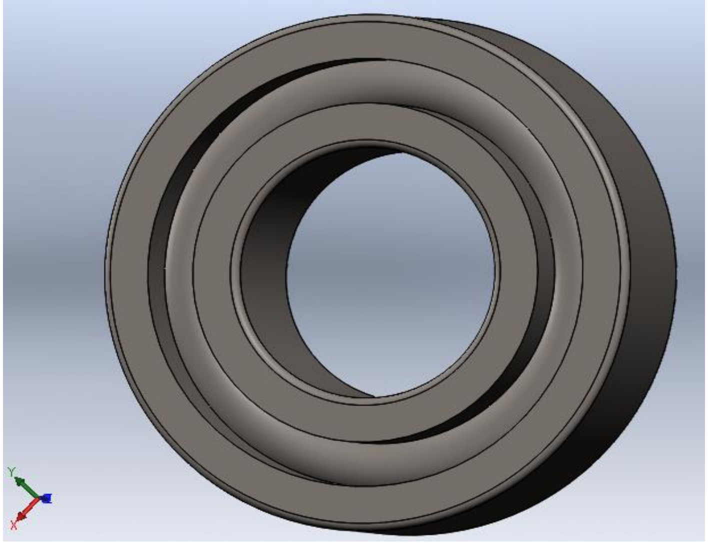


Figure 3. 7 : Bearing type 6005

3.8 Screws

A screw, or bolt are types of fasteners that characterized by a helical ridge, defined as an external thread or thread-wrapped around a cylinder. Some screw threads are designed to mate with a complementary thread, known as an internal thread.Usually it comes in the form of a nut or an object that has the internal thread formed into it. Other screw threads are designed to cut a helical groove in a softer material as the screw is inserted. The most common uses of screws are to hold objects together and to position objects.

Most often,screws have a head,however, a set screw is an example of a screw without a head which is a specially formed section on one end of the screw that allows it to be turned, or driven. Common tools for driving screws include screw drivers and wrenches. The head is usually larger than the body of the screw, which keeps the screw from being driven deeper than the length of the screw and to provide a bearing surface. There are exceptions; for instance, carriage bolts have a domed head that is not designed to be driven; set screws often have a head smaller than the outer diameter of the screw. J-bolts have a J-shaped head which is not designed to be driven, but rather is usually sunk into concrete allowing it to be used as an anchor bolt. The cylindrical portion of the screw from the underside of the head to the tip is known as the shank; it may be fully threaded or partially threaded.In our project we have used screws with the following properties

B18.6.7M - M6 x 1.0 x 40 Type I Cross Recessed PHMS --38S

Tall	40 mm
Diameter	6 mm

Figure 3. 8 : Screw M6 x 1.0 x 40 Type I Cross Recessed PHMS -38S

3.9 Support

When we change the mechanical equipment positions that should be balanced, stability and balance are important. Therefore, supports are used due to torque changing of blades while rotating. Wind turbine motion can result in a fatigue stress over the support part. Solving this issue can be done by selecting a high fatigue strength.

3.10 Pulley

We have used two pulley for torque transformation.The first pulley is attached to the rotor shaft while the second pulley is connected to the generator shaft.In order to transform the motion between these two pulleys we have used a rubber belt.

3.11 Design Calculations

3.11.1 Airfoil Calculations

As in the equation 3.2, for finding the coordinates of the airfoil the following formula must be taken into account.

$$y = \frac{t}{0.2} c \left[0.2969\sqrt{\frac{x}{c}} - 0.1260\left(\frac{x}{c}\right) - 0.3516\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 + 0.1015\left(\frac{x}{c}\right)^4\right] \quad \text{.....} \mathbf{(3.2)}$$

For NACA 0015:

Maximum thickness=15% of chord length

Where,

Chord length, c=12cm

Therefore,

Maximum thickness = 12x0.15

Maximum thickness = 1.8cm

Here the position along the chord (x) varies from 0 to 12.

The position of the chord is initiated as follows,

0.000, 0.150, 0.300, 0.600, 0.900, 1.200, 1.800, 2.400, 3.000,

3.600, 4.800, 6.000, 7.200, 8.400, 9.600, 10.800, 11.400, 12.000.

When x1=0cm then

$$y1 = \frac{t}{0.2}c\left[0.2969\sqrt{\frac{x1}{c}} - 0.1260\left(\frac{x1}{c}\right) - 0.3516\left(\frac{x1}{c}\right)^2 + 0.2843\left(\frac{x1}{c}\right)^3 + 0.1015\left(\frac{x1}{c}\right)^4\right]$$

$$y1 = \frac{t}{0.2}.12\left[0.2969\sqrt{\frac{0}{12}} - 0.1260\left(\frac{0}{12}\right) - 0.3516\left(\frac{0}{12}\right)^2 + 0.2843\left(\frac{0}{12}\right)^3 + 0.1015\left(\frac{0}{12}\right)^4\right]$$

$y1 = 0$

When x2=0.150cm,

$$y2 = \frac{t}{0.2}.12\left[0.2969\sqrt{\frac{0.15}{12}} - 0.1260\left(\frac{0.15}{12}\right) - 0.3516\left(\frac{0.15}{12}\right)^2 + 0.2843\left(\frac{0.15}{12}\right)^3 + 0.1015\left(\frac{0.15}{12}\right)^4\right]$$

$y2 = 0.01896$cm

When x3=0.300cm, then y3=0.39456cm

The calculations are done for 18 values and the results are plotted in table 3.5:

Table 3. 5 : Airfoil coordinates

X	Y(UPPER)	Y(LOWER)
12	0.01896	0.01896
11.4	0.12096	0.12096
10.8	0.2232	0.2232
9.6	0.39348	0.39348
8.4	0.5496	0.5496
7.2	0.68448	0.68448
6	0.79404	0.79404
4.8	0.87048	0.87048
3.6	0.87624	0.87624
3	0.89124	0.89124
2.4	0.86064	0.86064
1.8	0.80184	0.80184
1.2	0.69996	0.69996
0.9	0.63	0.0.63
0.6	0.53316	0.53316
0.3	0.39456	0.39456
0.15	0.28404	0.28404
0	0	0

3.11.2 Design of Shaft

Power:

is represented by Eqn 3.3

$$P=\frac{2\pi NT}{60} \qquad \textbf{(3.3)}$$

Torque:

is represented by Eqn 3.4:

$$T=W\,r \text{ .... } \mathbf{(3.4)}$$

Where,

r=60cm=600mm

W=sum of weights of airfoils

Load:

is represented by Eqn 3.5

$$W=W1+W2+W3 \text{ .... } \mathbf{(3.5)}$$

The weight of airfoils is represented by Eqn 3.6:

$$W=3W1 \text{ .... } \mathbf{(3.6)}$$

The weight of airfoil 1 W1 are equal: W1= =0.5 kg

W1=0.5x9.81=4.905 N

W =3x4.905 N=14.715 N

The weight of the radial arm is considered to be negligible

T=W r

T=14.715 x500

T =7. 3575N.m

Table 3. 6 : Model inputs

S.NO	WIND SPEEDS(m/s)	SPEED(RPM)
1	1.5	4
2	2	6
3	3	8
4	4	11
5	4.5	13
6	5	14

Taking N=30 rpm

$$P=\frac{2\pi NT}{60}=\frac{2*\pi*30*7.3575}{60}=23\text{ W}$$

P=23 W

Power:

To choose the generator we calculate the power.In our project we have used a pulley to increase the rotation of motor shaft due to:

1- power is lower

2- speed is lower

In the following table 3.7 for a VAWT 24V Generator data sheet [19].

Table 3. 7 : VAWT 12V Generator data sheet

Model	MY1016
Standard	250W 24V
No-load currency/A	≤1.6/1.2
No-load rate speed /rpm	2650
Rating Torque/N·m	0.90
Rating speed /rpm	2750
Rating currency/A	≤13.7
Efficiency/%	≥78

The following figure shows VAWT generator:

Figure 3. 9 : MY1016 350W 24V DC generator [20]

Table 3. 8 : Pugh Matrix of Generator Selection

Key criteria	Permanent magnet motor	Generator	Brushless motor	Liner magnet
Safety	Good	Moderate	Moderate	Moderate
Cost	Good	Poor	Moderate	Moderate
Durability	Moderate	Moderate	Good	Poor
Efficiency	Good	Moderate	Good	Poor
Easy to assemble	Good	Poor	Good	Moderate
Reliability	Moderate	Poor	Good	Poor
Sum of Positives	4	0	4	0
Sum of Negatives	0	3	0	3
Sum of 0	0	0	0	0
TOTALS	4	-3	4	-3
Continue?	Yes	No	Yes	No

Shaft:

Shear stress acting on the shaft :

$$T=7.3575$$

$$T=\frac{\pi}{16}\tau d^3 \quad \text{.....................................} \ \textbf{(3.7)}$$

$$7.3575=\frac{\pi}{16}\tau * 0.025^3 \quad \rightarrow \quad \tau = 2.399x10^6(\text{N}/m^2)$$

Compressive stress acts on the shaft is represented by Eqn 3.8

$$\sigma_c=\frac{P_c}{A}= \text{...} \ \textbf{(3.8)}$$

P_c= (weight of 3 airfoils + weight of 3 radial arms) **... (3.9)**

P_c= (14.715+1.8)x9.81=32.373 N

Cross-sectional area of shaft $A=\frac{\pi}{4}d^2 = \frac{\pi}{4} * 0.025^2 = 4.9x10^{-4}(m^2)$

$\sigma_c=\frac{P_c}{A} = \frac{32.373}{4.9x10^{-4}}$ =0.0659x10^6 (**N/m^2**)

Here the design stresses of steel are:

Tensile yield strength=247x10^6 (N/m^2)

Shear yield strength is represented by Eqn 3.10

Shear yield strength= $\frac{\text{Tensile yield strength}}{2}$**……………. (3.10)**

$= \frac{247x10^6}{2}$=123.5x10^6 (N/m^2)

Design shear stress is represented by Eqn 3.11:

Design shear stress, $[\boldsymbol{\tau}] = \frac{\boldsymbol{shear\ yield\ strength}}{\boldsymbol{factor\ of\ safety}}$ **….……. (3.11)**

Assuming → factor of safety =4

Design shear stress, $[\boldsymbol{\tau}] = \frac{123.5x10^6}{\mathbf{4}}$=30.875x$10^6$ (N/m^2)

On comparing

30.875x10^6 (N/m^2)>2.399$x10^6$ (N/m^2) → design is safe

3.11.3 Tip speed ratio vs Power coefficient

TSR= w*R/V **………………(3.12)**

Where,

w= angular velocity (rad/s)

R= rotor radius (mm)

V= wind velocity (m/s)

w=2pi*rpm **……….….……(3.13)**

Where,

pi=3.14

rpm= radius per minute

Cp Calculations:

Cp= Protor / Pwind **……………………..……..(3.14)**

P= 0.5*Density of air*Area*v^3**……….(3.15)**

When v=8 m/s:

P1= 0.5(1.225 kg/m^3) (0.98m^2) (8^3)

=307.328 watts

Cp1= 12/307.328 = 0.039

When v=7 m/s:

P2= 0.5(1.225 kg/m^3) (0.98m^2) (7^3)

=205.88 watts

Cp2= 11/205.88 = 0.0534

When v=6 m/s:

P3= 0.5(1.225 kg/m^3) (0.98m^2) (6^3)

=129.654 watts

Cp3= 10/129.654 = 0.077

3.11.4 Radial Arms Calculations

The arms have the bending load.The figure below shows the Bending load on radial arms.

