DESIGN AND ANALYZING OF SMALL BLADE WIND TURBINE

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"The good life is inspired by love and guided by knowledge."

-Bertrand Russel.

"The beginning of knowledge is the discovery of something we do not understand."

- Frank Herbert.

IN LOVING MEMORY:

AMAT JAFAR BIN ASMAT

Specially dedicated with an everlasting love to

MAMA, SIS & BRO

For all the Care, support and believe in me.

And to all my dearest UMP friends;
Our journey starts with smile, as we trying to find our place in here.
It comes to an end, as we already know where we belong in this world.
I engraved all the memories that we shared in my heart, the smile, the laughter, and the cries
For I am so grateful to have know each and every one of you
Thank you for this loving memory.

Sincerely,
Zarina binti Amat Jafar

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In the Name of Allah, the Compassionate,
The Merciful,
Praise is to Allah, Lord of the Universe.

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ABSTRACT

Renewable energy is now very popular in replacing the power sources that been available in the market. It was a good source which gives a lot of advantages to the environment also to the world community. For this project, the focus is on one of renewable energy that been popular since 19th century. Wind power system before had been a popular used among the farmer and rural country which did not have any electric supplier. The blade wind turbine, play an important role to the wind turbine performance. According to the previous research, it had been stated that the shape of blade wind turbine is the most critical part in wind turbine as it the one that will capture the wind. From the previous research, the pioneer of the small wind turbine already was using an aerodynamics concept in making the shape design for the blade wind turbine. There are several types of aerofoil concept in the market, but the shape that always being used is three popular type that is flat bottom, curved bottom and symmetrical. For this project, the analysis is to find out from these three types of shape which can produce a higher lift force with lower drag force. The analysis was done by using CFD Cosmos Floworks. In CFD, the parameter being search is the Lift and the Drag force. From the analysis result that being review, it was clear that the best shape design that can produce higher lift force with lower drag force is the flat bottom type with 0.03m thickness.

ABSTRAK

Tenaga angin merupakan salah satu tenaga yang dikenalpasti sebagai sumber tenaga yang boleh di perbaharui dari hari ke sehari tanpa perlu bimbang akan kehabisannya. Penggunaannya pada masa sekarang adalah sangat popular kerana mampu menggatikan sumber mentah lain yang telah berada di pasaran. Itu adalah sumber yang bagus yang memberikan banyak keuntungan kepada persekitaran juga untuk masyarakat dunia. Tenaga anginsudah begitu popular dan telah diperkenalkan kepada masyarakat dunia sejak awal kurun ke 19 lagi Sistem tenaga angin sebelumnya telah popular digunakan di kalangan petani dari luar bandar yang tidak punya bekalan elektrik yang mencukupi untuk menampung penggunaan tenaga tersebut sehari harian. Kipas turbin angin, memainkan peranan penting untuk prestasi turbin angin. Menurut kajian sebelumnya, telah dinyatakan bahawa bentuk kipas turbin angin adalah bahagian paling penting dalam turbin angin kerana ianya di gunakan untuk mengumpul segala kuasa dari angin yang bertiup. Dari penelitian sebelumnya juga, pelopor turbin angin kecil telah menggunakan konsep aerodinamik dalam membuat rekaan bentuk untuk kipas turbin angin. Ada beberapa jenis konsep aerofoil di pasaran, tetapi bentuk yang selalunya digunakan adalah tiga jenis yang popular iaitu jenis tapak rata, tapak melengkung dan simetrik. Untuk projek ini, tiga jenis aerofoil ini digunakan untuk mengetahui yang mana satu kah daripada tiga jenis bentuk ini dapat menghasilkan gaya angkat lebih tinggi dengan gaya tarikan yang lebih rendah. Analisis ini dilakukan dengan menggunakan CFD Cosmos Floworks. Dalam CFD, parameter yang akan di cari adalah daya tujahan dan daya tolakan. Daripada keputusan analisis yang sedang diperiksa, jelaslah bahawa rekan bentuk terbaik yang dapat menghasilkan gaya angkat lebih tinggi dengan gaya tarik yang lebih rendah adalah jenis tapak rata dengan ketebalan 0.03M.

