DESIGN AND FABRICATION OF MICRO HYDRO TURBINE

A final year project report

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Bachelors of Mechanical Engineering

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ABSTRACT

The project was initially started with the objective of designing a power generation system that could be used in open channel water flow anywhere around the globe. The purpose was to make a turbine that could provide for the power requirements of general public when on an adventurous trip or for a small scale power requirement in a forest or any other unreachable place, i.e. our aim was to have an output of about 25-30 Watts. We set out to find out if setting up such a system in open channel water flow will actually yield results or not. The idea was to set up small capacity power generation system, hence the name micro-hydro turbine and to discover new way of providing electricity to the people. To design such a system, we studied different types of turbines and discovered that vertical axis turbines were most suited for small capacity generation systems. Working from there we designed a Vertical Axis turbine using a specific Airfoil design to (theoretically) give the best possible results.

Our team then completed the manufacturing of a small prototype based on the idea with which we started i.e. to produce electricity on a small scale just enough to provide light in a remote area where travelers might be camping for a day or few. We tested the speed of water in a canal near Taxila and we designed our prototype according to the speed we measured (1.6m/s) and the Calculations were done accordingly. Our turbine is portable by the use of nuts and bolts and can simply be taken anywhere easily by just unscrewing a few nuts and bolts. The idea was to help people so that they can take the whole turbine to any place they desire easily with convenient transportation.

PREFACE

A turbine converts energy in the form of falling water into rotating shaft power. The selection of the best turbine for any particular hydro site depends on the site characteristics, the dominant ones being the head and flow available. Selection also depends on the desired running speed of the generator or other device loading the turbine. Other considerations such as whether the turbine is expected to produce power under part-flow conditions also play an important role in the selection. All turbines have a power-speed characteristic. They will tend to run most efficiently at a particular speed, head and flow combination.

A turbine design speed is largely determined by the head under which it operates. Turbines can be classified as high head, medium head or low head machines. Turbines are also divided by their principle way of operating and can be either impulse or reaction turbines. This report is our work on how to make a hydro-turbine into a portable device that can be used in multiple applications.

ACKNOWLEDGMENTS

First of all we would thank ALLAH Almighty, who gave us knowledge and dedication to be able to complete this research. We would also like to thank our Faculty advisor, AP Ammar Tariq, who at each and every step, assisted us, encouraged us and guided us to complete the project successfully. Moreover we will like to appreciate the help that our Co-Supervisors gave us throughout the project. We would further like to thank Dr. Sajid for his insight into ANYSYS and helping us with the design problems we were facing in the beginning.

We would also show our gratitude to our Senior Talha Naeem Rao for giving us the guidelines that we needed to jump start our project and in understanding of Micro Hydro Turbines. And we would like to thank our beloved friend Ahmed Nasir Gill who helped us in testing our turbine and gave us all the support that we needed. Furthermore we would like to pay our regards to Lec Shoaib Ahmed was his help and efforts in making this report organized and well sequenced.

Last but not the least the project was possible because of the prayers and motivation that our parents put in for us. We dedicate our project to our parents.

ORIGINALITY REPORT

We Certify that this research work titled "**Design and fabrication of a Micro hydro turbine**" is our own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred. We have not copied anything or anyone else's work and the work done is original and all result of our own hardwork.

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ABREVIATIONS

VAWT Vertical Axis Wind Turbine

HAWT Horizontal Axis Wind Turbine

NACA National Advisory Committee for Aeronautics

NOB Number of Blades

VAT Vertical Axis Turbines

DVAT Drag Vertical Axis Turbine

LVAT Lift Vertical Axis Turbine

AOA Angle Of Attack

FYP Final Year Project

NOMENCLATURE

Symbol	Description	Unit
α	Angle of Attack	[^{o}]
γ	Pitching Angle	[^{o}]
μ	Dynamic Viscosity	[kg/m^3]
ω	Angular Velocity	[rad/s]
ρ	Density	[kg/m^3]
θ	Azimuthal Angle	[^{o}]
A	Area	[m^2]
B	Number of Blades	[-]
C	Chord	[m]
C_D	Drag Coefficient	[-]
C_L	Lift Coefficient	[-]
C_P	Power Coefficient	[-]
D	Diameter	[m]
F_D	Draf Force	[N]
F_L	Lift Force	[N]
F_N	Normal Force	[N]
F_T	Tangential Force	[N]
h	Height	[m]
L	Length	[m]
P	Power	[W]
p	Pressure	[N]
Q	Torque	[Nm]
r	Radius	[m]
Re	Reynolds Number	[-]

CHAPTER NO 1

INTRODUCTION

1.1-Turbine

A turbine is a machine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor.

And hydro turbine is a machine that uses water kinetic or potential energy to rotate its blades and convert that energy in the rotation energy

Turbines are of two types

- Impulse turbine works on the velocity of flowing water
- Reaction turbine utilizes the head of the water for rotation

1.2-Background

Micro hydro turbine is such type of turbine that produces power using natural flow of water and produces about 5-100KW of power. Below this rating of 5KW the turbines are called Pico hydro turbines. Micro hydro turbine is also called hydroelectric turbine. These hydro power turbines can be used to provide power to remote areas, or may be used to light a camp on river side. They can also be used to supply power to individual houses or small community. These types of hydro turbines are more preferable in the developing countries like Pakistan where power shortage is major problem in the country as these hydro turbines can provide power on small installations. They also does not need any kind of fuel to run them on the same side does not increase burden on the imports of oil because our country have not enough potential of producing oil and meet country’s requirements. This type of power producing source is more reliable than other small power producing sources like solar and other etc because in winters when solar power decreased this system can then also supply power with the flow of water. These are some basic uses of micro hydro turbine and this turbine utilizes Pelton turbine where water supply is low and head is very high as this pelton is a type of impulse turbine so this turbine uses head of water for its working. These types of turbine don’t require any specific head for their operation. Instead they operate on kinetic energy provided by the running water.

1.3-Aims and Objectives

We are using Vertical Axis Wind Turbine (VAWT). This VAWT may have two types of orientations horizontal axis and vertical axis. This VAWT has ability to install in the water channel. Water is flowing with the gravity and this flowing water in turn rotates the turbine to produce electricity power.

The main objective of this project is to design and fabricate the VAWT for the production of power using water as primary source.

Our main objective is to produce electricity power from our project as also it can be portable to use for the camping purpose.

1.4-Research methodology

Before working on the project the first step is to gather information and then design that project. And same way while designing our turbine the first step in the process was to understand the basic concept of the turbine design and the mathematical model that determines the performance outputs of the turbine by complete studying the literature present on the turbines and decide the most suited type of turbine available for the project. After selecting the type, the team investigated the different design parameters of the turbine as to how their change affected the outcome and chose the best option to our understanding.

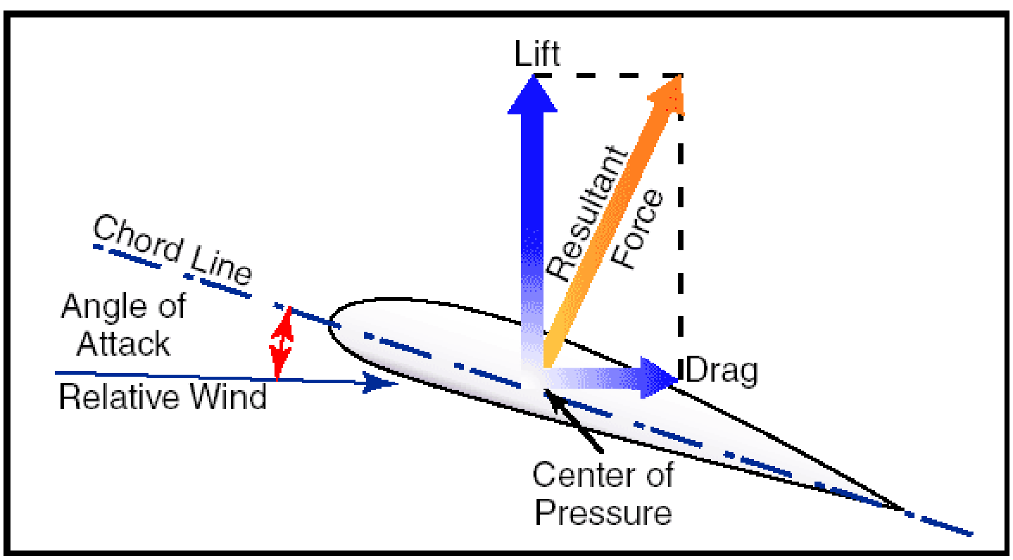


Figure 1: Nomenclature of an Airfoil (E.N.Jacobs, 1933)

CHAPTER NO 2

LITERATURE REVIEW

2.1-Need for Micro-hydro Turbine:

Pakistan has abundant supply of free streams and rivers on the northern side of the country. The remoteness of the area and the provision of electricity to those specific areas makes up for huge cost. For the scattered and isolated villagers of the mountainous areas of Pakistan, those costs can be measured not only by low incomes, but by poor health and safety as pinewood sticks and costly kerosene lamps make a precarious substitute for the lack of electricity. Moreover the travelers and the people set out to discover new places and have some adventure face the problem of lack of power and electricity in such open areas. The free streams in such areas and the open canals and streams can provide power in such circumstances.