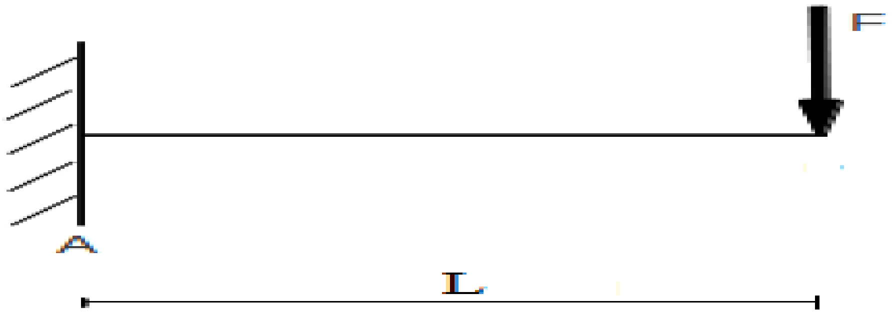


Figure 3. 10 : Bending load on radial arms

Here:

L = 0.5m (arm length is supposed)

F = 0.5kgx9.81 = 4.905N

E = 70 x$*$ 10^9 N/m2

Deflection of beam at the end Eqn 3.16

$$y_{end} = \frac{wL^2}{3\,E\,I} \quad \text{……….………………. (3.16)}$$

Here:

W: Airfoil weight (N)

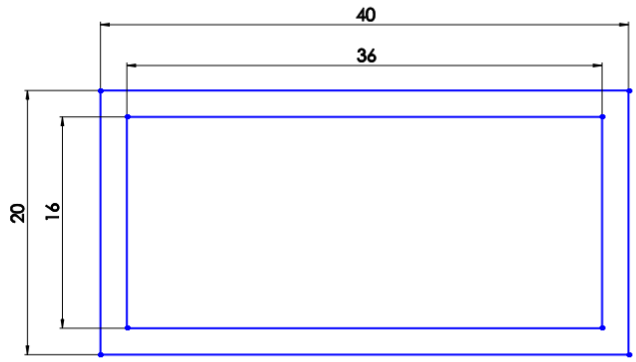
E: Young’s modulus in (N/m2)

I: Moment of inertia (Kg.m2)

Where:

$$E = 70 \text{ x } * 10^9 \text{ N/m2}$$

Moment of inertia is represented by Eqn 3.17



$$I = \frac{bd^3 - hk^3}{12} \quad \textbf{.. (3.17)}$$

Where,

$I = \frac{40x20^3 - 36x16^3}{12}$ =14378.667mm^4= 1.437x10^{-8} m^4

$y_{end} = \frac{wL^2}{3\,E\,I} = \frac{4.905*0.5^2}{3*70 \text{ x } *10^9*1.437\text{x}10^{-8}}$ = $4.06x10^{-4}$ m

3.11.5 Design of Bearings

FR = [Airfoils weight + three radial arms and shaft] x 9.81**............................ (3.18)**

FR = [(0.5 x 3) + (0.6x 3) + (1.091 /2)] x 9.81

FR = 51.919 N

Axial load, Fa = [(0.5 x 3) x 3 + (1.091 /2)]x9.81=49.49N

$\frac{Fa}{Fr} = \frac{49.49}{51.919}$=0.95

For, Inner diameter of the shaft, d = 25 mm

Dynamic capacity, Co = 8.8KN=8800N

At, Bearing number, = 6005-2RS

$\frac{F_a}{\text{Co}} = \frac{49.49}{8800}$=0.005

Corresponding to $\frac{Fa}{Fr}$=0.97 and $\frac{F_a}{\text{Co}}$=0.005

Radial factor, X = 0.56

Thrust factor, Y = 2.30

Service factor, S = 1.2

Equivalent represented by Eqn 3.19

$$P=[X * F_r + Y * F_a]*S \quad \textbf{(3.19)}$$

$$P=[(0.56 * 51.919\ ) + (2.30 * 49.49\ )]*1.2$$

$$P=142.9N$$

Static capacity represented by Eqn 3.20

$$C=(\frac{L}{L_{10}})^{1/k}*p \quad \textbf{(3.20)}$$

K = 3 (for ball bearings)

L_{10} = 1 x 10^6 rev

Life in hours, L_H = 24 hours in 3 years

L_H = 3 x 365 x 24

L_H = 26280 hrs

Life in revolutions, represented by Eqn3.21

$$L = 60NL_H \quad \textbf{(3.21)}$$

L = 60 x 30 x 26280

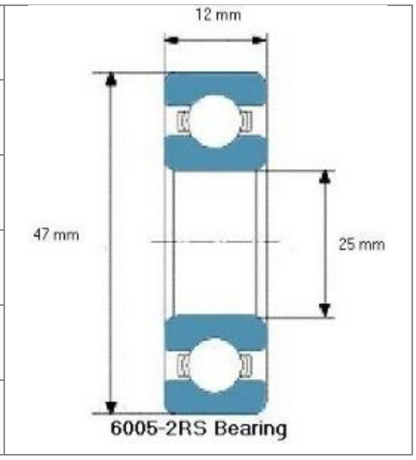
L = 47.304 x 10^6 rev

$C=(\frac{47.304 \text{ x } 10^6}{1*10^6})^{1/3}*142.9=516.8N=51.68kgf$

In the following table 3.10 Properties of bearing for 25mm of shaft diameter:

Table 3. 9 : Properties of 25 mm shaft diameter bearing

Number of bearing	**6005**
Inner diameter	d = 25mm
Outer diameter	D = 47mm
Bearing width	B = 12mm
Static loading	P = 598kgf
Dynamic loading	C = 1025kgf



Where:

$([C]) > C$ 1025kgf > 51.68kgf

Therefore, the design of bearing is safe. All the mentioned value were taken from a design data book for VAWT [16].

3.12 Manufacturing

3.12.1 Purchasing the materials

Radial arms and airfoils manufacturing process has started by purchasing steel, wood and cork.Cork has been used for making the blade harder to bent and has less deformation due to wind effect.

3.12.2 Manufacturing of airfoils and radial arms

After choosing the design concept and application of the theories in the previous topics, we still had to perform the deign practically.

3.12.3 Airfoils manufacturing

We have used steel plates,wood and cork . For pressing the two sheets of the blade we have used clamps . Later the sheets should be tested to ensure that the sheets are linked. Then, we cut the sheets to a specific length that we need. We used pattern machine to bond the sheets, then by hand we ensure that it is stable. Finally, we used glass paper for surface finishing to remove excess material and getting more accurate profile.

3.12.4 Radial arms installing

Firstly, we have drawn the radial arms using solidWorks software, specifying the dimensions. We used cutting machine to cut the radial arms from an aluminum sheet.

3.12.5 Drilling process

After the cutting and bonding processes, we use drilling machine to drill a specific number of holes in the frame of the radial arms. These holes are drilled according to the position of the radial arms and the diameter of the threads used following the standards. Each airfoil will be attached to an arm by a thread and nut.

3.12.6 Shaft purchasing

In our design, we decided to purchase a standardize shaft that is made of steel. Due to the fact that the shaft is going to be thin, drilling a hole in it requires a high level of accuracy. As a result, we preferred getting the shaft from a hardware store or buying it from an online supplier which is better than manufacturing it at the workshop.

3.12.7 Materials selection considerations:

When choosing the materials to be used for our design some important properties can be plotted and shown as a diagram to illustrate the action of materials toward some common mechanical properties.

1) Density of materials and Young's Modulus:

When we choose the materials for our turbine parts some parts require a low density material such as the blades which manufactured from wood. Also aluminum is used for covering the blades which is considered as a light metal compared with other high strength materials. As shown in Ashby Diagram in Figure 3.2 different materials varies in density values. Therefore, it has a different strength.

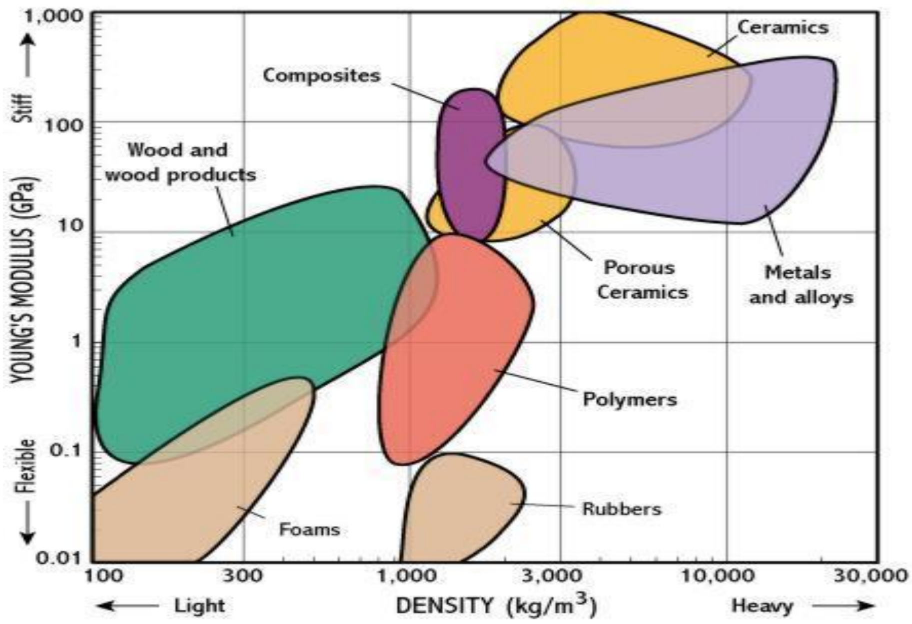


Figure 3. 10 : Density of different materials and its corresponding young's modulus [21]

2) Cost of materials and Young's Modulus:

As we have determined our design cost limitations, we have tried to choose low cost materials for some parts as it can be changed and modified later in our testing procedure. For example, choosing wood for blades design and steel for shaft. Ashby diagram in figure 3.3 shows the low cost materials at the upper left side. These materials include ceramics and metals.

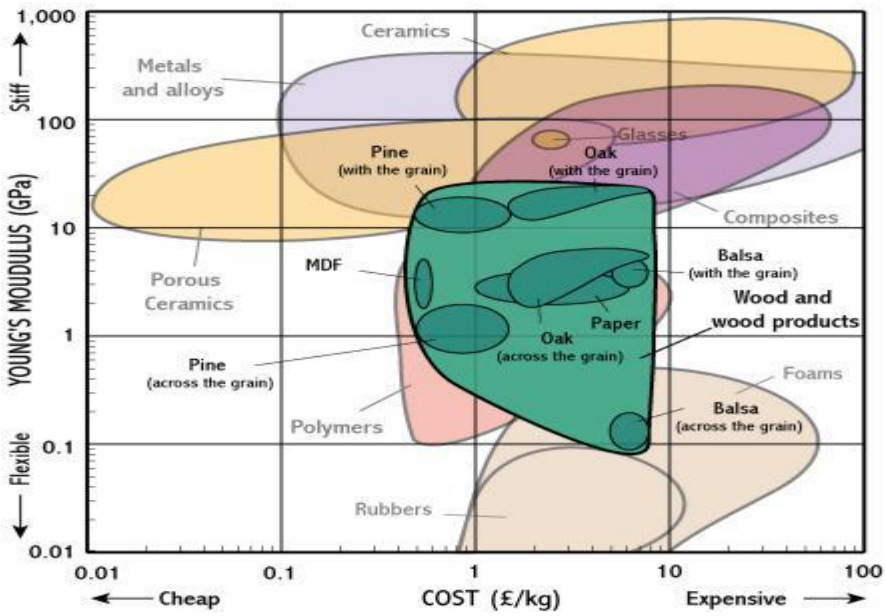


Figure 3. 11 : Cost of different materials and its corresponding young's modulus [21]

3) Strength-Density Diagram :

Strength is an important property to consider in materials selection. It's used to measure how the material can resist against failure when a load is applied. In figure 3.4 the chart shows us how do materials act under tension. This chart can be used to determine the appropriate materials for a high strength and low density at the same time as shown in the left of the top. Therefore, a high strength material with low density can be a good choice for our selection.