TABLE OF CONTENTS

TITLE PAGE		**i**
PANEL DECLARATION		**ii**
SUPERVISOR'S DECLARATION		**iii**
STUDENT'S DECLARATION		**iv**
DEDICATION		**v**
ACKNOWLEDGEMENTS		**vi**
ABSTRACT		**vii**
ABSTRAK		**viii**
TABLE OF CONTENTS		**ix**
LIST OF TABLES		**xii**
LIST OF FIGURES		**xiii**
LIST OF SYMBOLS		**xiv**
LIST OF ABBREVIATIONS		**xv**
LIST OF APPENDICES		**xvi**
CHAPTER 1	**INTRODUCTION**	
	1.1 Introduction	1
	1.2 Problem Statement	2
	1.3 Objectives	4
	1.4 Scope of Study	4
	1.5 Summary	4

CHAPTER 2 OVERVIEW ON WIND TURBINE

2.1 Introduction 5
2.2. History of wind turbine 5
2.3 System in wind turbine 7
2.3.1 Types of wind turbine 7
2.3.1.1 HAWT 7
2.3.1.2 VAWT 9
2.3.2 Component in wind turbine 11
2.3.2.1 Rotor 12
2.3.2.2 Drive Train 13
2.3.2.3 Main frame and nacelle 14
2.3.2.4 Tower 15
2.4 Summary 15

CHAPTER 3 BLADE DESIGN METHOD

3.1 Introduction 16
3.2 Design blade using SolidWork 19
3.2.1 Basic dimension for the blade design 20
3.2.2 Material selection 20
3.3 Design type and proposed final design 20
3.3.1 Flat type bottom 21
3.3.2 Curved bottom type 23
3.3.3 Symmetrical type 24
3.4 Analysis in CFD 25
3.5 Summary 26

CHAPTER 4 RESULT AND DISCUSSION

4.1 Introduction 27
4.2 Simulation result 28
4.3 Summary 33

CHAPTER 5	**CONCLUSION**	
	5.1 Conclusion	34
	5.2 Recommendation	35
REFERENCES		36-37
APPENDICES A-B		38-46

LIST OF TABLES

TABLE NO	TITLE	PAGE
3.1	Wind Speed at Kuantan along September 2009	18
3.1	Basic dimension on the design	20
3.2	Material selection	20
4.1	Drag and lift force analysis	28
4.2	Frontal area for three designs	30
4.3	Drag coefficient for three design	30
4.4	Percentage of drag reducing	31
4.5	Lift, Drag coefficient, Lift to drag coefficient ratio	31
4.6	Lift and drag force for three different thicknesses	32

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
2.1	Various concept for HAWT	
	[Manwell, McGowan, Rogers, 2002]	10
2.2	Various concept for VAWT	
	[Manwell, McGowan, Rogers, 2002]	11
3.1	Flow chart of overall project .	17
3.2	Flow Chart of the methodology	19
3.3	Example of flat Bottom Type (Johnson, 2002-2009)	21
3.4	After modification flat bottom type design	21
3.5	Angle of the design from the cambered line .	22
3.6	Span Length	22
3.7	Curved bottom type	23
3.8	Overall dimension for curved bottom	23
3.9	Angle of the curved bottom from	24
	the cambered line (dashed line)	
3.10	Example of symmetrical type (Johnson, 2002-2009)	24
3.11	Overall dimension for the modified	25
	design of symmetrical type	
3.12	Computational Domain	26
4.1	Graph Drag and Lift force vs. the design shape	29
4.2	Drag and lift forces vs. the thicknesses	33

LIST OF SYMBOLS

Symbol		Units
D_f	- Drag force	N
L_f	- Lift force	N
ρ	- air density	kg m^{-3}
V	- wind speed	mls^{-1}
C_d	- Drag coefficient	-
C_l	- Lift coefficient	-
A	Frontal area	m^2

LIST OF ABBREVIATIONS

Computational-aided design	CAD
Computational-fluids dynamics	CFD
Horizontal axes wind turbine	HAWT
Vertical axes wind turbine	VAWT

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Analysis in CFD	38
B	Analysis flow in CFD	41

CHAPTER 1

INTRODUCTION

1.0 Introduction

Wind energy consumption had become a very critically and practically used in 21^{st} century (Peter, 2007). The usage of wind energy had now increased due to the awareness of the people around the world, how much advantages the wind energy can bring to the world. To collect the energy from the wind, what we need is a wind turbine.