The free flowing water streams in such areas are a natural resource and in turn a free mode of power generation capable resource. The idea of this project is to understand the feasibility of the application of turbine installation within these pipes and whether they are able to sufficiently supply electricity to the concerned group of people. The need for the provision of electricity to these people is of paramount importance if the Tourism sector in Pakistan and its northern areas has to be grown. These micro hydro turbines will give an easy way out because of their relatively smaller size and easy to use instructions and will make a very good alternative source of electricity.

2.2-Turbines:

Water under pressure contains energy (kinetic) which has the potential to be used a s a Power Souce. Turbines convert the kinetic energy in water into mechanical energy in the form of rotating mechanical energy. This Mechanical energy drives a shaft and runs a turbine which when connected to a generator produces Electricity. [10]

2.3-Principle Types of Turbines

1. Impulse Turbines
2. Reaction Turbines

Impulse Turbines:

Impulse turbines convert the kinetic energy of a jet of water to mechanical energy. The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the down side of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for **high head, low flow** applications.

Impulse turbines tolerate sand, are Easy to fabricate, efficient at wide a range of head and flow. Nozzle converts pressurized water into a high-speed jet of water.

Reaction Turbines:

Reaction turbines convert the potential energy in pressurized water to mechanical energy. In a reaction turbine, the blades sit in a much larger volume of fluid and turn around as the fluid flows past them. A reaction turbine doesn't change the direction of the fluid flow as drastically as an impulse turbine: it simply spins as the fluid pushes through and past its blades. Wind turbines are perhaps the most familiar examples of reaction turbines.

If an impulse turbine is a bit like kicking soccer balls, a reaction turbine is more like swimming; in reverse. To better understand this think of how you do freestyle (front crawl) by hauling your arms through the water, starting with each hand as far in front as you can reach and ending with a "follow through" that throws your arm well behind you. What you're trying to achieve is to keep your hand and forearm pushing against the water for as long as possible, so you transfer as much energy as you can in each stroke. A reaction turbine is using the same idea in reverse: imagine fast-flowing water moving past you so it makes your arms and legs move and supplies energy to your body! With a reaction turbine, you want the water to touch the blades smoothly, for as long as it can, so it gives up as much energy as possible. The water isn't hitting the blades and bouncing off, as it does in an impulse turbine: instead, the blades are moving more smoothly, "going with the flow."

A **Reaction turbine** is a type of steam turbine that works on the principle that the rotor spins, as the name suggests, from a reaction force rather than an impact or impulse force.

2.4-Turbine types based on axis of rotation

There are two types of turbine if we categorize due to their axis of rotation

1. Horizontal axis turbines
2. Vertical axis turbines

Horizontal axis turbines

Rotational axis of turbine is parallel to the flow direction. Conventional horizontal axis wind turbines are lift-based machines.

Vertical Axis turbines

Rotational axis of turbine is perpendicular to the flow direction.

This kind of turbine is sometimes called "cross-flow turbine", as the turbine in principle also can be tilted 90 degrees to have a horizontal axis while still having its rotational axis perpendicular to the flow.

Types of VA Turbines:

VA turbines can be categorized in two broad categories based on their working principle.

1. Drag based VAT
2. Lift based VAT

Drag based VAT

Drag based vertical axis turbines apply force in the direction of relative flow. Drag-based devices rely on variation of the drag coefficient with respect to the orientation of the object. To create a reasonably efficient drag-based turbine, the drag coefficient should be high in one direction and low in the opposite direction, which gives a torque on the turbine. Drag-based devices achieve lower power coefficients than the lift-based

Savonius turbine is S-shaped if viewed from above. This drag-type turbine turns relatively slowly

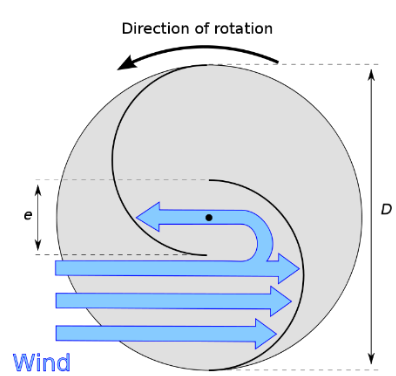


Figure 2 : Savonius Turbine (D.Anderson, 2007)

but yields a high torque. It is useful for grinding grain, pumping water, and many other tasks, but its slow rotational speeds are not good for generating electricity.

Lift based VAT

Lift based VA turbines apply force perpendicular to the direction of relative flow. Main types of lift based VAT include Darrieus turbines, H-rotor turbines, Gorlov helical turbines.

Lift-based turbine was originally invented by the French engineer George Jean Marie Darrieus in the 1920's. The patent application of Darrieus covers the curved blade turbine and the H-rotor, as well as turbines with varying pitch angle and ducted turbines. It is suggested in the patent that the designs work both for wind and tidal energy. The aim of the curved blade design is to reduce the bending stresses in the blades due to centrifugal forces.

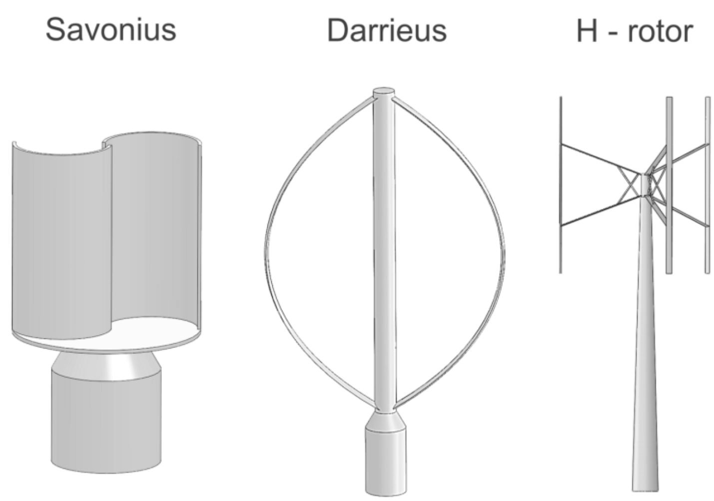
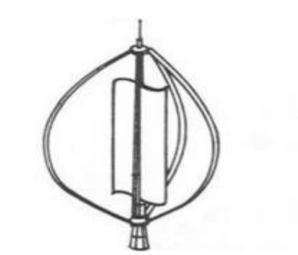


Figure 3: Lift Based Turbine (D.Anderson, 2007)

Darrieus Turbines:

The Darrieus wind turbine is a type of vertical axis wind turbine (VAWT). The curvature of the blades allows the blade to be stressed only in tension at high rotating speeds. There are several closely related wind turbines that use straight blades.



Combined Darrieus and Savonius vertical axis wind turbine.

Figure 4: Darrieus and Savonius combination turbine (D.Anderson, 2007)

2.5-General Lift and Drag Forces:

Lift force is caused by pressure and viscous effects from the air that is exerted on an airfoil. It acts orthogonally to the relative velocity and is oriented perpendicular to the drag force. The air exerts a force on the airfoil in the direction of the flow called drag, which is caused by pressure and friction. The normal and tangential forces are found by summing the tangential and normal components of the lift and drag forces. The AOA i.e. Angle Of Attack is defined as being the angle between the relative velocity and the chord, shown in figure below. The chord is the straight line from the leading edge to the trailing edge of the wing profile. For objects which are designed to generate lift, the contribution from the viscous effect can be neglected, so the lift force is only depending on the pressure differences at the airfoil's surfaces. The drag force is a sum of friction (skin) drag and pressure (form) drag. The induced drag which is related to end effects of airfoils will be described separately. Both lift and drag coefficients are dependent the airfoil's orientation in the flow. This orientation is represented by the AOA. Airfoils are designed to generate lift and minimize drag. [6]

2.5.1-Lift Force:

Lift is mainly generated by the pressure distribution on the surface of an airfoil. This pressure distribution is formed by the shape of the airfoil. The airfoil is designed so that the top and bottom surfaces can have different curvatures, which means that the flow moving over and under the airfoil will have to take a different length path. For a symmetrical profile, this difference is created by changing the AOA.