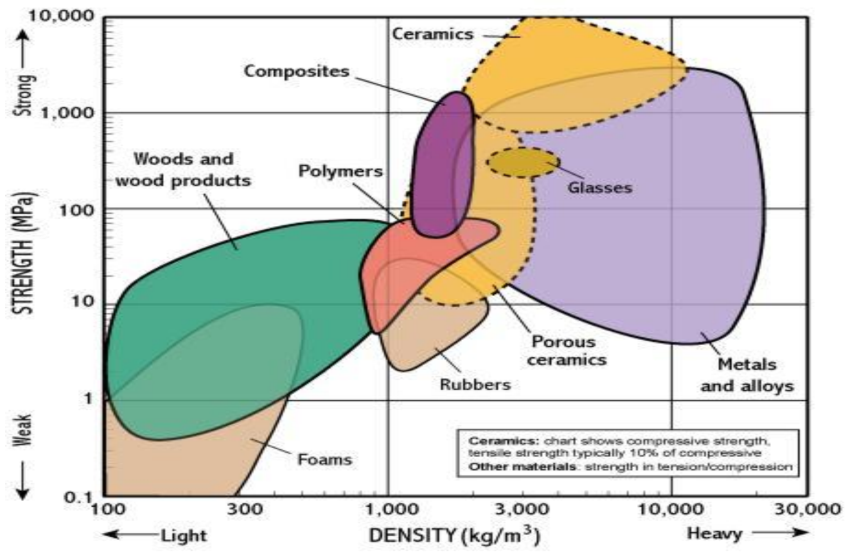


Figure 3. 12 : Strength of materials with respect to its densities under tension [21]

4) Strength-Cost Ashby chart:

Some materials can be a preferred choice for our selection. These materials have a high strength and low cost such as composites and ceramics that lie at the upper left of the chart.

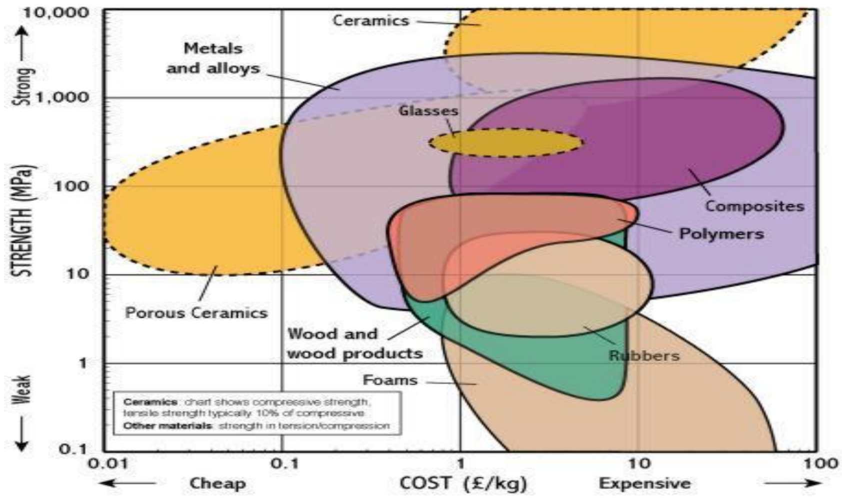


Figure 3. 13 : Cost of materials and its mechanical strength [21]

3.12.8 Manufacturing Process Classifications

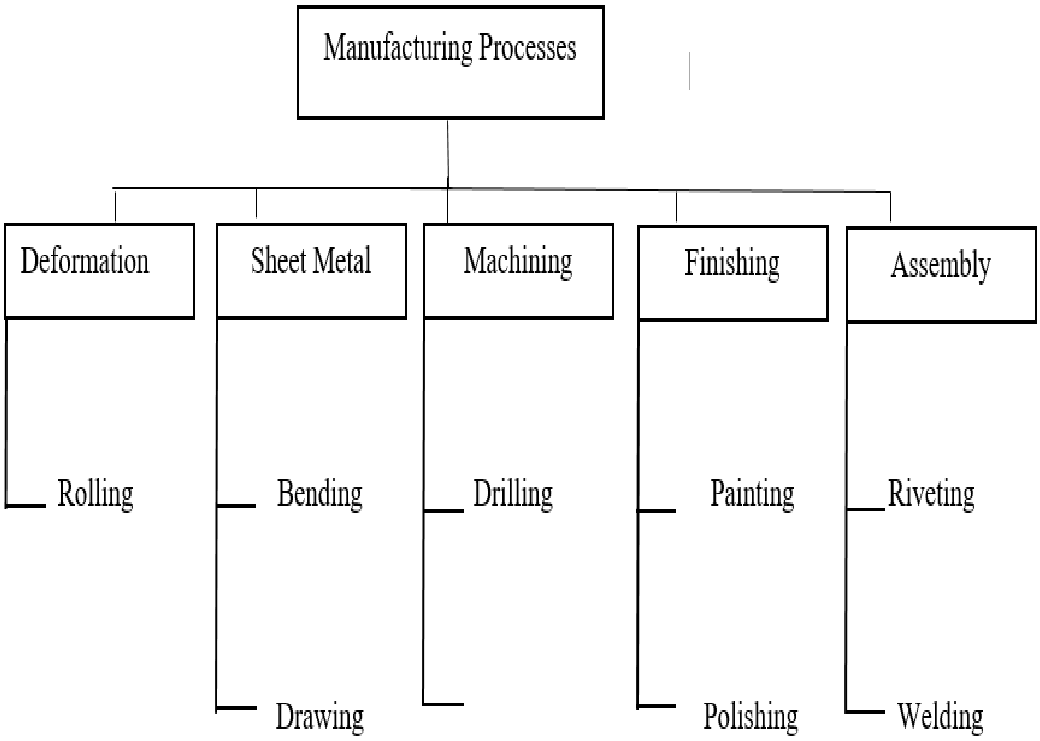


Figure 3. 14 : Manufacturing classifications

Deformation:

Rolling: Changing shaft diameter of the lower part

Sheet metal:

Bending: Bending of blades sheets.

Machining:

Drawing: Drawing the arms dimensions and airfoil coordinates on the material.

Drilling: Drilling holes for screws and threaded bolts installing.

Finishing:

Painting: After manufacturing the base we have painted it with a steel paint

Polishing: Cleaning the blades plates surface with a polishing substance.

Assembly:

Riveting: Installing the arms and blades by fixing them with each other using screws.

Welding: Welding steel blocks using welding electrodes for the base.

3.13 Cost analysis

In terms of costs, the percentage on the total cost of the different components is divided as shown in the table3.11 below:

Table 3. 10 : Wind turbine cost analysis (% of total)

Components	Cost
Tower (Base)	26% =158$
Rotor blades	22%= 134$
Other materials	14%= 85$
Gearbox	6% =35$
Assembly	8%=48$
Arms	8%= 48$
Generator	16% =97$

3.14 Bill of materials

Table 3. 11 : Bill of materials

Part	**Material**	**Quantity**	**Weight**	**Cost**	**Supplier**
Shaft	steel	1	1.091 kg	20$	hardware store
Blade	Steel+wood+cork	3	1.5	120$	manufacturing
Bicycle dynamo generator		1	0.241kg	16$	hardware store
Arms	Aluminum	2	1.8kg	48$	manufacturing
Base	Iron	1	21.500kg	158$	manufacturing
Silicon		2	-	10$	Hardware store
Welding electrodes	NIL	10	0.359kg	10 $	Hardware store
machine screws	Stainless steel	30	0.472 kg	15$	Hardware store
Pulley	Aluminum	2	0.300kg	35 $	Hardware store
Bearing	chrome steel	2	0.270kg	20 $	Hardware store
Other cost				200$	
Total				608$	

CHAPTER 4

MANUFACTURING AND TESTING

4.1 Assembly details

After manufacturing each part of the wind turbine structure separately we reach the assembly process at which we attach all the parts together using our knowledge about the wind turbine mechanism, and the important considerations of wind power and design objectives.

4.2 Assembly Procedure

Firstly, we have considered our base as the starting point of our assembly.We have installed the shaft of the turbine rotor into the base and make sure that the shaft is stable. For the purpose of preventing friction between the shaft and the base we have installed two steel bearings for the upper and lower structure of the shaft. Also these bearing will improve the efficiency of the rotor rotation.As shown in figure 4.1,the first step of base constructing using welding machine.Later the base is to be completely constructed with a pyramid shape to resist the structure load for more stability as shown in figure 4.2 and 4.3 .

Figure 4. 1 : Base-shaft installing

Figure 4. 2 Base blocks welding

Figure 4. 3 : Final shape of base

Secondly, we have installed a rounded pulley which is a roller trolley of a washing machine. This trolley acts as a pulley which transform the rotation of the shaft to the gear of the generator by a belt connected between both of the gear and pulley as shown in figure 4.4. The diameter of this pulley can affect the round per minute rate of the wind turbine. That means when we have bigger ratio between both the pulleys, the rounds per minute will increase.

Figure 4. 4 : Shaft-pulley connection

Secondly, we installed the radial arms by fixing it on the shaft using an appropriate steel supporter to handle the arms and separate it from the upper bearings. With the assistance of threaded bolts, those supporters are fixing each radial arm from both sides to keep it stable and fixed to the shaft as shown in figure 4.5 and 4.6.

Figure 4. 5 : Arms final shape after manufacturing

Figure 4. 6 : Radial arms fixing with supporters

Figure 4. 7 : Radial arm fixed to the shaft

Fourthly, we get to the airfoils installation step. Following to the previous steps of installing the shaft and the radial arms, we fixed the three airfoils between the radial arms using small screws and nut bolt washers. The placing of the airfoils depends on the angle of attack at which the wind affects the airfoil and get the maximum wind power over the section area of the airfoil as shown in figure 4.7.

Finally, we had to supply the wind turbine structure with a dc generator that is connected to a gear that is attached to a bigger diameter as shown in figure 4.8. The aim of this generator is to convert the rotation of the wind turbine to a power that is transferred from the dc source to a voltmeter which tests our device current that gives us a specific amount of power.

Figure 4. 8 : Final assembly of the Giromill wind turbine

4.3 Testing of Results

For determining the effectiveness of the system that we have manufactured, we had to perform some tests. Moreover, we measured the power output of the blades as shown in table 4.1 .According to the figure below,it shows that the values obtained from test is different than the expected result.This error is due to the heavy structure of the wind turbine we have manufactured.

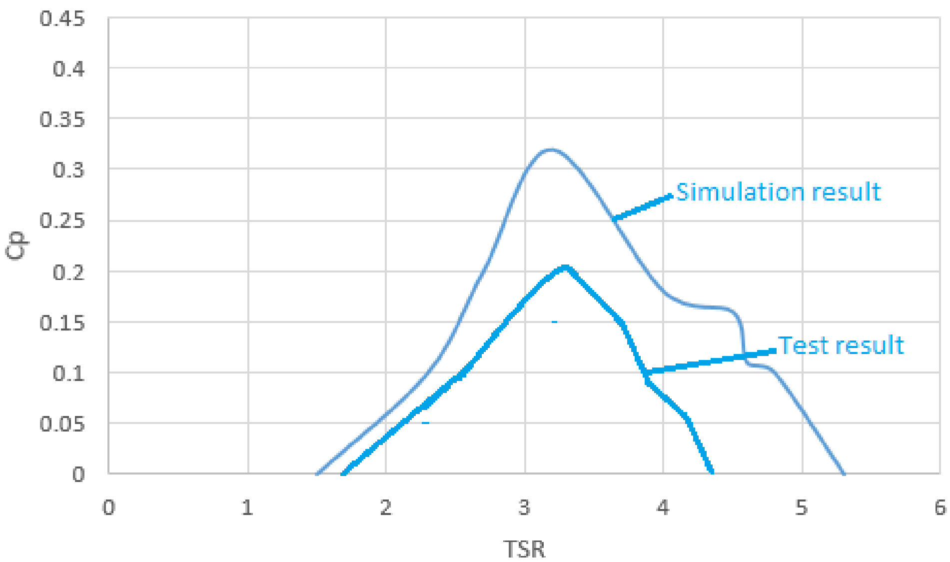


Figure 4.9 : Power of coefficient vs Tip speed ratio

4.3.1 Turbine testing

For determining how efficient is the turbine, we have used an adjustable angle for changing the blades angle. We changed the positioned angle of the blades different times to get the best angle that has the greater wind effect on the blades. After that we calculated the output power at that angle and the revolutions per minute. These results will be compared to show the effect of angle of attack over the rotor speed.