Wind power as a renewable energy has started to develop rapidly since the late of the 1970s. The market for renewable energy has started to develop since the awareness of the energy used on that time has already facing some crisis on to finish and cannot be reused as the wind can provide (Wizelius, 2007).

As the wind energy does not create pollution and also does not need any fuel transport which can be harmful to the environment and also does not leave any damage waste behind it, it was become popular in some country (Wizelius, 2007).

Modern wind turbines are more efficient, more reliable and can generate power at a very cheap cost. As one of the renewable energy source, wind power can be seen as the most successful development compare to other renewable energy such as solar energy and running water energy (Wizelius, 2007).

This project is focused on designing and analyzing the best shape of small blade wind turbine. Wind turbine is a device which we used to convert the wind energy to become electricity power. The wind turbine can vary in its size. Turbine can vary from a very small wind turbine that can be built with a rotor only 0.5 meter to the giant machine with its rotor diameter can reach up until 100 diameters (Gipe, 2004). Larger the rotor diameter, we will gain the higher power output and vice versa.

Main focus of this project is to find the best shape of blade wind turbine. For the wind turbine to produce more power from the wind energy, it was decided by the performance of the blade wind turbine itself. The rotation speed of the blade also affects the energy being captured by the blade. The faster the rotation of the blade is the more energy can be captured by the wind turbine. All of the statement support the idea on how much the shape design for the blade wind turbine important to the wind turbine to ensure it perform on its optimum.

1.1 Problem statement

Now, more people aware about the effect of the used of emission gasoline combustion vehicle, which can cause air pollution, when the exhaust stream from the engine was released in to the air. Solution for this problem is by using an electric vehicle. As a general the project was focus on to find another alternative of battery-charging for electric vehicle.

Electric vehicle is different to the combustion vehicle due to its ‘fuel’. For the combustion vehicle, fuels such as petrol or diesel are needed to make the combustion happen, in other word to let the vehicle moved. While for the electric vehicle, what was needed is a pack of battery which can be re-charged over and over to make this type of vehicle moved. To recharge the battery what we need is an energy that can be gain without any loss to our environment.

Wind energy consumption as an alternative energy to be used in so many things. This type of energy cannot be finished and always can be used for our advantage in daily life. By using wind power, we can give solution to the battery-charging for electric vehicle also for home usage. With wind turbine we could never to worry about source of electric anymore.

Wind energy also can reduce pollutions in our country. The source of energy is taken from the nature, thus there is no pollutant can be created. As for these past few years our environment has become worse, these renewable energy can give solution to the matter.

By using wind energy, we can save a lot of money. The cost for wind energy can be said as free. The only cost we need to worry is cost for developing the wind turbine. The price to built wind turbine is not too expensive as all the tools and material needed, can be use from a junk thing.

The blade is important in wind turbine. It shape plays an important role to make sure the blade can give its optimum performance. To make sure the blade reaches its optimum performance the aerodynamic concept was applied to the design which the aerofoil design was chosen.

In aerodynamics, there are few forces acting on the airfoil shape such as thrust, drag and lift force. Thrust force is the an acting force that act on the blade. Lift force was defined to be perpendicular to direction of the oncoming airflow. The lift force is a consequence of the unequal pressure on the upper and lower airfoil surfaces.

Drag force was defined to be parallel to the direction of oncoming airflow. The drag force is due both to viscous friction forces at the surface of the airflow and to unequal pressure on the airfoil surfaces facing towards and away from the oncoming flow.

In order to make the blade move during an attack of air the lift forces plays an important role. This project was to make sure the lift force is higher than the drag force. The higher the lift force the blade can move even faster as long as the drag force was lower.

1.2 Objectives

The main objective of this project is to produce an optimized design of the blade for small wind turbine. In this project, three different designs that applied aerodynamic concept on it was chose, and modification of the design will be done to suit the project. Another objective is to find the lift and drag force that will be produced after the speed was being applied to it.