Conservation of mass requires that the amount of air before and after the airfoil must remain constant. The difference in path length causes the flow over the longer section (the top surface) to briefly accelerate. According to Bernoulli's equation this increase in velocity results in a decrease in pressure. The pressure vacuum along the top surface of the airfoil creates a pressure gradient which is what creates the lift force. The pressure distribution on an airfoil can be seen in figure below. [3]

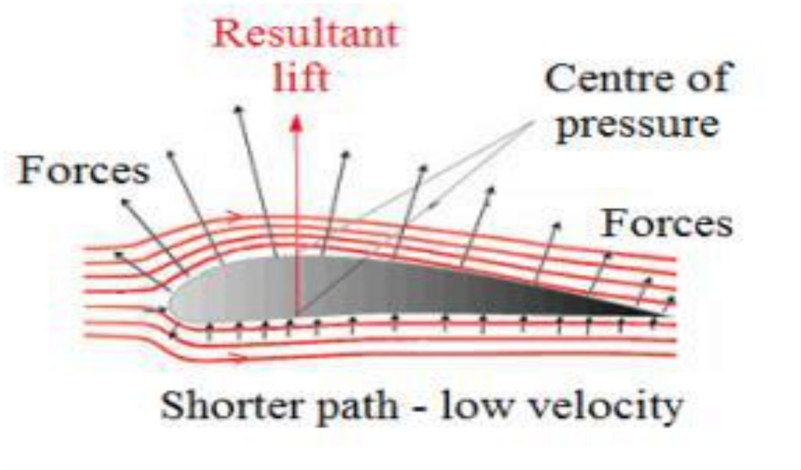


Figure 5: Pressure Distribution on an Airfoil (ManWell, 2002)

As the flow passes over the airfoil the faster moving fluid on the top must begin to decelerate as it approaches the trailing edge. The flow at the trailing edge must have the same velocity on the top and the bottom of the airfoil. If it does not then there will be a shearing in the flow that will cause significant amount of drag and turbulence downstream of the airfoil. If the flow does have the same velocity on top and bottom of the profile and the trailing edge is sharp, then the Kutta Condition will be met. This will result in a stagnation point at the trailing edge which allows the air to be smoothly shed from the airfoil. Figure below shows how there initially is a large pressure drop on the top surface due to the acceleration of the flow, but as the flow passes over the profile the pressure drop decreases so that the velocities on both surfaces of the trailing edge are equal.

$$C_L = \frac{F_L}{\frac{1}{2}\rho V^2 A} \tag{1}$$

Where,

C_L = lift coefficient [-]

F_L = lift force [N]

V = velocity of the fluid [m/s]

A = area of the airfoil [m^2]

The lift coefficient is a non-dimensional number that describes how effectively an airfoil changes the flow to generate lift. Due to the different geometries of airfoils, there are unique values of the coefficients of lift for each airfoil. These lift coefficients is plotted based on AOA at a given Reynolds number.

2.5.2-Drag force:

Drag forces resist the forward motion of an object, so for vehicles such as airplanes the drag force must be compensated by an increase in thrust. Drag is broken into two categories: friction (skin) drag and pressure (form) drag. Frictional drag is due to surface shear stresses and is a function of viscosity. The Reynolds number is inversely proportional to viscosity, so at higher Reynolds numbers the contribution from frictional drag will become less significant. When frictional drag is exerted on a body in a turbulent flow it is also a function of the surface roughness. A smooth and nonporous material has less frictional drag than a rough or porous one.

The pressure drag is a function of the frontal area and the pressure difference between the front and back of an object. The pressure drag is small for streamlined objects such as an airfoil. When it is not possible for the flow to follow the surface, it separates from a location called the separation point. The flow after the separation point can be described as highly turbulent and creates eddies that are in a low pressure region. This means that the pressure drag will continue to increase as the AOA increases because the pressure gradient from leading to trailing edge is increasing.

Drag is calculated with an equation very similar to lift. Like lift, a non-dimensional number, called the coefficient of drag, has been created to express the drag as a function of AOA and Reynolds number. [9]

$$C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A} \qquad (2)$$

Where,

C_D = drag coefficient [-]

F_D = drag force [N]

V = velocity of the fluid [m/s]

A = Area of the airfoil [m^2]

Considering finite wings, the end effect of the wings will be an important parameter, because there will be a fluid leakage between the top and bottom of the airfoil. The leakage on a lift producing wing is caused by the flow curling from the high pressure side, to the low pressure side.

The curling of flow around the wing tips creates trailing vortex at both wing tips, as shown below. These tip vortices tend to take the surrounding air with them, which creates a small downwards velocity also called downwash.

2.6: Airfoil

2.6.1-Introduction

It is a fact of common experience that a body in motion through a fluid experiences a resultant force which, in most cases is mainly a resistance to the motion. A class of body exists, However for which the component of the resultant force normal to the direction to the motion is many time greater than the component resisting the motion, and the possibility of the flight of an airplane depends on the use of the body of this class for wing structure. Airfoil is such an aerodynamic shape that when it moves through air, the air is split and passes above and below the wing. The wing's upper surface is shaped so the air rushing over the top speeds up and stretches out. This decreases the air pressure above the wing. The air flowing below the wing moves in a comparatively straighter line, so its speed and air pressure remains the same. Since high air pressure always moves toward low air pressure, the air below the wing pushes upward toward the air above the wing. The wing is in the middle, and the whole wing is "lifted." The faster an airplane moves, the more lift there is. And when the force of lift is greater than the force of gravity, the airplane is able to fly. [4]

2.6.2-Nomenclature of an airfoil

An airfoil is a body of such a shape that when it is placed in an airstreams, it produces an aerodynamic force. This force is used for different purposes such as the cross sections of wings, propeller blades; windmill blades, compressor and turbine blades in a jet engine, and hydrofoils are examples of airfoils. The basic geometry of an airfoil is shown in Figure below: [2]

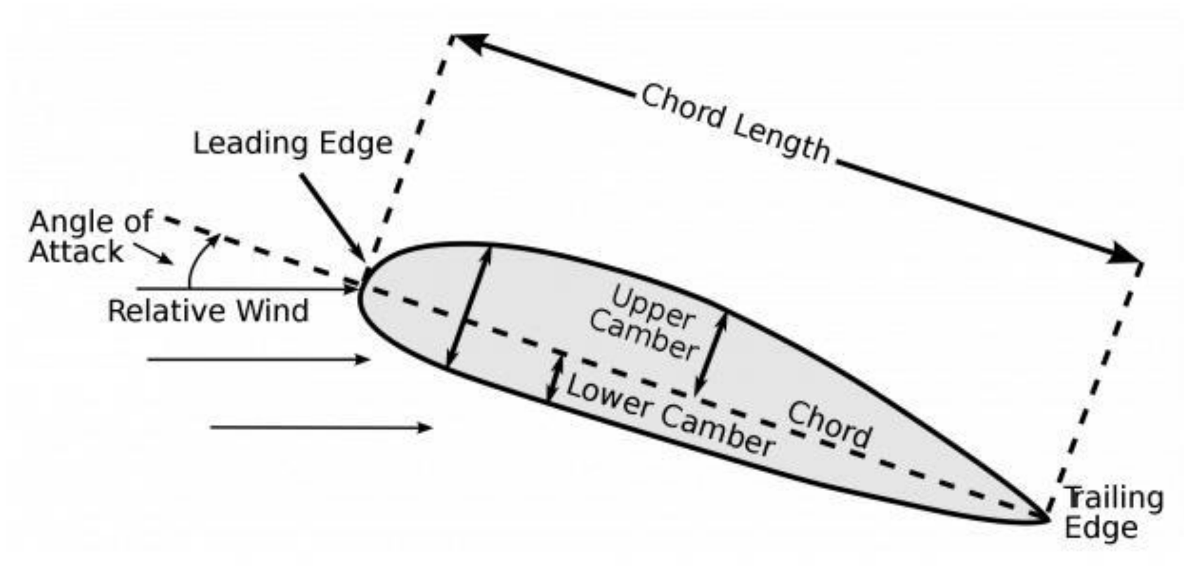


Figure 6: Basic Geometry of an Airfoil (ManWell, 2002)

The leading edge is the point at the front of the airfoil that has maximum curvature. The trailing edge is defined similarly as the point of maximum curvature at the rear of the airfoil. The chord line is a straight line connecting the leading and trailing edges of the airfoil. The chord length or simply chord is the length of the chord line and is the characteristic dimension of the airfoil section.

2.6.3- Angle of Attack

If you stretch your arm out through the window of car that is moving at a good speed, you can feel your arm pushed backward. If you hold your arm straight with your hand parallel to the road, and change the angle slightly, you can suddenly feel that it is drown upwards. The hand and arm work like the wing of an airplane and with the right angle (of attack) you can feel a strong lift force.