4.3.2 Turbine Data

We took the turbine data at different times. As a result of low wind speeds the output of our design has reached a maximum of 12V power generating. This value of voltage varies according to wind speed. However, the varying results had an error which occurs due to inaccurate reading of the measurement devices used in the testing procedure.

Figure 4. 10 : Devices used in testing

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Maximum rotational speed

The rotor speed should be calculated when we have the highest wind speed. In order to get an ideal result of our rotor speed we should take the data of 2 hours. The results are varying from 2 m/s up to 7 m/s wind speed.

5.2 Load Testing

Some loads measurements should be calculated in order to determine the effect of wind speed over the turbine blades as force acting on the blades area. These calculations include the loads of the structure parts, wind speed effect over the blades and bending moments.

5.3 Mechanical Braking

A braking system is usually placed on a high speed shaft between the generator and the gearbox, however these brakes can be used for low speed shafts when it is installed between the turbine and gearbox. Some designs use a disk brake for stopping the turbine when it is under a high speed. Also this brake can hold the structure of the wind turbine for maintenance purposes as it locks the system. However, our design is a low speed system and does not require a braking system under the current conditions. In order to get benefited from this system, improving our design concept and variables can increase the power output and be a more efficient wind turbine.

5.4 Difficulties and Constraints

5.4.1 Blades Design

We have faced some difficulties in designing the NACA0015 blades due to lack of materials available in the store. After a long search for materials we decided to choose the available materials which are wood, steel and aluminum. However, the blades could be more efficient if it was provided with some missed materials.

5.4.2 Wind turbine Placing

As a result of manufacturing the design in an island, we had to deal with a low average wind speed at most of the time cause the area surrounding is at sea level and there is no high regions such as mountains or peaks. Although wind speed can be measured at its maximum value during the afternoon however, it is difficult to measure a data for a long period.

5.4.3 Power Generating

Due to lack of resources, we had to choose steel and iron as an alternative for titanium and copper which are lighter materials and can be used for wind turbines.As we couldn't purchase a generator that suits our small wind turbine design, we had to choose a scooter motor generator with a dc which makes our design more challenging and require more torque to start up.This solution gives us less power generation but can be a solution for our case and a proof of concept for the wind power at the same time.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

CONCLUSION

In this project we have done many calculations a searches about the wind turbine before choosing the design concept. As a result of looking deeply about the mechanism of wind turbines, we have gain a lot of knowledge about the wind energy. This knowledge will help us in performing the practical part of the design, knowing the materials properties which we are dealing with, and how to assemble the parts of the wind turbine. Moreover, the theoretical part helped us in choosing the appropriate materials, and choosing the suitable conditions that the Giromill wind turbine works with such as wind speed, site, safety considerations. In addition to this, we have learned that wind turbines types have different efficiency and respond to environment conditions. According to these conditions and effectiveness VAWT are used in our life for specific applications for home use and widely power producing.

FUTURE WORK

As a summary of our data many improvements can be considered to develop the potential of the system. Wind turbines are a vital source for generating power and considered as a clean source of energy that can supply humans with an important, low cost output. This output depends on the variables, objectives and constraints of the design that is planned to be achieved. For our design the data and testing results have shown that having a good material selection, better site placing and more accurate variables can bring us a better design.

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APPENDICES

APPENDIX A

LOGBOOK

Amir’s logbook:

Dates	Details
20/10/2015	First of all, we met our supervisor to choose the topic of the project. Dr. Qasim Zeeshan explained briefly about the topics and allowed us to search about the topics to determine a specific one.
21/10/2015	After searching for many topics of wind energy, we have chosen the vertical wind turbine subject and submitted it to Dr. Zeeshan.
22/10/2015	Me and Suliman had searched for some vital information about the VAWT to submit a proposal to Dr. Ozada.
29/10/2015	I wrote a first draft about the VAWT introduction. Suliman was responsible to write a comparison of VAWT types.
03/11/2015	We met Dr. Zeeshan to discuss the introduction and Literature Review writing that we prepared.
12/11/2015	We have visited Dr. Zeeshan to get an assistance in choosing a specific model of a VAWT.
8/12/2015	Me and Suliman have visited Dr. Zeeshan to get help in choosing the power input, dimensions of the Giromill VAWT design.
12/12/2015	We had put a work plan after discussing some data about the Giromill VAWT.I was responsible for writing the introduction and literature review. Suleiman and Yasir were responsible to prepare the design section.
18/12/2015	Applying the last thoughts about the topic. I started to gather the introduction and literature review data that prepared before. Suleiman started to prepare the design models and calculations.
20/12/2015	We met to gather the project materials that prepared. We made a revision to the project parts and finished the organizing of the subjects.
21/12/2015	The last day of preparing the report writing. We collected our work and references. We add all the materials required.

07/03/2016	Visiting Dr.Zeeshan to discuss the initial requirements of manufacturing process of the wind turbine.
14/03/2016	I have met my group members to determine our wind turbine fabrication needs. We talked about the materials and parts needed for manufacturing the wind turbine structure. We have chosen the materials to be purchased from different stores.
17/03/2016	Me and my group members Suliman and Yasir have visited many hardware stores in Famagusta to select the appropriate sources to buy our materials.
21/03/2016	We have met Dr.Zeeshan to get some information about our project materials to be selected for each part of the turbine structure.
28/03/2016	After searching about Giromill wind turbine materials selection, we selected specific materials for the blades, shaft, base and radial arms.
5/04/2016	Me and my group members Suliman and Yasir have been to the aluminum factory for purchasing aluminum sheets to be used in blades manufacturing. Moreover, we have purchased an aluminum shaft for the rotor.
13/04/2016	We have visited the hardware store to buy some important materials such as screws, nuts, bolts, washers and threaded bolts.
3/05/2016	We have started to manufacture the blades. We used wood NACA0012 airfoils attached to each other.
5/05/2016	Later, me and my group members have covered the wood airfoils with aluminum sheets using silicon and screws.
11/05/2016	Following the blades manufacturing process, we have fabricated the rotor arms which produced from wood.
16/05/2016	We met each other to manufacture the base of our wind turbine. The selected material is steel. We used welding electrodes and welding machine for this process.
20/05/2016	We have reached the hardware store to buy different bearings sizes for the turbine shaft.
23/05/2016	After the manufacturing of main parts, we prepared the shaft by choosing the right diameter using turning machine.
25/05/2016	We have assembled the turbine parts. Dr.Zesshan gave us a feedback about our work and the improvements that can be done for better design.

Suliman's logbook:

Date	Details
20/10/2015	We visited our supervisor for selecting the topic of project. Dr. zeeshan gave us a brief information about the topics. He asked us to look for some information about the subjects.
21/10/2015	We selected the VAWT subject and submit it to Dr. zeeshan.
22/10/2015	I searched for some information to submit it as a proposal to Dr. Ozada
27/10/2015	I searched for the advantages and disadvantages of VAWT types and made a comparison between these types
3/11/2015	We visited Dr. Zeeshan office to ask about writing the introduction and literature review format.
12/11/2015	We asked Dr. Zeeshan for helping us in choosing a specific type of VAWT.
8/12/2015	Me and Amir, have visited Dr. Zeeshan to ask him about choosing the power output of the VAWT and the dimensions.
14/12/2015	After distributing the work by a work plan, I started to prepare the design and calculations. Amir was responsible for writing the introduction and literature review
18/12/2015	I completed the design and calculations preparing after choosing the appropriate sources and equations.
20/12/2015	We met to discuss the organizing of the project.
21/12/2015	Me and Amir met to gather the project materials after making a revision on subjects and organizing of topics.
7/03/2016	We visited Dr.Qasem to discuss the manufacturing process requirements.
14/03/2016	I met my group members Amir and Yasir to specify our design needs. We have selected the materials needed for the design.
5/04/2016	We visited the aluminum factory to buy aluminum sheets for blades manufacturing process and a shaft for rotor.
13/04/2016	We went to the hardware store to purchase some important materials for parts fixing.

03/05/2016	We have manufactured the airfoils using wood. Then, we attached them with each other.
5/05/2016	Me, Amir and Yasir have covered the blades with aluminum sheets using screws and silicon.
11/05/2016	After we manufactured the blades, we used wood to produce the rotor arms.
16/05/2016	Me and my group members started to manufacture the base which is made from steel
20/05/2016	We bought some bearings and screws for out design.
23/05/2016	We used the turning machine to manufacture the rotor diameter.
25/05/2016	We have met to assemble the turbine parts. Dr.Qasem helped us to improve our design.

Yasir’s logbook:

Dates	Details
20/10/2015	First of all, I received our capstone project from my advisor prof. Dr. Qasim Zeeshan with our team members.
21/10/2015	After a long search, Dr. Qasim Zeeshan and we decided to Choose the VAWT.
22/10/2015	Me and my group had searched for some information about the VAWT throw internet.
27/10/2015	I help my group to write introduction about VAWT.
03/11/2015	We met Dr. Zeeshan to discuss the introduction and Literature Review writing that we prepared.
12/11/2015	Me and my group visited Dr. Zeeshan to get some information about our topic
5/12/2015	I did some searching throw internet to get some information to design our project.
14/12/2015	Me and my group discussing some values about our VAWT and we wrote the design chapter.
19/12/2015	Me and my group starting with some calculating for our design.
20/12/2015	I met the group for adding the materials and organize it.
7/03/2016	We visited Dr.Qasem to get some instructions about of design.
14/03/2016	I met my group members to talk about the materials we are going to use in our design.
17/03/2016	We went to many hardware stores to select our materials
21/03/2016	We visited Dr.Qasem to help us in design manufacturing.
28/03/2016	We selected the materials of shaft,base and other parts.

5/04/2016	We went to aluminum factory to buy aluminum sheets for blades manufacturing
13/04/2106	We bought some screws, bolts from the hardware store.
03/05/2016	We manufactured the blade airfoils. Then we attached them together.
05/05/2016	We covered the wood blades with aluminum sheets
11/05/2016	We worked on fabricating the rotor arms that are produced from wood.
16/05/2016	I met my group members to manufacture the base using steel blocks.
20/05/2016	We went to the hardware store to buy some bearings.
23/05/2016	We fixed the shaft of the rotor by turning machining.
25/05/2016	We met each other to assemble the wind turbine parts together.