1.3 Scope of the study

The scope of this project is to use a Computer Aided Design (CAD) which is SolidWork to design the shape of the blade. The shape was based on three different shape that already being used in aerodynamics field. Second approach is to analyze the design using Computation fluids dynamics (CFD) that is Cosmos Floworks. In Cosmos Floworks, we were about to find the lift force and the drag force. Which are from the three shape of design can give higher lift with lower drag force.

1.5 Summary

Overall of this chapter, is to discuss and explain the guideline of the project. It is briefly discuss about the title, and what will be the main focus in this project.

CHAPTER 2

OVERVIEW ON WIND TURBINE

2.1 Introduction

This chapter discuss briefly on wind turbine system including types of wind turbine, and the advantages of wind turbine as a renewable energy. Another discussion is on the blade performance.

2.2 History of wind turbine

Wind turbine in today's modernization can be divide in two types, first is, by converting electrical to mechanical energy which we call it as windmills, and second types is we called it as wind generator or wind charger, which for this type it convert mechanical energy to electrical energy. This project will go further to the second type, wind charger.

Before going through to the system used in wind turbine in a modern day, we must consider some of the history related to the wind turbine. As for this section, it will briefly explain on the historical part of the wind turbine, how it began and how it expands into the future used.

As stated on many research, wind turbine was first started with windmill. There was always an argument on the exactly time of the first windmills. According to the Manwell *et. al*, at 900 AD, the first windmills that been documented were built by the Persian which at this time these windmills was used a vertical axes and were drag types devices. For this type of windmills is not efficient and can be damage at the high speed of wind. (Manwell, McGowan, Rogers, 2002). According Wizelius, the first windmill might be started in 3000 years ago at China and Japan (Wizelius, 2007).

At the end of 12th century, the European had been built their first windmill on the Mediterranean coast and in northern France and for this windmill the overall technology had been change from the Persian windmill where for this type of windmill their used horizontal as an axes for the turbine (Wizelius, 2007). This type of windmill was used for mechanical task such as water pumping, grinding grain and many more as well as it was a post mills which the whole mill can be turned to face the wind (Manwell, McGowan, Rogers, 2002).

According to Eric Hau, during early 19th century, when the number of windmill reaching its peak in Europe, a New World mainly at East Coast also built numerous numbers of windmills. At the West, this started in USA (Hau, 2006). As the type that widespread used in USA is mostly used for pumping water. It was used for the livestock and also to supply water for used in the steam railroads (Manwell, McGowan, Rogers, 2002).

In the 1930s, the initial changing from used for mechanical power to the electrical demand was now developed (Wizelius, 2007). According to Eric Hau, Poul La Cour is the one who make the turning-point from the windmill used to the power generating wind turbine (Hau, 2006). As the demand for electricity in the countryside was increased, the development of new type of wind turbine – the wind charger, that charged the batteries begin to take parts on this technology (Wizelius, 2007).

In the small wind turbine development, the most notable pioneer is Marcellus Jacob. They rotor had three blades with the aerofoil shape and began to resemble the turbine of today include it features of battery storage (Manwell, McGowan, Rogers, 2002). In the 1950s, Ulrich Hütter in Germany is known as one of the pioneer of wind energy where he focused on applying modern aerodynamic principles to wind turbine design (Manwell, McGowan, Rogers, 2002).

At the time of Industrial revolution, the used of wind power began to disappear due to the used of coal which at that time give so many advantages compare to the wind power (Manwell, McGowan, Rogers, 2002). As the diesel engines and steam turbines being a popular used for generating electricity, the used of wind energy, gradually boost again when the two world wars approach as the fuel supply started to scarce (Hansen, 2000).

At the end of 1970s, a serious effort in developing a wind power was begin as the oil crises pushed several countries to search for new energy sources. In the 1980s, the wind power industry starts to kick-off and was developed very fast. It was now a competitive industrial branch for large-scale utilization of wind power for energy supply on global scale (Manwell, McGowan, Rogers, 2002).

2.3 System in wind turbine

In wind turbine system, there are main components which have it own task to complete the wind turbine. On this section, discussion will further to the main component in the wind turbine. As stated above, each component act it task to make sure the wind energy can be used in wind turbine system. Also discussed on this section are types of wind turbine.