AOA is the angle between the oncoming air or relative wind and a reference line on the airplane or wing. Sometimes the reference line is a line connecting the leading edge and trailing edge at some average point on a wing. Most commercial jet airplanes use the fuselage center line or longitudinal axis as the reference line. It makes no difference what the difference line is as long as it used as consistently. As the nose of the wing turns up, AOA increases, and lift increases. Drag goes up also, but not as quickly as lift. During take-off an airplane builds up to a certain speed and then the pilot “rotates” the plane that is, the pilot manipulates the controls so that the nose of the plane comes up and, at some AOA, the wings generate enough lift to take the plane into the air. Since an airplane wing is fixed to the fuselage, the whole plane has to rotate to increase the wing's angle of attack. Front wings on racecars are fabricated so the angle of attack is easily adjustable to vary the amount of down force needed to balance the car for the driver. [08]

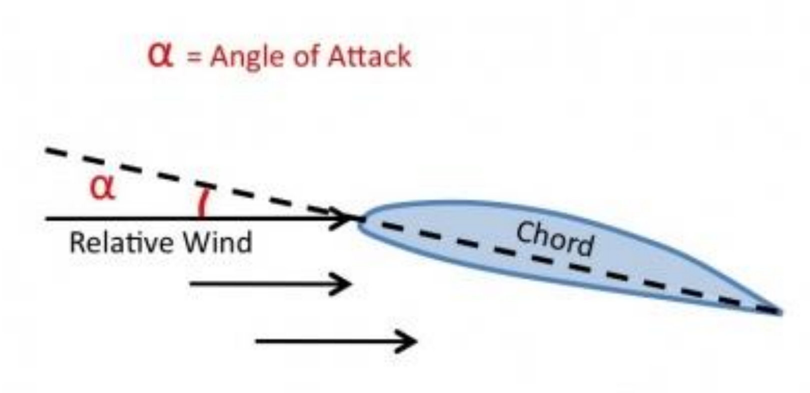


Figure 7: Angle of Attack on Airfoil (ManWell, 2002)

2.6.4- Coefficient of Drag and Coefficient of Lift

The drag equation,

$$F_d = \frac{1}{2}\rho v^2 c_d A \qquad (3)$$

also coefficient of drag is given by the,

$$c_d = \frac{2F_d}{\rho v^2 A} \qquad (4)$$

is essentially a statement that the drag force on any object is proportional to the density of the fluid and proportional to the square of the relative speed between the object and the fluid. In fluid dynamics the C_d is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment such as air or water. It is used in the drag equation where a lower drag coefficient indicates the object will have less aerodynamic or drag. The drag coefficients always associated with a particular surface area. The drag coefficient of any object comprises the effects of the two basic contributors to fluid dynamics drag: skin friction and from drag. The drag coefficient of a lifting airfoil or hydrofoil also includes the effects of lift induced drag. The drag coefficient of a complete structure such as an aircraft also includes the effects of interference drag. The overall drag coefficient defined in the usual manner is the reference area depends on what type of drag coefficient is being measured. For automobiles and many other objects, the reference area is the projected frontal area of the vehicle. This may not necessarily be the cross sectional area of the vehicle, depending on where the cross section is taken and for an airfoil the surface area is a plane form area. The lift 1equation,

$$L = \frac{1}{2}\rho v^2 A C_L \tag{5}$$

So coefficient of lift is given by the,

$$C_L = \frac{L}{\frac{1}{2}\rho v^2 S} = \frac{2L}{\rho v^2 S} = \frac{L}{qS} \tag{6}$$

A fluid flowing past the surface of a body exerts a force on it. Lift is the component of this force that is perpendicular to the oncoming flow direction. It contrasts with the drag force, which is the component of the surface force parallel to the flow direction. If the fluid is air, the force is called an aerodynamic force.

The lift coefficient of a fixed-wing aircraft varies with angle of attack. Increasing angle of attack is associated with increasing lift coefficient up to the maximum lift coefficient, after which lift coefficient decreases. As the angle of attack of a fixed-wing aircraft increase, separation of the airflow from the upper surface of the wing becomes more pronounced, leading to a reduction in the rate of increase of the lift coefficient. The figure shows a typical curve for a cambered straight wing. A symmetrical wing has zero lift at 0 degrees angle of attack. The lift curve is also influenced by wing platform. A swept wing has a lower, flatter curve with a higher critical angle. Identically the value of drag coefficient is zero at the zero AOA and it increase slowly till the stall condition and at the time of stall as well as after stall it increase readily as shown in figure 3.

Particular airspeed, the airspeed at which the aircraft stalls varies with the weight of the aircraft, the load factor, the center of gravity of the aircraft and other factors. However the aircraft always stalls at the same critical angle of attack. The critical or stalling angle of attack is typically around 15° for many airfoils.

2.6.5- NACA Airfoils

The NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). 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 NACA four-digit wing sections define the profile. [12] For example, the NACA 2412 airfoil has a maximum camber of 2% located 40% (0.4 chords) from the leading edge with a maximum thickness of 12% of the chord. The NACA 0015 airfoil is symmetrical, the 00 indicating that it has no camber. The 15 indicates that the airfoil has a 15% thickness to chord length ratio: it is 15% as thick as it is long. [7]

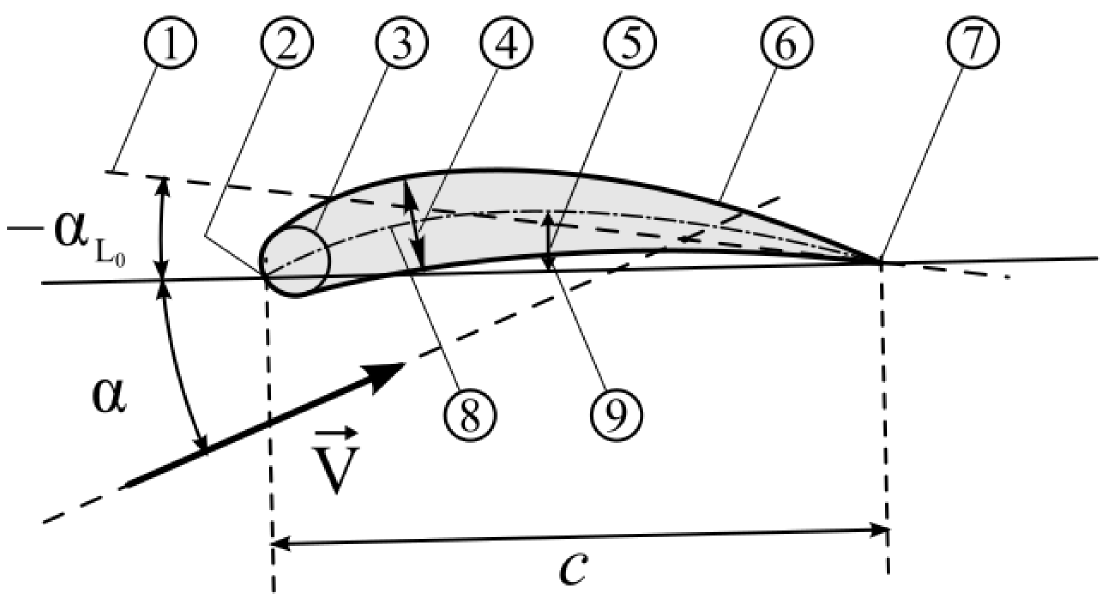


Figure 8: Geometry of an Airfoil (E.N.Jacobs, 1933)

2.6.5.1- Q-Blade

QBlade is an open source wind turbine calculation software, distributed under the GPL. The integration of the XFOIL/XFLR5 functionality allows the user to rapidly design custom airfoils and compute their performance polar and directly integrate them into a wind turbine rotor design and simulation. The software is especially adequate for teaching, as it provides a ’hands on’ design and simulation capabilities for HAWT and VAWT rotor design and shows all the fundamental relationships of design concepts and turbine performance in an easy and intuitive way. QBlade also includes extensive post processing functionality for the rotor and turbine simulations and gives deep insight into all relevant blade and rotor variables. In addition to that, the resulting software is a very flexible and user-friendly platform for wind turbine blade design.

CHAPTER NO 3

DESIGN AND SIMULATION

Design considerations involve assessing several parameters of blade design to find the most optimum design of blade. To accomplish the task, Blade design software QBlade and Fluid Module of ANSYS were used.

Defining Parameters for Turbine Design:

1- Diameter of a pipe

2- Velocity of Water

3- Turbine Diameter

4- Turbine Height

5- Blade Air Foil

6- Solidity - Chord Length

7- Number of Blades

3.1- Blade Profile:

The NACA profile is a standard that describes the geometry of an airfoil. NACA profiles can be described by four, five, or six digits, but in this report only the four digit series will be used. Many of the common four digit NACA profiles have experimental data available that gives plots of the coefficients of lift and drag. For uncommon profiles there are programs available to calculate the coefficients of lift and drag. The NACA profile is shown in figure 9, with the terms related to an airfoil. The chord is the straight line, from the leading edge to the trailing edge of the wing profile, see figure 9. The mean camber line is a line of points, half way between the lower and upper surfaces. The camber is the difference between the chord and the mean camber line. If the camber of a wing profile is great enough, the chord will travel outside of the physical structure of the wing profile. The mean camber line will always remain inside the wing profile. The thickness is the distance between the upper and lower surfaces oriented normal to the chord.