APPENDIX B

GANNT CHART

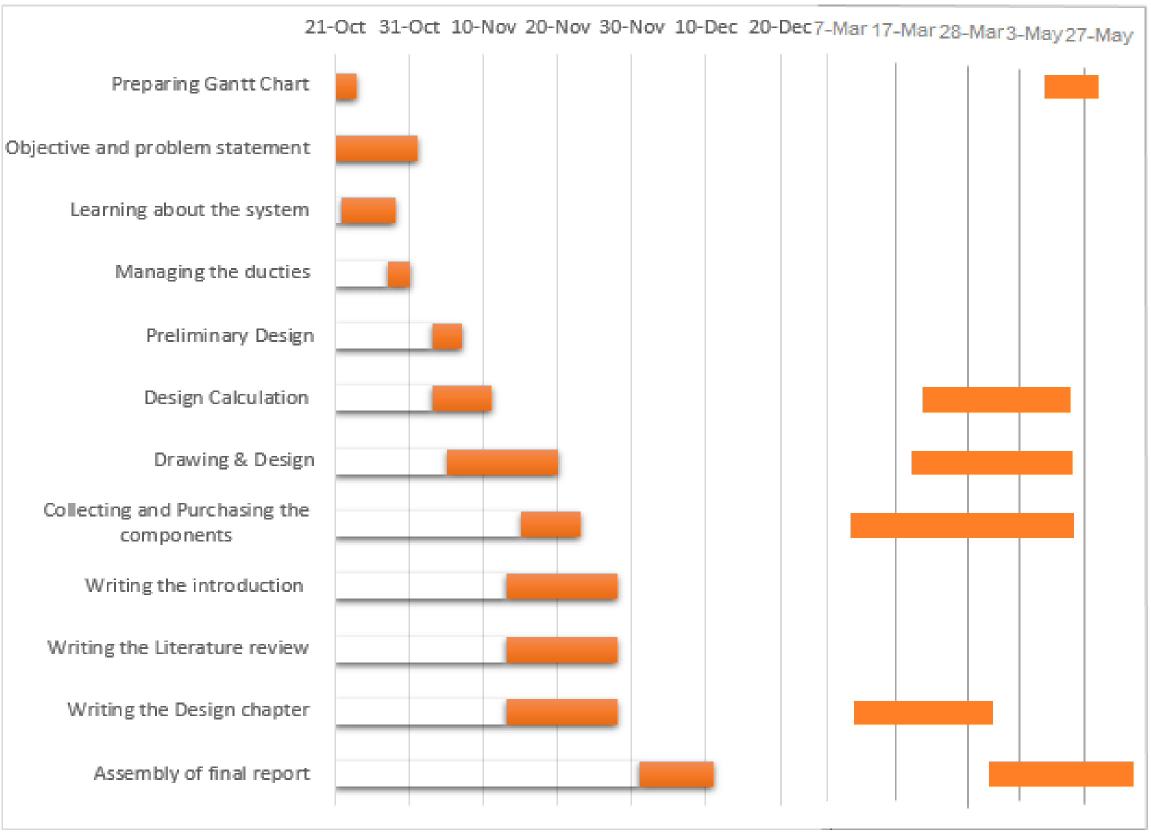
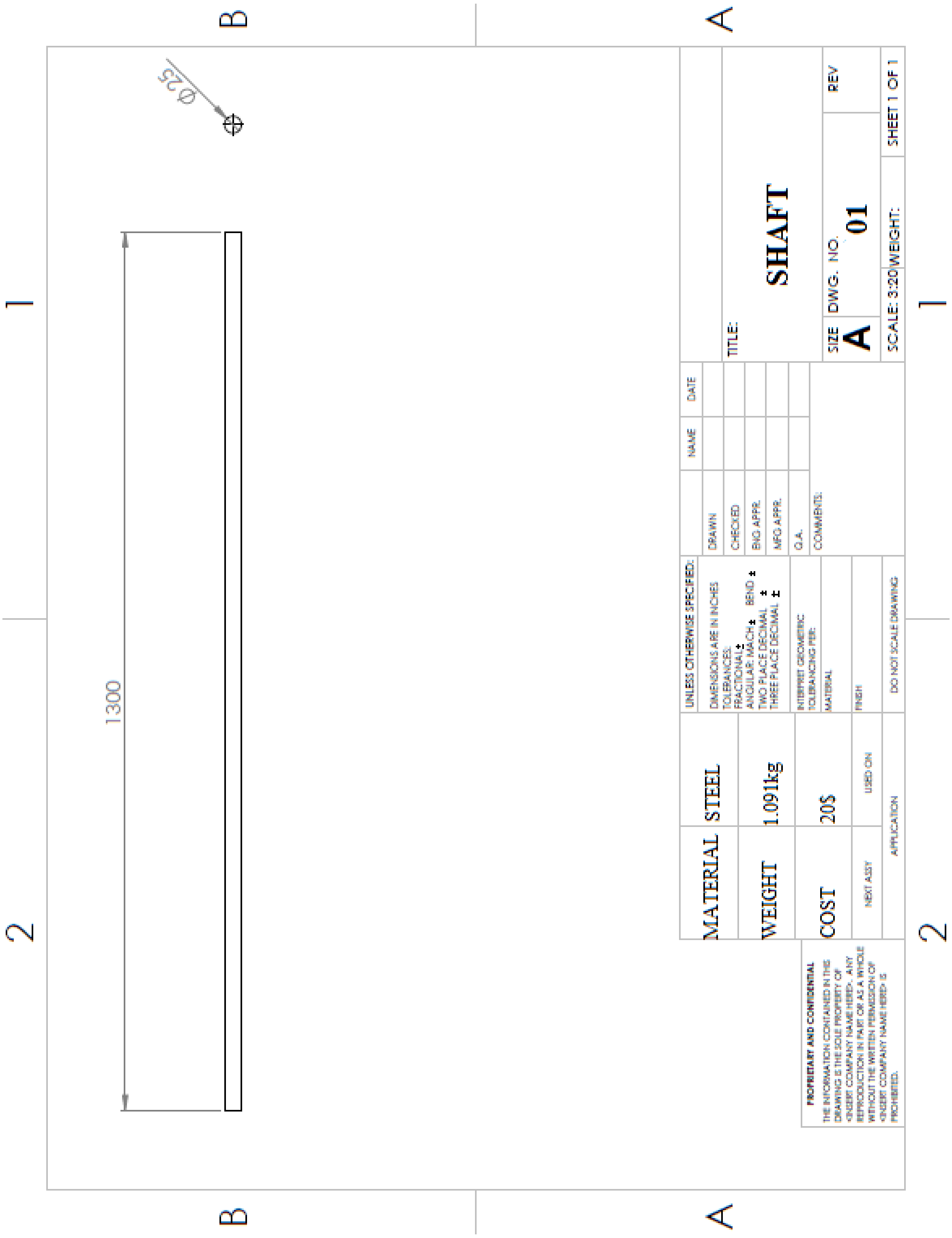
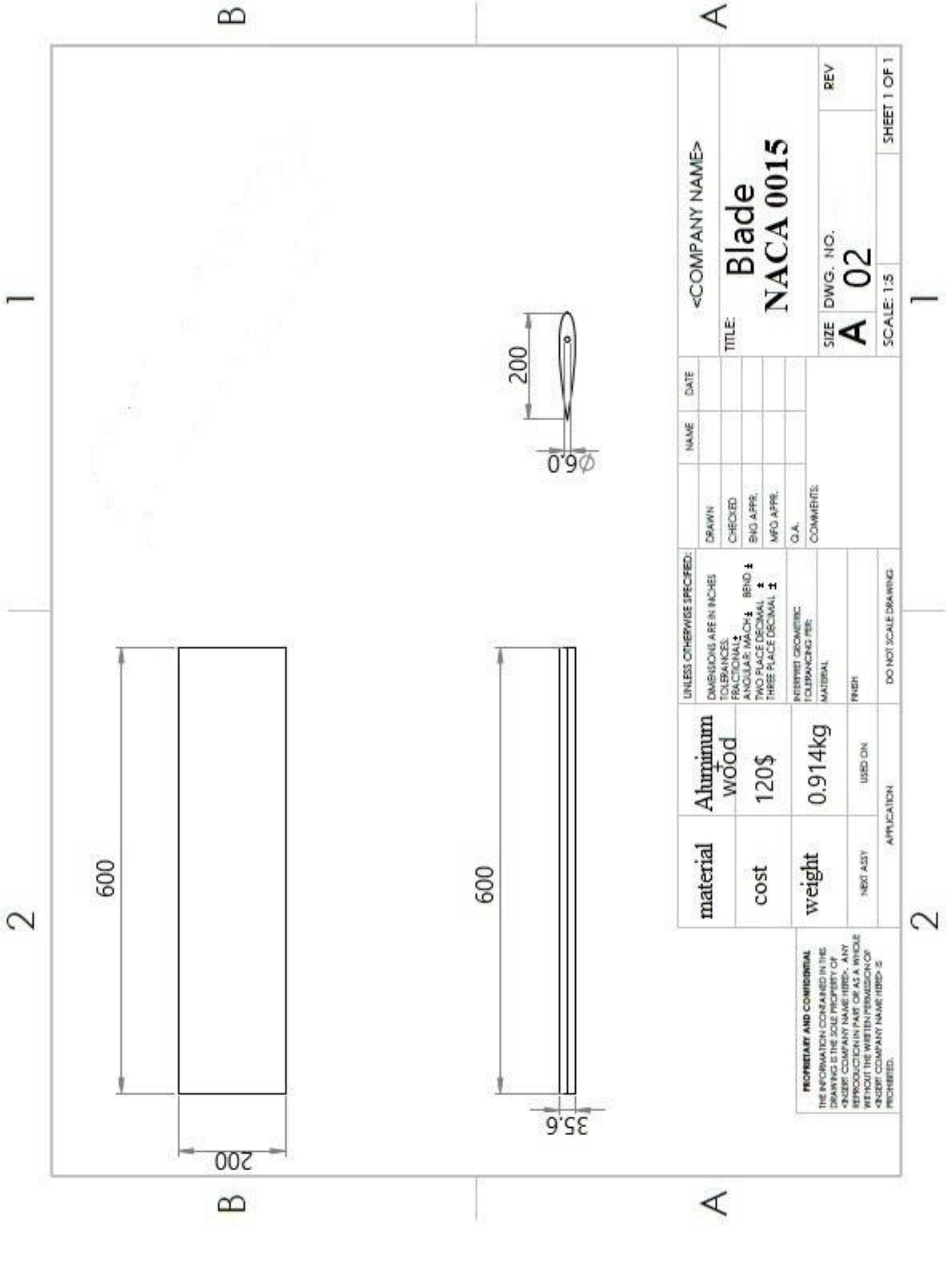


Figure A1. Gantt Chart

APPENDIX C

DRAWINGS





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200
600
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200
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ANGULAR: MACH± BEND ±
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THREE PLACE DECIMAL ±
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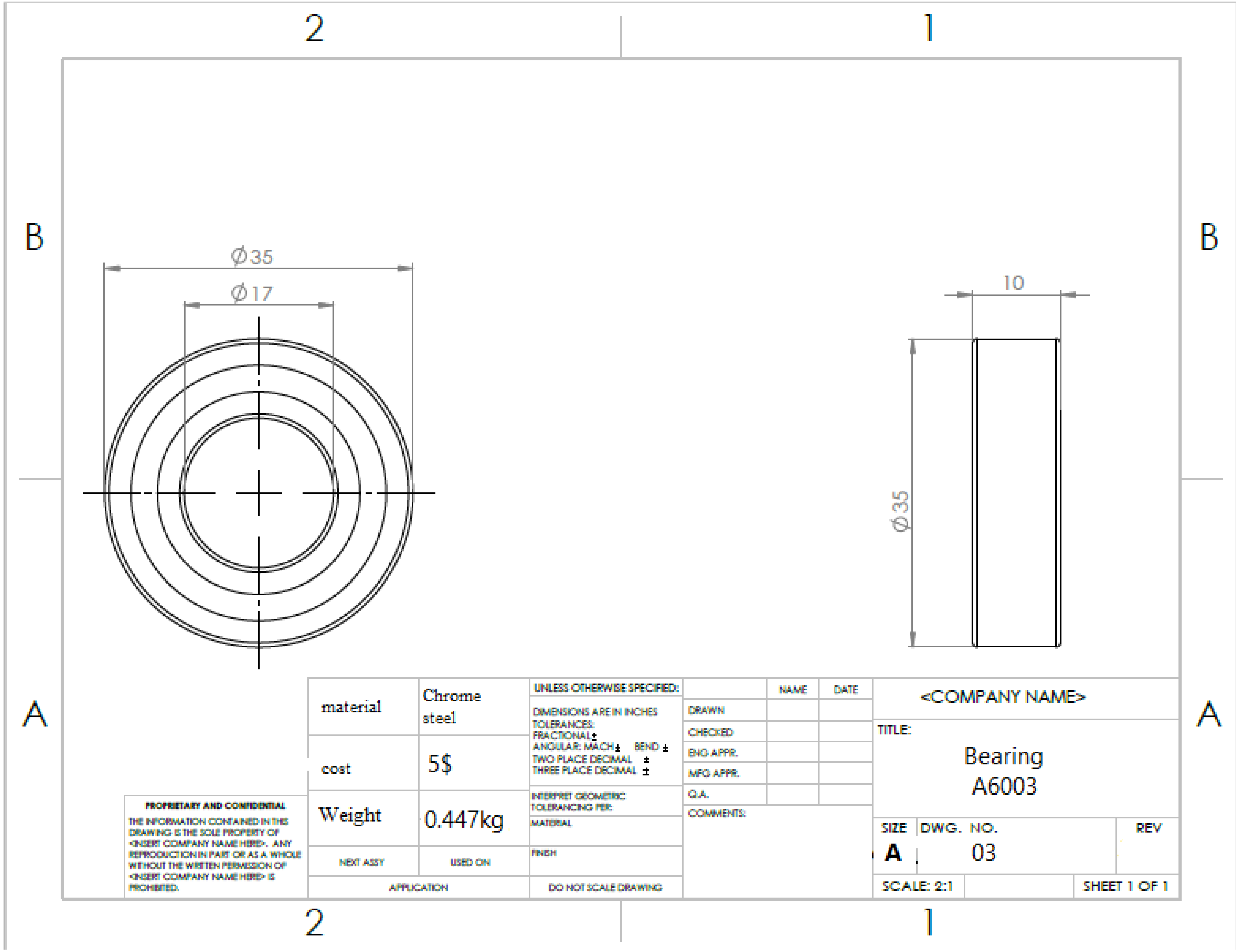