2.3.1 Types of wind turbine

According to Wizelius, in wind turbine design concept, there were several differences on it. Horizontal axis wind turbine (HAWT) and Vertical axis wind turbine (VAWT) is one basic classification in wind turbine (Wizelius, 2007). In this section focus is mainly on HAWT as it will be used in the project, and it’s different from VAWT.

2.3.1.1 Horizontal axis of wind turbine (HAWT)

HAWT, as according to Manwell *et. al*, is the most common design which was used in the modern types of wind turbine. The axis of it rotation is parallel to the ground

(Manwell, McGowan, Rogers, 2002). HAWT can be classified into two different types of rotor, upwind where the rotor was attack first by the wind and downwind which the wind will first pass the tower and nacelle before it reach the rotor (Wizelius, 2007). For this type of wind turbine, it was driven by the lift forces (Manwell, McGowan, Rogers, 2002).

The most used turbine today is upwind rotor, but there are also several model of wind turbine that vary in size from MW-class to the smaller turbine with power range from 20-150kW, and there is also a 19th century water pumping wind wheels that used downwind rotors (Wizelius, 2007).

As conventional wind turbines, HAWT are not multi-directional and due to this fact, if there is slightly changes in wind direction the HAWT must change it direction with the wind. This action applied to the upwind rotor wind turbine which the rotor orientation must relate to the wind and traditionally there must have some devices attached to it that will point the rotor into the wind (Gipe, 2004).

As for example, the Dutch windmill, the wind were constantly being watched by its manufacturer and as the wind change it direction they will pushed a long tail pole or by turned a crank on the milling platform to face the windmill's massive rotor back into the wind. But, as the technology expand; the manufacturers take a step by creating a fan tails that will turn the rotor facing the wind, mechanically. As for smaller wind turbine, a simple tail vane will do such a task, pointed the rotor to the wind regardless of the change in wind direction (Gipe, 2004).

For fan tails and tail vanes work, to orientate the rotor upwind its will used the force from the wind itself. It does not need human force to do the task anymore, to help the upwind turbine catch-up with the wind direction changes. But it differ to the downwind turbine which do not need a tail vanes or fan tails to change it direction and facing the wind. The design in downwind turbine a bit different from the upwind turbine, which in downwind turbine the blades are swept slightly downwind, giving the spinning rotor the shape of a superficial cone with its culmination at the tower. The coning to the blades causes the rotor to naturally orient itself downwind. According to the British aerodynamicist Andrew Garrad, for heavy blades the coning angle may be in between 1 to 2 degrees only while for the lightweight blades it was between 8 to 10 degrees (Gipe, 2004).

Each type of this HAWT, upwind rotor or downwind rotor, give it own pro and contra to the wind turbine usage. As for the downwind rotor, the advantages of using it is one do not have to worried how it captured the wind when the wind starting to change its direction because it will adjust itself to the wind direction (Wizelius, 2007). But due to this, some considered it to become like hunter of the wind, which the turbine will moving around the tower in search for the wind, and as for this, it can cause the tower to creates a shadow that disrupts the air flow as the blades pass behind the tower. Due to this, the performances will decrease, increase the wear and on two blade design it will produce a sound that people found it very disturbing (Gipe, 2004). As same as to the upwind turbine, as it cannot captured the wind without helped from the tail vanes, but due to its performances, upwind rotor is much better used compared to the downwind (Gipe, 2004). At the beginning of the 21st century upwind rotor turbine with three blades is the most popular used in the market (Wizelius, 2007).

2.3.1.2 VAWT

Due to its name, one can conclude that the differences between these two wind turbine is the axis of it rotor blade will rotate. As mention above, for HAWT, it axis of rotation is parallel to the ground while for the VAWT is perpendicular to the ground, due to its name Vertical axis wind turbine. For VAWT, it was not efficient compare to the common type of HAWT, but in the low wind situation it gives a lot of advantages, such as, they can be much safer, easy to build. Plus its generator was installed at the ground make it easier to installed and maintaining (REUK.co.uk, 2009)

In VAWT, there are several types that already been built and used up by the manufacturer. As well as the HAWT.