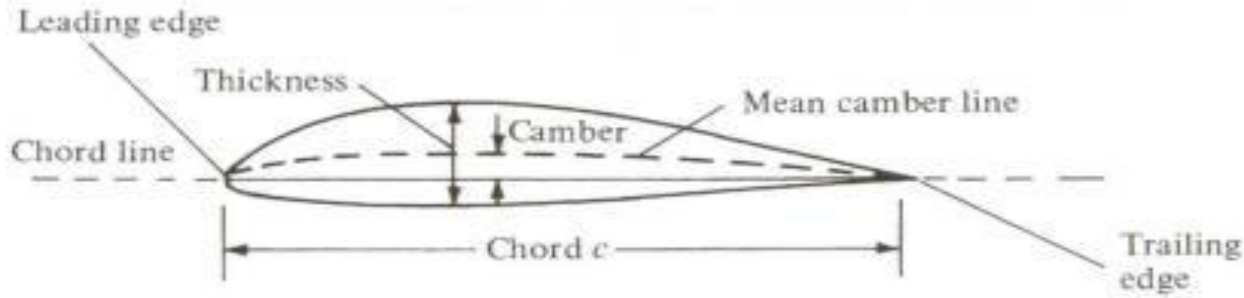


Figure 9: Terms used for NACA profiles (ManWell, 2002)

Each digit represents information used for drawing the NACA profile. The functions of each digit in the four digit NACA profiles are described below:

• 1st: The first digit describes the maximum camber as a percentage of the chord.

• 2nd: The second digit is the location of the maximum camber, from the leading edge in tenths of the chord.

• 3rd and 4th: The last two digits describe the maximum thickness in hundredths of chord.

Several blades profiles were analyzed on the software (shown in Table 1) and the best one with the highest Cl/Cd ratio was selected. NACA 4415 was selected not only on the basis of the aforementioned ratio, but also the fact that cambered profile is better than symmetrical profiles for self-starting purposes which is a major issue with vertical axis turbines.

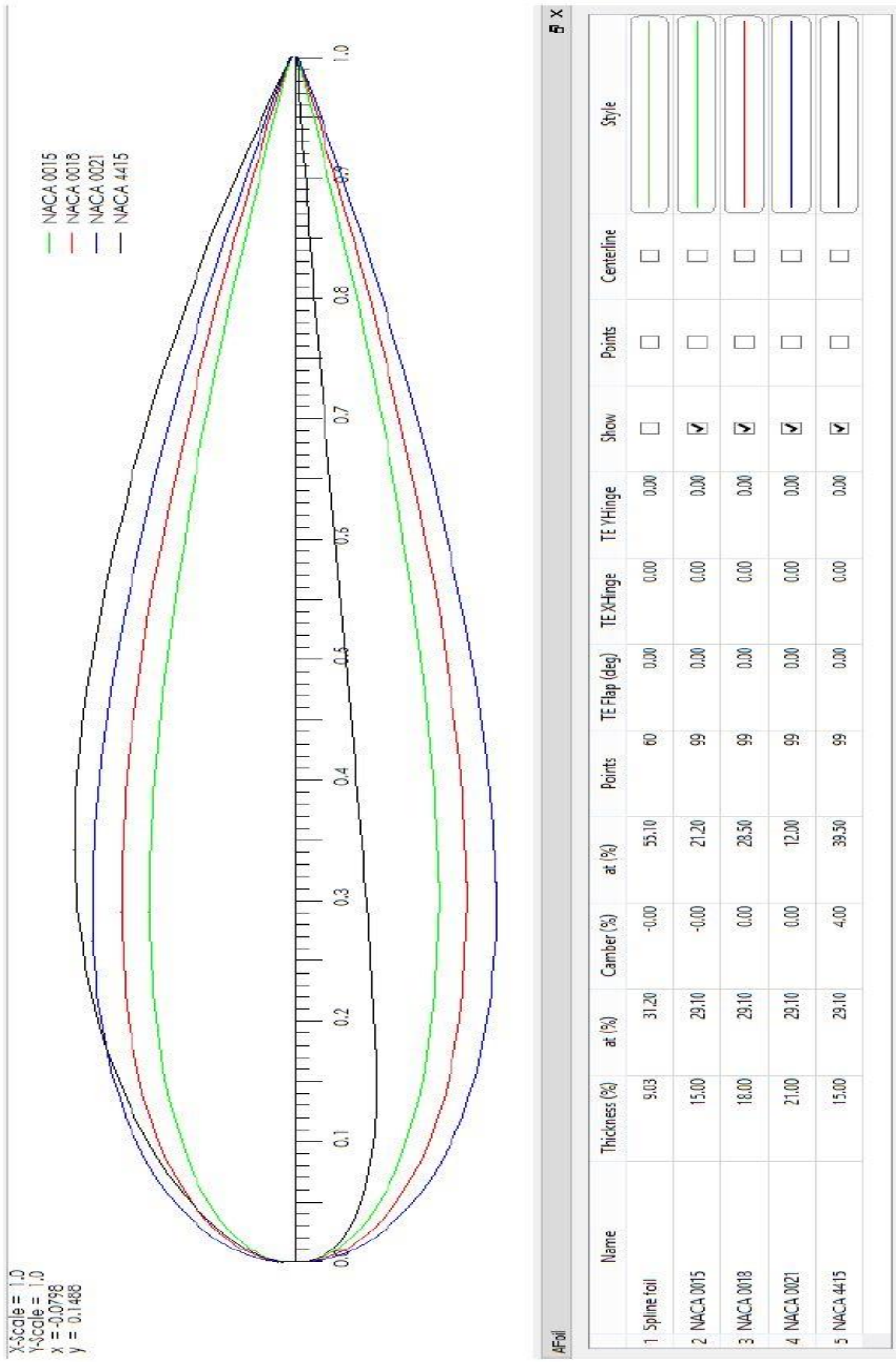


Figure 10: Cl/Cd vs solidity ratio for NACA Airfoils

A model for the Savonius turbine with 2 blades was designed on Solidworks was simple structural feasibility analysis, stress analysis test, power and torque calculations. The design is shown below:

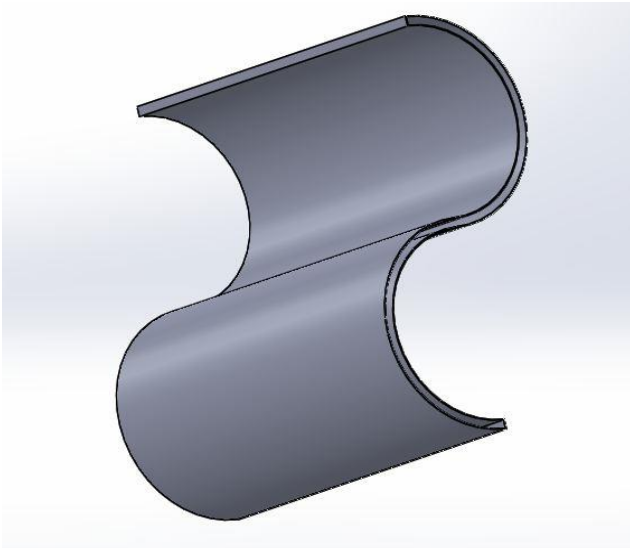


Figure 11: Savonius Turbine

A Darius turbine with 3 rotor blades using NACA 4415 airfoil was designed in Solidworks for carrying out the structural analysis, stress analysis. This design was the main crux of the project on which the furthermore success was relying upon. The design is shown below:

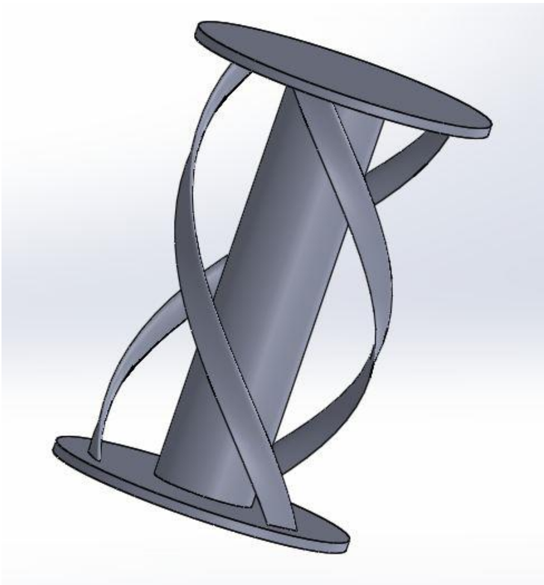


Figure 12: Turbine blades

Next we designed our water proof bearing in Solidworks so that the simulations could be done on a real time model that would give us close to real values. The designed bearing is shown as below:

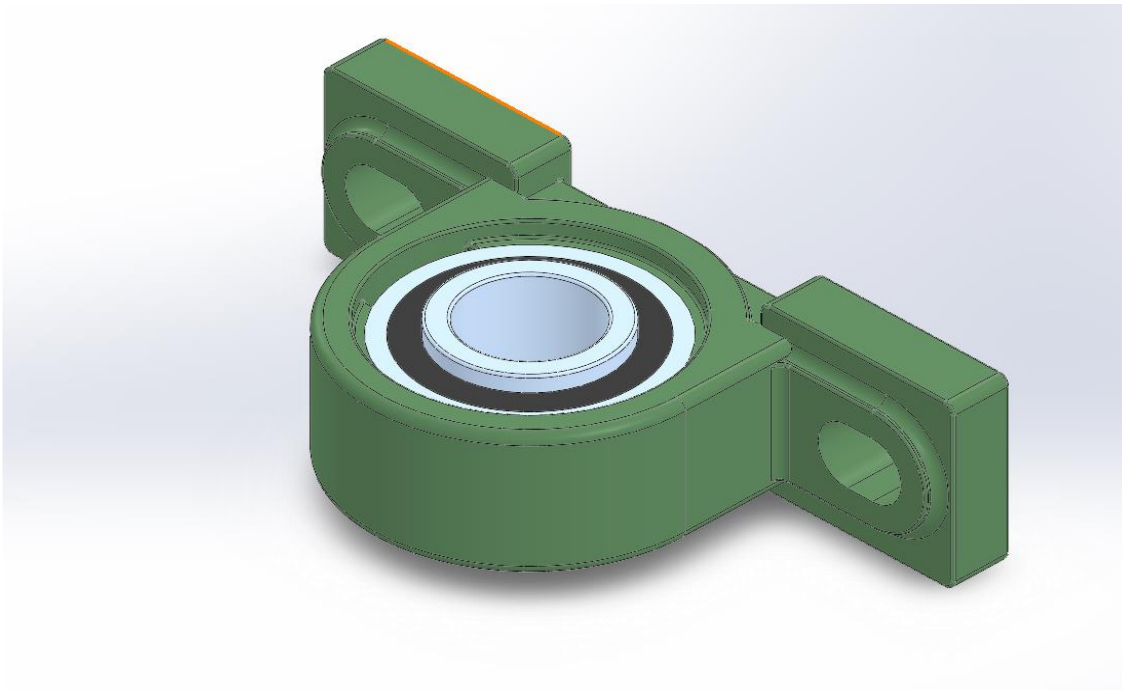


Figure 13: Waterproof Bearing

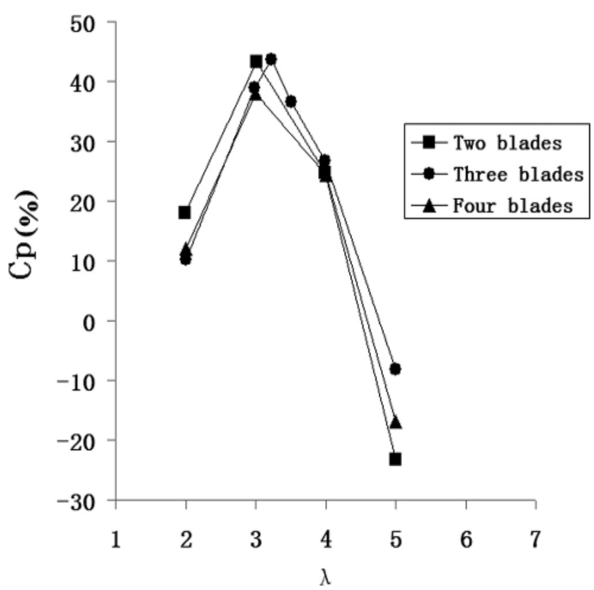


Figure 14: Co-efficient of Performance vs Solidity

We selected the 3 blades design because of solidity ratio calculated which will be shown in the later stages of the FYP report which is shown in the graph above

A stand was designed for the turbine for its structure to withstand the weight of turbine and the flow of water. It was designed to bear the load of the turbine along with the load of the generator and the gearbox that would be an essential part of the turbine. There is also a possibility of addition of a controller along with the motors that would control the orientation of all three air foils. [5]

SolidWorks was used to do the simulation testing of the stand and two models were obtained. The models shown first shows the static nodal stress test

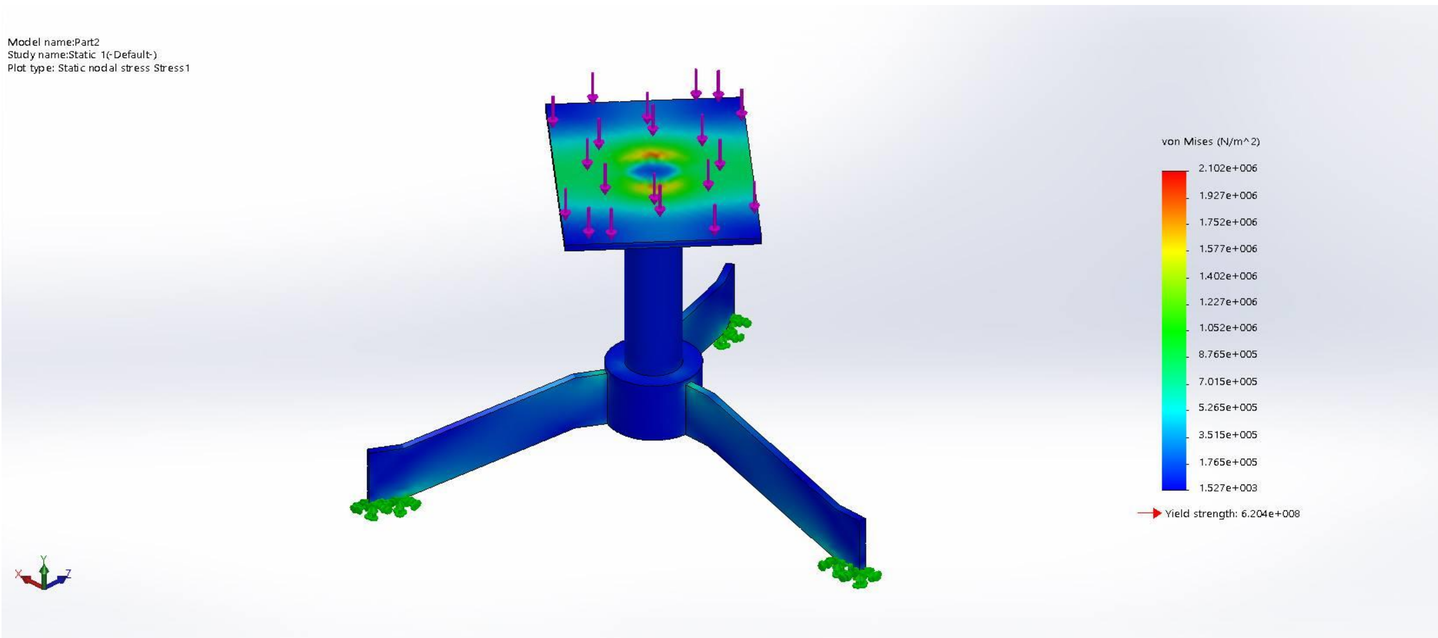


Figure 15: Nodal stress test

The latter part of the model shown represents the static displacement of the model.