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A
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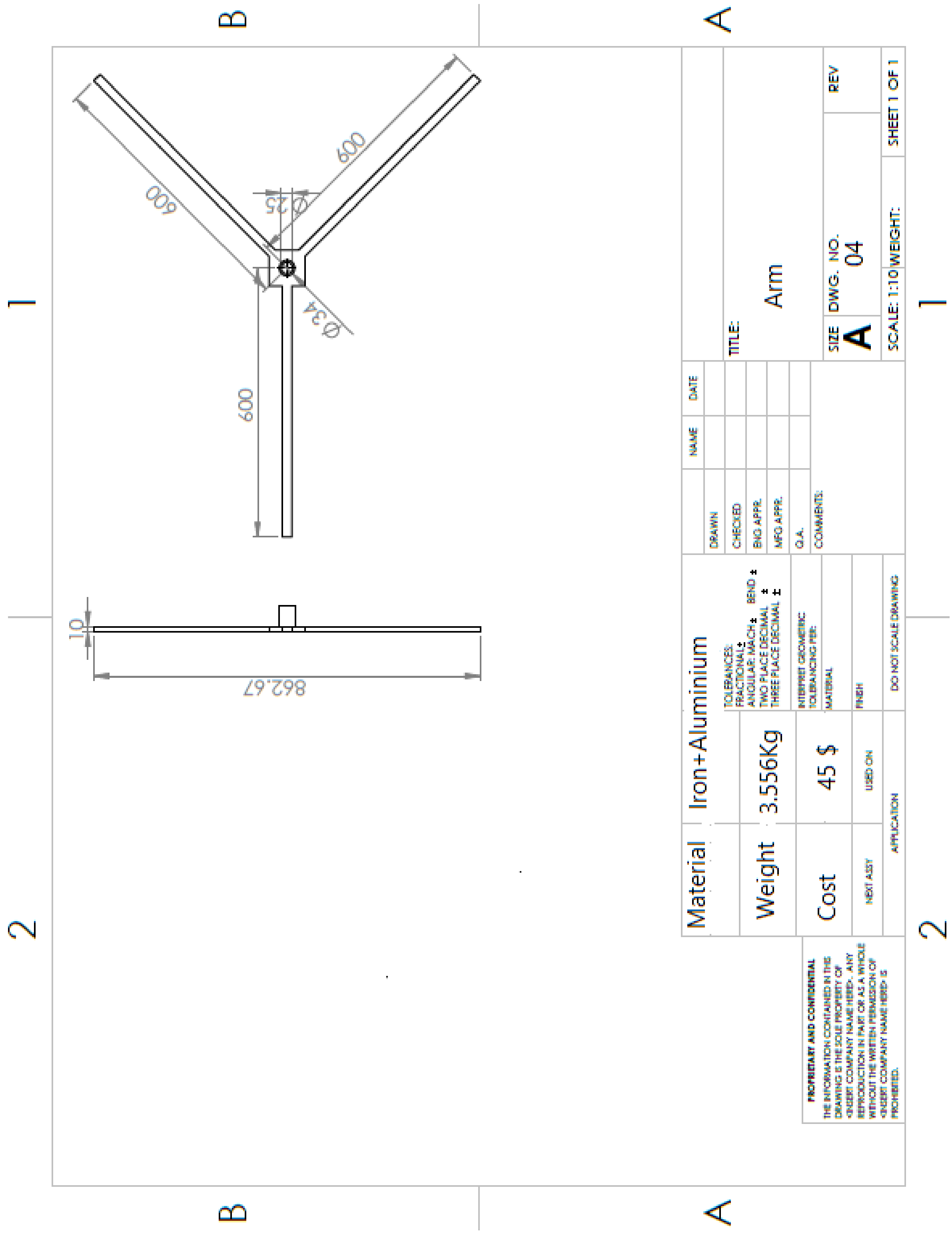
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MFG APPR.
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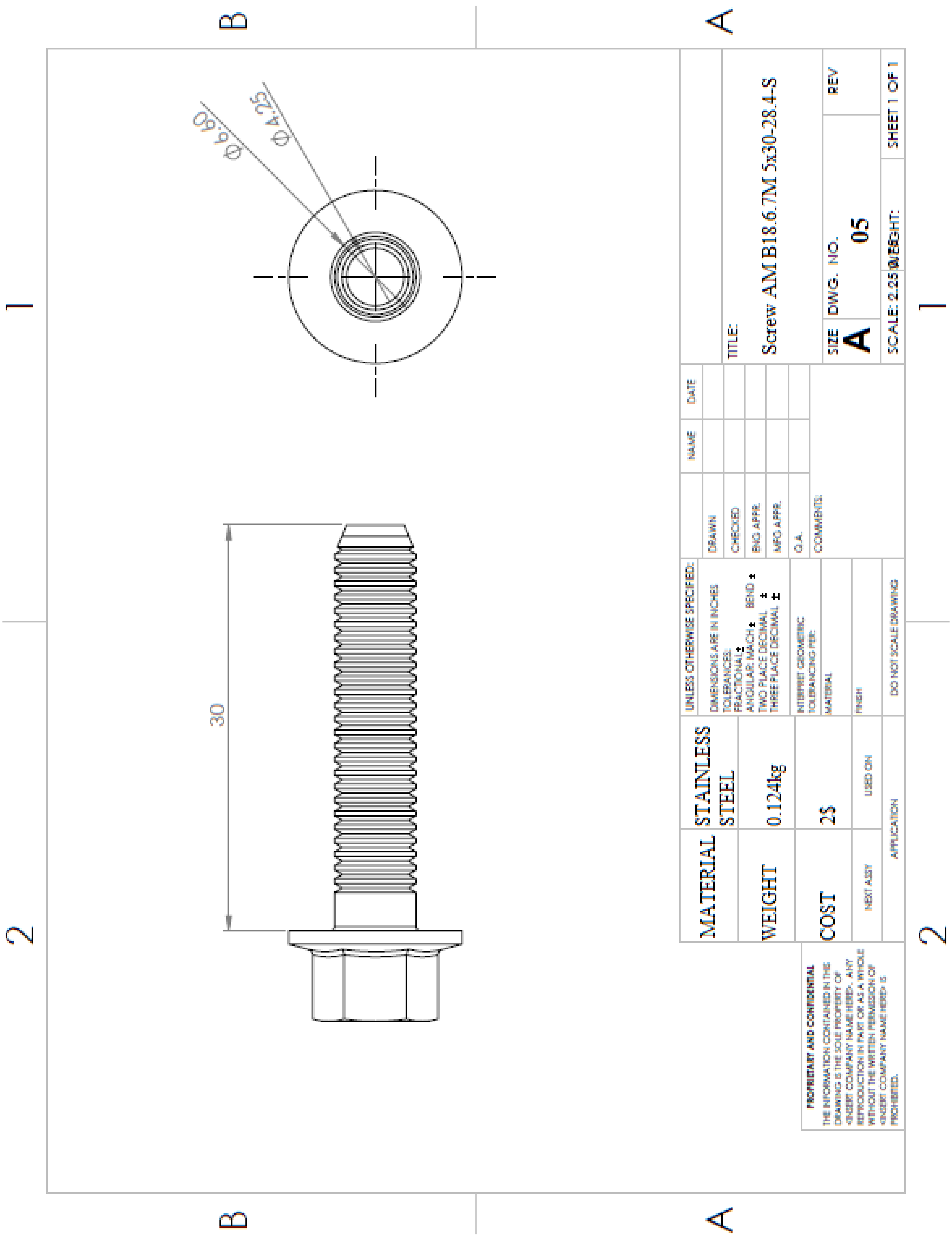
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THREE PLACE DECIMAL ±
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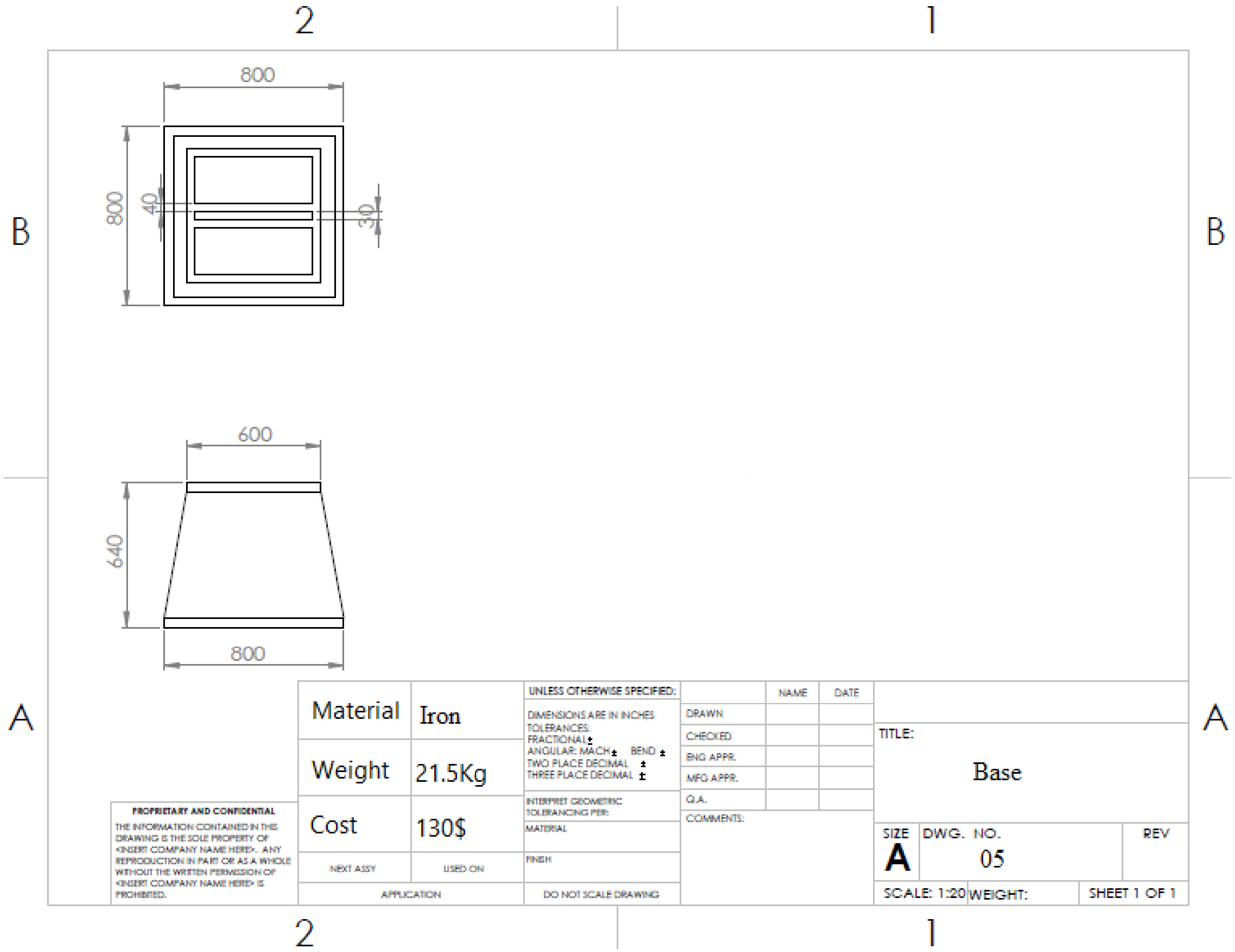
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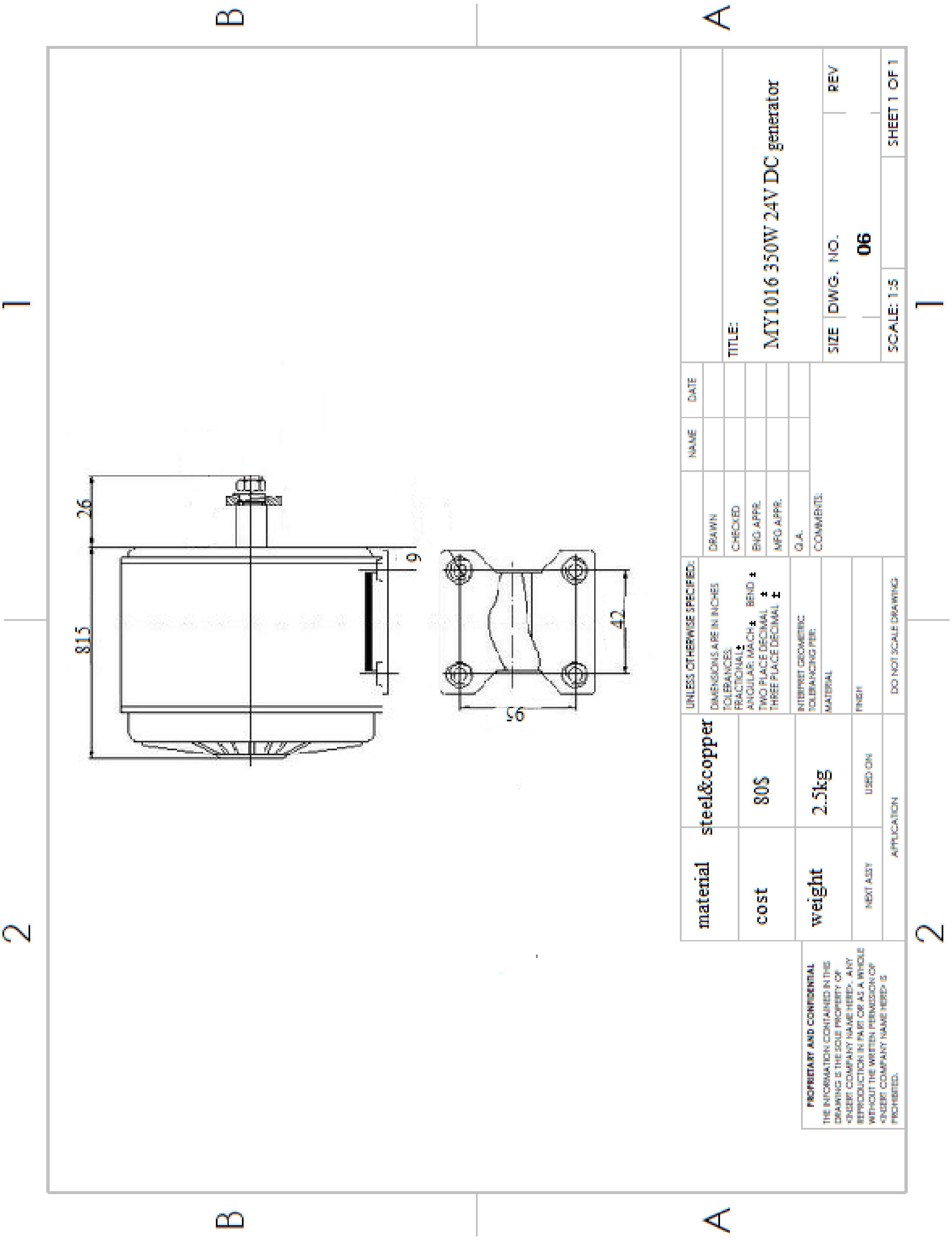