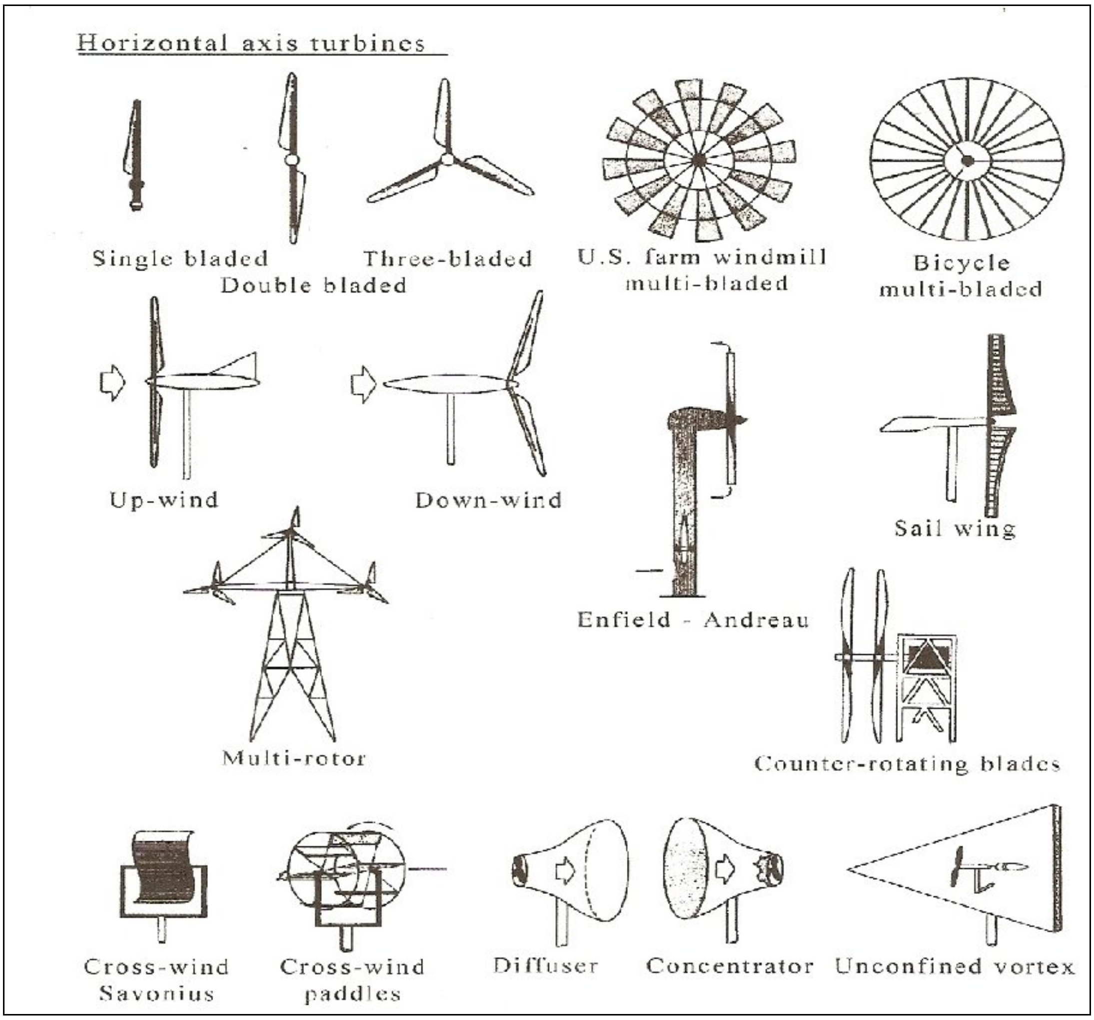


Figure 2.1: Various concept for HAWT [Manwell, McGowan, Rogers, 2002]

For figure 2.1, it shown the various concept for horizontal axis wind turbine from the first concept until the concept that been used in the modern day.