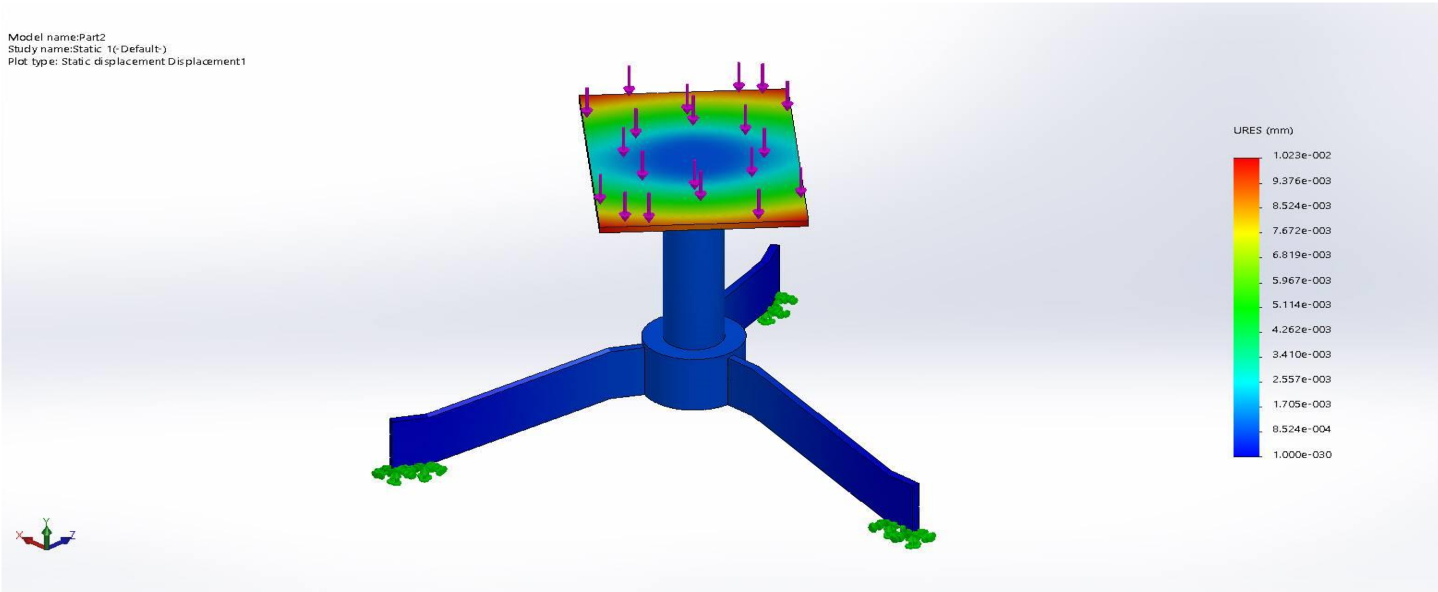


Figure 16: Static Displacement test

But when we tested the stability of the above mentioned stand, a new problem encountered. The stand was structurally stable and sound but when put in a flow of 2m/s or above, tipping occurred. For this purpose we designed a new stand which could bear velocities of water up to 7m/s and was designed in a better way to protect the turbine blades from rocks and other impurities in water from disturbing the rotation of turbine. The final design was made on Solidworks as shown:

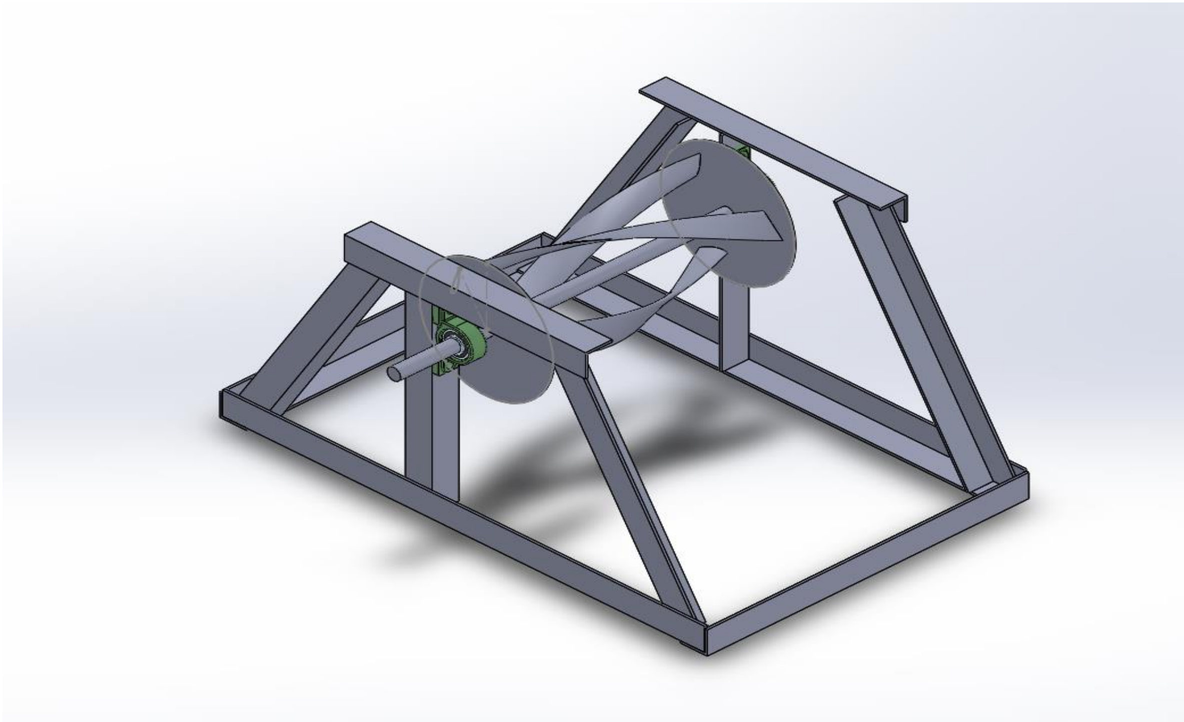


Figure 17: Turbine Model

3.2- ANSYS (Fluent) Simulation:

A simulation was carried out in ANSYS. After the model was developed in solidworks and it was exported in form of two parts

- The central rotating part including the air foil.
- The rectangular enclosure.

Both were then exported in the IGES(.igs) format to import the geometry in the Fluent module. It was then observed in design modeler and inlet, outlet walls were indicated. We were to observe the torque produced by the water flow in the open channel. Water inlet velocity was set at 1.6 m/s. The flow was transient and k-epsilon model was used. The pressure drop will occur at the airfoil because of their specific design. Because of the pressure difference created due to the design, we will observe a force that will act on the blades. This force when multiplied with the radius of the blades will give us the torque acting on the turbine blades.

Moreover when torque was plotted against time, the solution did not converge to a specific value.

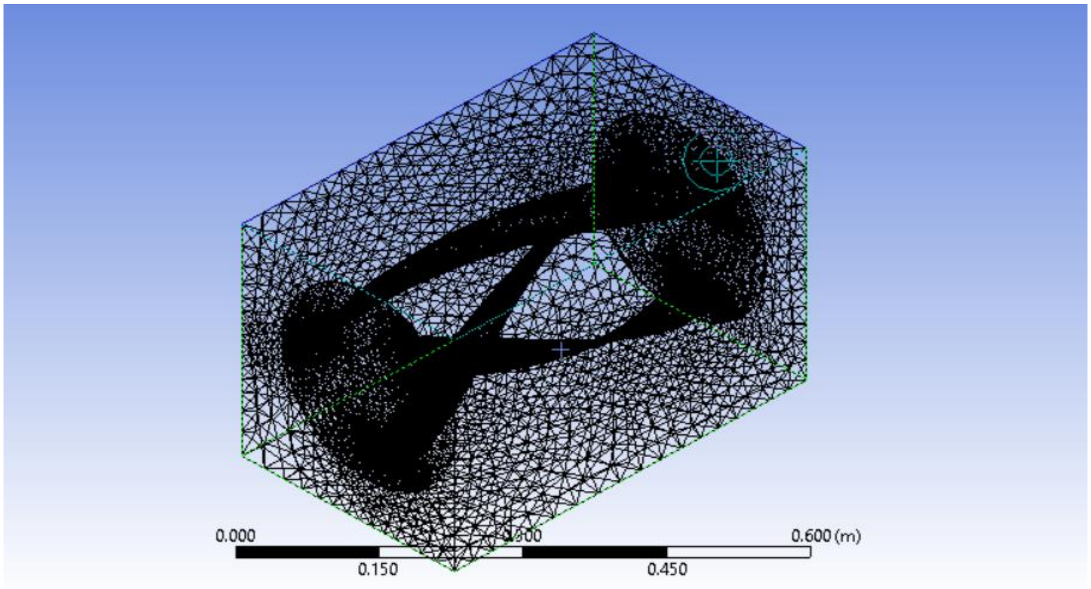


Figure 18: Ansys. igs model

The prssure contour that we simulated for our turbine showed that the turbine blades can sustain the pressure and torque for a velocity of water upto 6m/s. The pressure contour is shown below:

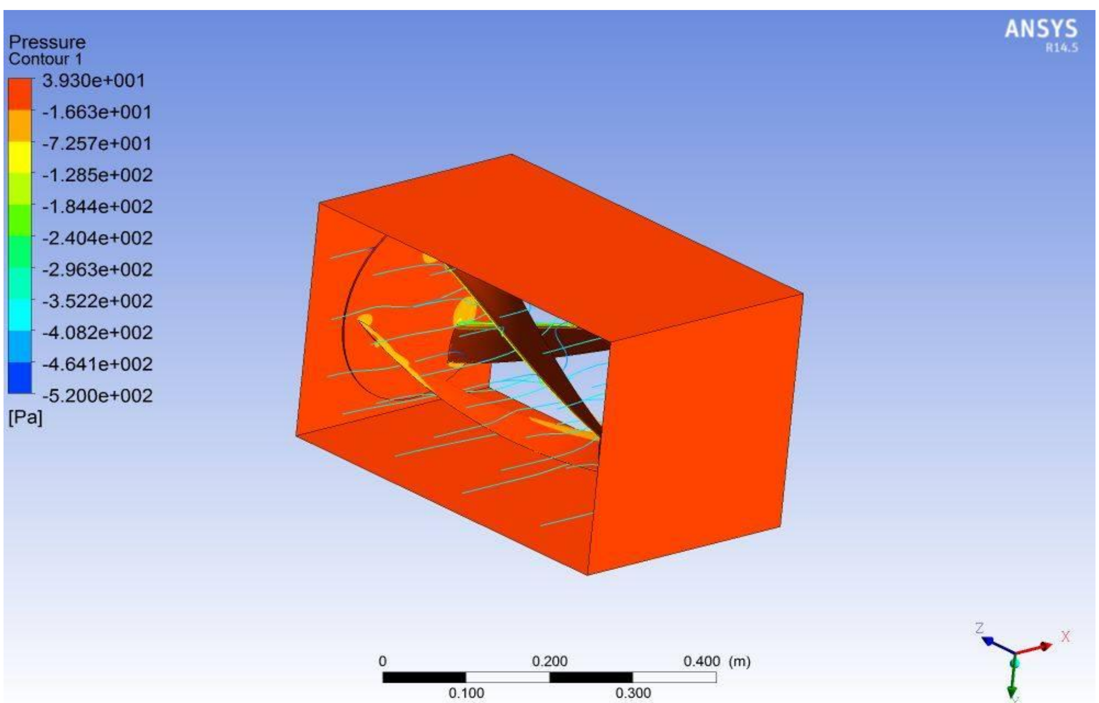


Figure 19: Pressure Contour on turbine

CHAPTER NO 4

METHODOLOGY

The manufacturing of our turbine was a rigorous and a very time consuming part of our project completion. In order to simplify the whole process that we had to go through, we have divided the methodology part into different sections as given below:

4.1- Intro

There are several steps in development of any prototype or product. These steps are dependent on each other and are required to be executed in a specific sequence. After our literature review and design we move towards converting our design into reality that is the fabrication of the prototype. We have divided fabrication into three main parts that are discussed below completely.

4.2- Rotor fabrication

The most technical and crucial part of our prototype is the rotor which is the only rotating part in our prototype and is responsible for effectiveness. Thus it requires more care and accuracy. For the rotor fabrication we decided to use 3D printing as it gave an efficient and more accurate solution to our problem

4.3- 3D Printing

Since our rotor is based on three helical air foils there is no other reliable way we to fabricate those without 3D printing. So we used 3D printing to print a single air foil then we used it as a mold to cast the other parts in order to lower the cost and maximize the strength of our blades. Filing was done on the blades later on to make it as smooth as possible as the casting left many blisters and unfinished surface on the blades.

There was a limitation about the size of bed of 3d printer. Our blade was 18 inch in length while the 3D printer had a bed size of (6 x 6 x 8) inches In order to overcome this issue the blade was divided into 3 parts 6 inches each which were later aligned and glued together to make one single profile before it went to the casting stage. Material used for 3d printing was poly lactic acid.

4.4- Material selection

There were several options under considerations regarding material selection for the fabrication of the turbine rotor, as the options available were: Fiberglass, Aluminum, Mild steel. Strength to weight ratios were compared for all three mentioned materials in the end we deducted aluminum to be the best option in order to minimize rotational inertia thus reducing the torque needed for the turbine to rotate and as it offered a rust free solution.

4.5- Casting

The 3d printed part was used as a mold and aluminum was used to cast the blade. Three such parts were casted and filed in order to achieve better finish on the surface.

4.6- Assembly

Central shaft used was made up of mild steel because of its strength. Two discs were placed and in between the blades were placed at intervals of 120 degrees according to the 3D model of final design. In order to make the turbine portable and easy to maintain temporary fixtures were used. Nuts and bolts were used for all the joints.

4.7- Frame fabrication

Since our operating conditions are harsh that is fluid at 1.6 m/s we needed a frame to house the rotor that can withstand such swift flow.

So we went with a frame of mild steel that is completely welded in order to re enforce it and give some extra strength. There is a slit within to facilitate the change in height of rotor according to water level as to make it adjustable.

4.8- Power generation assembly

We used a 12V DC Motor for the power generation purposes, Model GMX-7MP008A DC 20V 465 RPM. The motor is placed on the angle iron structure just above the shaft of the Turbine, held into place by 4 nuts and bolts that are in drilled holes on the angle iron. A Gear of 1.5 inch diameter has been used on the motor shaft while a gear of 8 inch diameter has been used on the turbine shaft. With a gear ratio of just above 3, when the turbine rotates with the flow of water, the shaft of the motor rotates at a speed more than 3 times to it. This way electricity is generated by the motor which is extracted by the wires assembly attached to it.

CHAPTER NO 5

CALCULATIONS AND TESTING

The turbine was tested in a canal near Taxila originating from Khanpur Dam. The initial data that we took from the Canal is as follow:

Speed of water = 1.3m/s

Depth of Canal = 1.5 feet

Temperature of water = 19 Degree Celsius

Reynold’s Number = 10^5

The Calculated values for our Turbine are as follow:

Table 1: Mathematical Model of Turbine

Parameters	**Values**
Solidity	0.34
Tip Speed Ratio	2.36
Co-efficient of Performance	21%
Turbine Frontal Area	0.07 (m^2)
Power from Frontal Area	19.31 (W)
RPM	194
Torque	1.47 (Nm)
Angular Speed	20,.31 (rad/sec^2)
Tip Speed of the blade	8.57 (m/s^2)
Co-efficient of Lift	2.23
Co-efficient of Drag	2.24
Co-efficient of Moment	0.04

5.1- Testing:

Testing of the turbine was done twice. The first time the turbine was without the power production unit on it, thus it was a test to see if the blade design was practically viable or not. The turbine gave an encouraging result by rotating at 158 rpm on a water stream with a flow of 0.8 m/s.

The second time the turbine was taken to the original testing site; a canal near Taxila originating from Khanpur Dam. This time the turbine was complete and had its power generation unit on it. A 12V DC Motor was GMX-7MP008A DC 20V 465 RPM. The values which were measured on site are as follow:

Table 2: Testing Results

Parameters	**Values**
RPM of turbine blades	97
RPM of Motor Shaft	301
Voltage	11.64 (Volts)
Current	2.47 (Amperes)
Power	28.75 (Watts)

Table 3: Testing Photographs

CHAPTER NO 6

CONCLUSIONS AND RECOMMENDATIONS

6.1- Conclusion:

- Aluminum 6061 is a suitable material for the turbine and is able to sustain the pressure applied by the water as it has the non-rusting ability as well.
- 3 Blade Turbine is more efficient than 2 blade turbine and is better than 4 Blade one in terms of pressure drop and economic consideration.
- There is an optimum rpm for turbine to work and that allows the system to achieve efficiency of 40 percent. However, results achieved were on lower water velocity and hence lower rpm, so Cp=0.2 was achieved. Imperfections in casted blades and motor efficiency also played their role in lowering the efficiency.
- Larger blades give much higher power output since power is directly proportional to square of its diameter. Also higher velocities increase the power manifolds since power is directly proportional to cube of water velocity.
- Experimental results though on the lower side but still are in very much agreement with the analytical results which makes it safe to assume that the original turbine calculations will prove to be accurate when applied to the larger scale for a Dam.

6.2- Recommendations:

Cambered profile was selected for the original turbine design with the intention of reducing starting torque application problem. That theory still needs to be tested in real time situation.

NACA profiles of only 4 digits were used. However, 5 or 6 digit profiles can be tested for research purposes since academic data is not in much abundance and it will give us new perspective as to possibilities attached with those profiles.

Helical angle allows for the rotation of the blades from any direction of water. However, the turbine was erected vertically and was tested in the same orientation in the canal. Testing it with varying orientations will also open new dimension of understanding the functioning of the turbine.

The turbine model that we designed and fabricated can be used in real time solutions after up scaling the model. The countless advantages could include use under bridges in northern areas for free street lights, use in a restaurant near a stream of river for its electricity etc. Thus there are countless possibilities for the future that lies ahead.

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APPENDIX - FORMULAE

- TSR = (RPM*π*Dia)/(60 * v)
- Tip speed of the blade = (TSR * velocity of water)
- Angular velocity = (RPM * 2π/60)
- Error = (Ideal value – experimental value)/ideal value * 100%
- Torque = (Power / angular velocity)
- Coefficient of Drag = (drag force/ q*Area)
- Where q = (1/2 * density * velocity^2)
- Coefficient of Lift = (Lift Force/ q*A)
- Coefficient of moment = (Moment/ q*A*Chord length)
- RPM = (hp * 2525)/Torque