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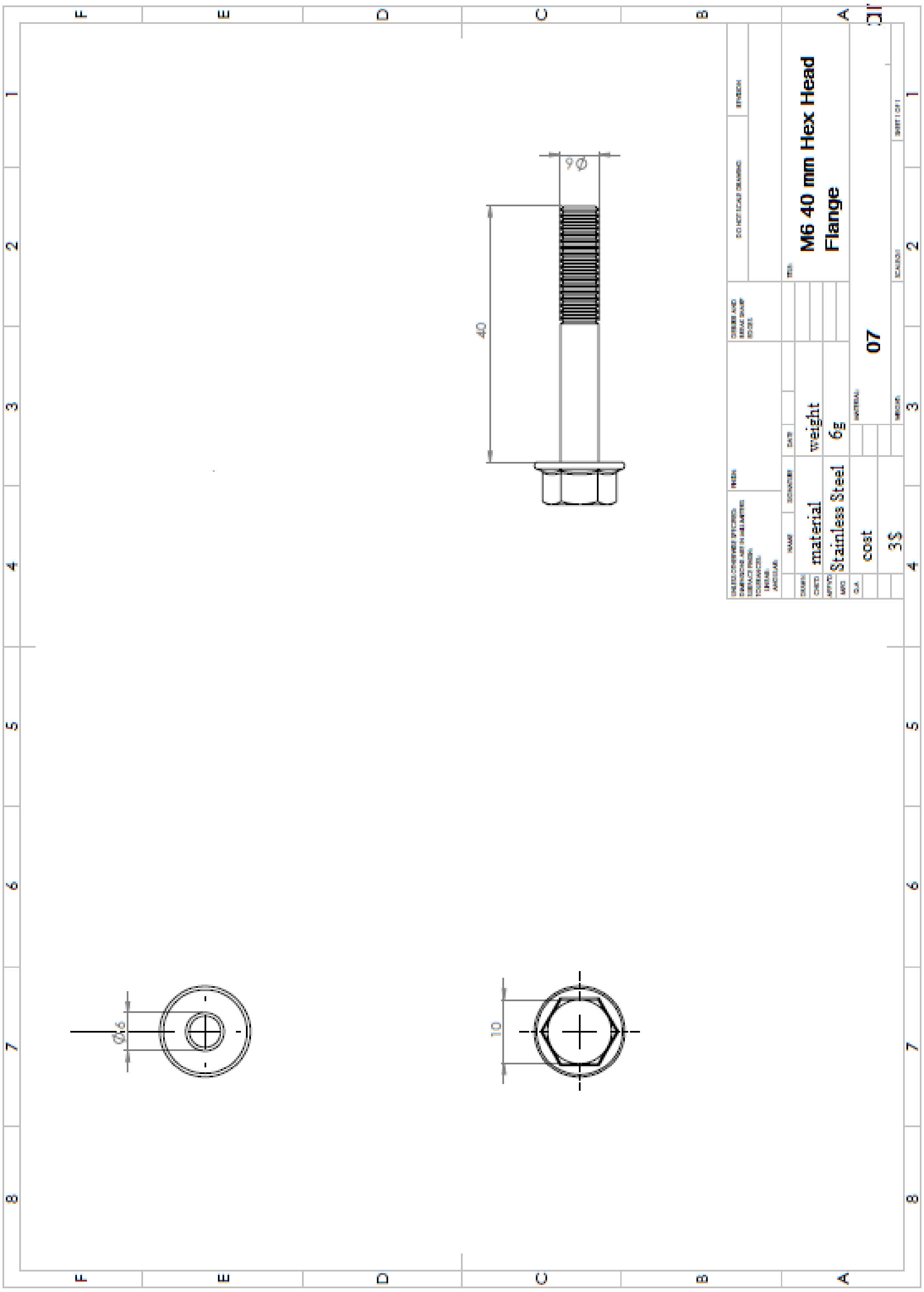
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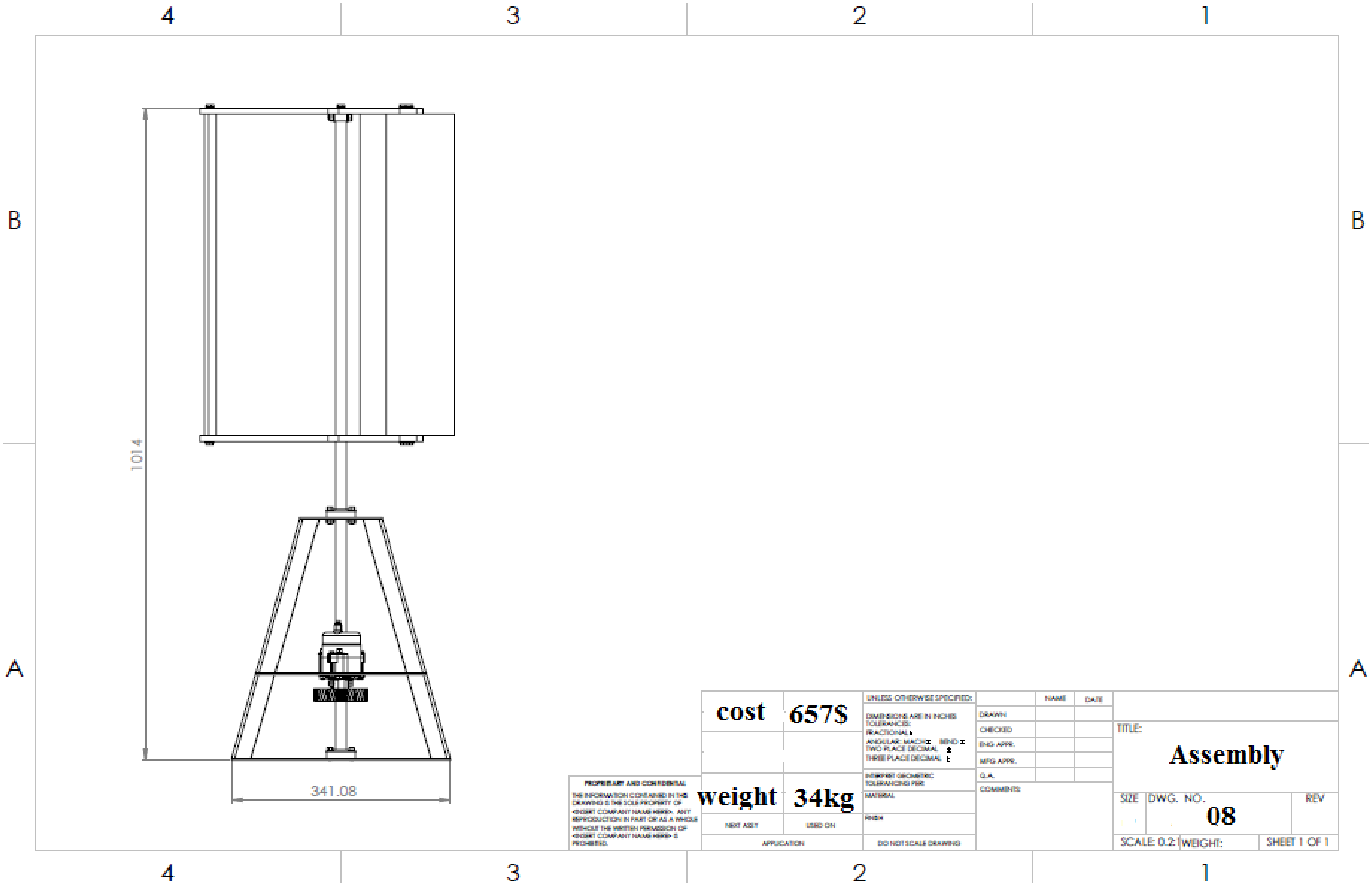
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APPENDIX D

Engineering Standards

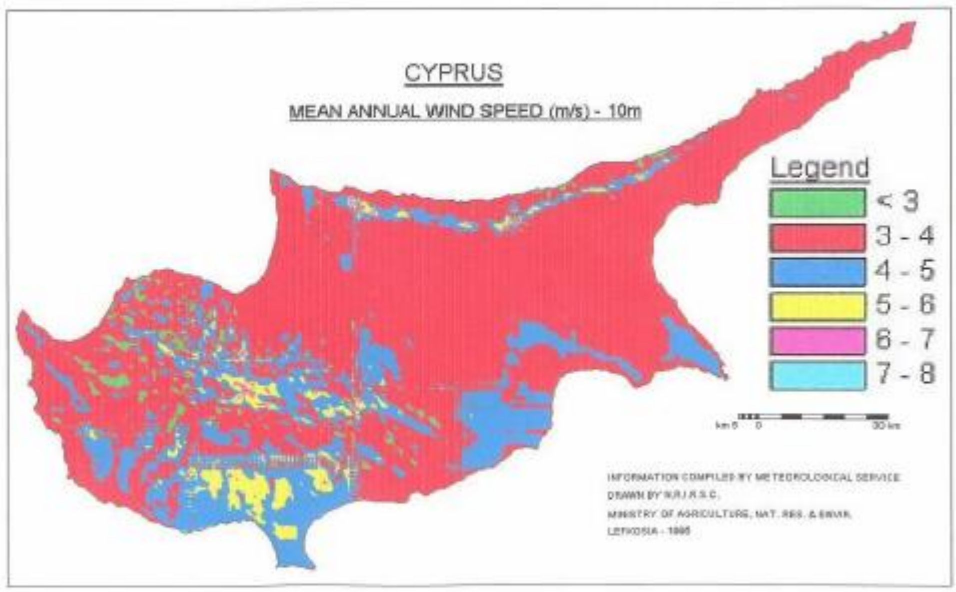


Fig D1: Wind speed in Cyprus

Table D1: VAWT Airfoils Lift Coefficient Data

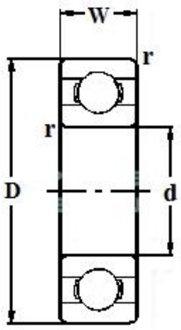
TABLE 1.—POST-STALL MAXIMUM LIFT COEFFICIENTS CALCULATED ACCORDING TO THREE MODELS AND COMPARED TO MEASURED COEFFICIENTS.
[Test data sources: see Lindenburg 2000]

Airfoil designation	Thickness ratio, *t/c*	Aspect ratio, *AR*	Meas. post-stall max lift coef., *CL2*max	Model calculations of post-stall max lift coef., *CL2*max		
				AERODAS model	StC model	Flat-plate model
NACA 0012	0.12	Inf.	1.111	1.173	1.143	1.170
NACA 0012	0.12	Inf.	1.118	1.173	1.143	1.170
NACA 0015	0.15	Inf.	0.933	1.163	1.137	1.170
NACA 4409	0.09	Inf.	1.220	1.180	1.182	1.170
NACA 4412	0.12	Inf.	1.210	1.173	1.174	1.170
NACA 4415	0.15	Inf.	1.200	1.163	1.166	1.170
NACA 4418	0.18	Inf.	1.170	1.151	1.157	1.170
NACA 0012	0.12	Inf.	1.171	1.173	1.143	1.170
NACA 23012	0.12	Inf.	1.217	1.173	1.166	1.170
NACA 23017	0.17	Inf.	1.152	1.156	1.149	1.170
FX-84-W-127	0.13	Inf.	1.232	1.171	1.173	1.170
FX-84-W-218	0.22	Inf.	1.152	1.133	1.175	1.170
LS-421 Mod	0.21	Inf.	1.193	1.138	1.205	1.170
NACA 23024	0.24	Inf.	0.990	1.121	1.122	1.170
NACA 63-215	0.15	Inf.	1.094	1.163	1.176	1.170
GA(W)-1	0.17	Inf.	1.094	1.156	1.213	1.170
GA(W)-1 Inverted	0.17	Inf.	1.094	1.156	1.082	1.170
NACA 4409	0.09	12	1.048	1.014	0.876	0.855
NACA 4412	0.12	12	0.991	1.007	0.871	0.855
NACA 4418	0.18	12	1.002	0.989	0.861	0.855
NACA 4409	0.09	9	0.937	0.919	0.839	0.824
NACA 4412	0.12	9	0.886	0.913	0.834	0.824
NACA 4418	0.18	9	0.814	0.897	0.824	0.824
Clark-Y	0.18	8	0.978	0.856	0.812	0.814
NACA 4409	0.09	6	0.835	0.800	0.802	0.796
NACA 4412	0.12	6		0.795	0.802	0.796
NACA 4418	0.18	6		0.780	0.802	0.796
Clark-Y	0.18	6	0.890	0.779	0.766	0.796
Infinite length airfoils						
			Mean deviation of model from test data:	0.021	0.021	0.032
			Standard deviation:	0.078	0.074	0.086
Finite-length airfoils:						
			Mean deviation of model from test data:	–0.023	–0.100	–0.104
			Standard deviation:	0.057	0.115	0.124
All airfoils:						
			Mean deviation of model from test data:	0.006	–0.021	–0.015
			Standard deviation:	0.074	0.091	0.099

Table D2 : Bearing Standards

Bore, mm	02-Series OD, mm	Width, mm	Load Rating, kN C_{10}	C_0	03-Series OD, mm	Width, mm	Load Rating, kN C_{10}	C_0
25	52	15	16.8	8.8	62	17	28.6	15.0
30	62	16	22.4	12.0	72	19	36.9	20.0
35	72	17	31.9	17.6	80	21	44.6	27.1
40	80	18	41.8	24.0	90	23	56.1	32.5
45	85	19	44.0	25.5	100	25	72.1	45.4
50	90	20	45.7	27.5	110	27	88.0	52.0
55	100	21	56.1	34.0	120	29	102	67.2
60	110	22	64.4	43.1	130	31	123	76.5
65	120	23	76.5	51.2	140	33	138	85.0
70	125	24	79.2	51.2	150	35	151	102
75	130	25	93.1	63.2	160	37	183	125
80	140	26	106	69.4	170	39	190	125
85	150	28	119	78.3	180	41	212	149
90	160	30	142	100	190	43	242	160
95	170	32	165	112	200	45	264	189
100	180	34	183	125	215	47	303	220
110	200	38	229	167	240	50	391	304
120	215	40	260	183	260	55	457	340
130	230	40	270	193	280	58	539	408
140	250	42	319	240	300	62	682	454
150	270	45	446	260	320	65	781	502

Bearing NO.	I.D d		O.D D		W B		Load Rating (KN) Dynamic	Static	Steel Ball Parameter NO.	Size	Max Speed Grease	Oil
	mm	inch	mm	inch	mm	inch	Cr	Cor		mm	r/min	r/min
6000	10	0.3937	26	1.0236	8	0.3150	4.55	1.95	7	4.763	29000	34000
6001	12	0.4724	28	1.1024	8	0.3150	5.10	2.39	8	4.763	26000	30000
6002	15	0.5906	32	1.2598	9	0.3543	5.60	2.84	9	4.763	22000	26000
6003	17	0.6693	35	1.378	10	0.3937	6.80	3.35	10	4.763	20000	24000
6004	20	0.7874	42	1.6535	12	0.4724	9.40	5.05	9	6.350	18000	21000
6005	25	0.9843	47	1.8504	12	0.4724	10.10	5.85	10	6.350	15000	18000
6006	30	1.1811	55	2.1645	13	0.5118	13.20	8.30	11	7.144	13000	15000
6007	35	1.3779	62	2.4409	14	0.5512	16.00	10.30	11	7.938	12000	14000
6008	40	1.5748	68	2.6772	15	0.5906	16.80	11.50	12	7.938	10000	12000
6009	45	1.7716	75	2.9528	16	0.6299	21.00	15.10	12	8.731	9200	11000
6010	50	1.965	80	3.1496	16	0.6299	21.80	16.60	13	8.731	8400	9800
6011	55	2.1653	90	3.5433	18	0.7087	28.30	21.20	12	11.000	7700	9000
6012	60	2.3620	95	3.7400	18	0.7087	29.50	23.20	13	11.000	7000	8300
6013	65	2.559	100	3.9370	18	0.7087	30.50	25.20	13	11.112	6500	7700
6014	70	2.7559	110	4.3307	20	0.7874	38.00	31.00	13	12.303	6100	7100
6015	75	2.9528	115	4.5276	20	0.7874	39.50	33.50	14	12.303	5700	6700
6016	80	3.1496	125	4.9213	22	0.8661	47.50	40.00	14	13.494	5300	6200
6017	85	3.3465	130	5.1181	22	0.8661	49.50	43.00	14	14.000	5000	5900
6018	90	3.5433	140	5.5118	24	0.9449	58.00	49.50	14	15.080	4700	5600
6019	95	3.7402	145	5.7087	24	0.9449	60.50	54.00	14	15.080	4500	5300
6020	100	3.937	150	5.9055	24	0.9449	60.00	54.00	14	16.000	4200	5000



Bearing No.	Bore d		Outer Diameter D		Width W		Radius r		Basic Load Rating (Lbs)	
	mm	in	mm	in	mm	in	mm	in	Dynamic C	Stastic Co
6005	25	0.9843	47	1.8504	12	0.4724	1.0	0.039	2260	1320

Table D3: Shaft Standards

Round Bar							
Size	Kg/m	Size	Kg/m	Size	Kg/m	Size	Kg/m
4.0mm	0.099	15mm	1.39	35mm	7.55	68mm	28.51
4.5mm	0.125	16mm	1.58	36mm	7.99	70mm	30.21
5.0mm	0.154	17mm	1.78	38mm	8.90	72mm	31.96
5.5mm	0.187	18mm	2.00	39mm	9.38	75mm	34.68
6.0mm	0.222	19mm	2.23	40mm	9.86	80mm	39.46
6.5mm	0.260	20mm	2.47	42mm	10.88	90mm	49.94
7.0mm	0.302	21mm	2.72	45mm	12.48	100mm	61.65
7.5mm	0.347	22mm	2.98	48mm	14.21	110mm	74.6
8.0mm	0.395	23mm	3.26	50mm	15.41	120mm	88.8
8.5mm	0.445	24mm	3.55	52mm	16.67	130mm	104
9.0mm	0.499	25mm	3.85	55mm	18.65	140mm	121
9.5mm	0.556	26mm	4.17	56mm	19.33	150mm	139
10mm	0.617	27mm	4.50	58mm	20.74	160mm	158
11mm	0.746	28mm	4.83	60mm	22.20	170mm	178
12mm	0.888	30mm	5.55	62mm	23.70	180mm	200
13mm	1.04	32mm	6.31	64mm	25.25	190mm	223
14mm	1.21	33mm	6.71	65mm	26.05	200mm	247

Table D4: NACA0015 Coordinates

NACA 0015	
X	Y
1.0000	0.00158
0.9500	0.01008
0.9000	0.01810
0.8000	0.03279
0.7000	0.04580
0.6000	0.05704
0.5000	0.06617
0.4000	0.07254
0.3000	0.07502
0.2500	0.07427
0.2000	0.07172
0.1500	0.06682
0.1000	0.05853
0.0750	0.05250
0.0500	0.04443
0.0250	0.03268
0.0125	0.02367
0.0000	0.00000
0.0125	-0.02367
0.0250	-0.03268
0.0500	-0.04443
0.0750	-0.05250
0.1000	-0.05853
0.1500	-0.06682
0.2000	-0.07172
0.2500	-0.07427
0.3000	-0.07502
0.4000	-0.07254
0.5000	-0.06617
0.6000	-0.05704
0.7000	-0.04580
0.8000	-0.03279
0.9000	-0.01810
0.9500	-0.01008
1.0000	-0.00158

Table D5: Cp Values for NACA airfoils

Airfoil	C_P max	Airfoil	C_P max	Airfoil	C_P max	Airfoil	C_P max
NACA 0010	0.2345	NACA 63415	0.1711	AG18	0.0123	FX66S196	0.2074
NACA 0015	0.2947	NACA 63418	0.2772	S 809	0.3428	FX77W256	0.1639
NACA 0018	0.2964	AH93W174	0.2469	S 9000	0.1696	FX71L150	0.2961
NACA 0021	0.2679	AH93W215	0.2541	S 1046	0.4051	FXL142	0.3311
NACA 6312	0.1290	AH94W301	0.2130	S 1014	0.2769	FXLV152	0.3576