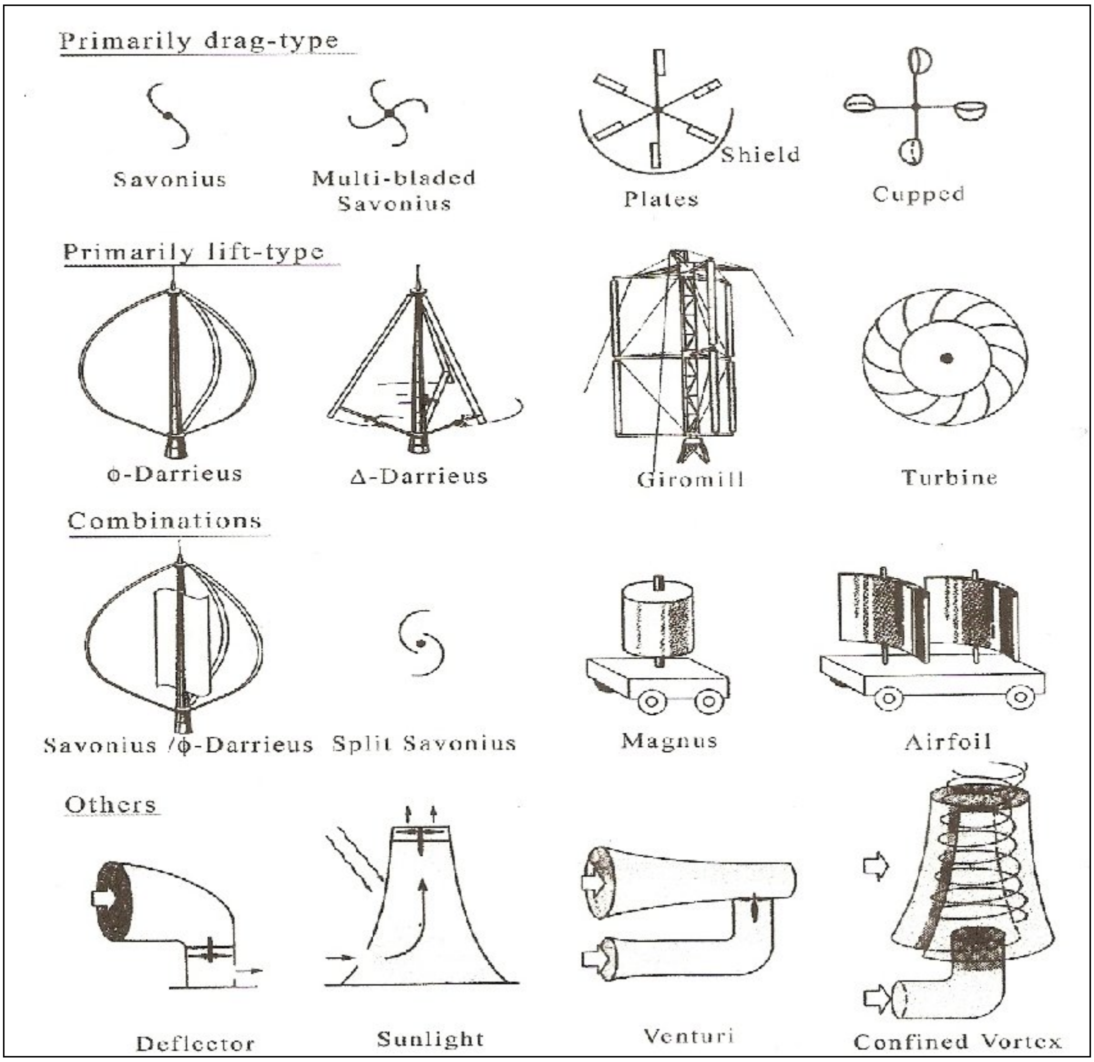


Figure 2.2: Various concept for VAWT [Manwell, McGowan, Rogers, 2002]

For figure 2.2, it shown the various concept for vertical axis wind turbine from the previous concept until the concept that been used in modern day.

2.3.2 Component in wind turbine (mechanical part)

To understand the system flow in wind turbine, on how it can produce electricity which can be stored, one must know basic component that is important in development of wind turbine. In wind turbine, a component such as rotor, can be considered the most important component that is, without it the wind turbine will not be functioning. In this section, focus is to give brief explanation on such component.

2.3.2.1 Rotor blade

As a general knowledge, rotor consists of hub and blades which can be considered the most important parts in wind turbine in term of its performance and cost standpoint (Manwell, McGowan, Rogers, 2002).

In blade wind turbine, it can vary on how many blades it used in wind turbine either one, two, three or multiple blade. In the last twenty years, few of single bladed turbine have been built and the advantages of single bladed turbine is, the turbine can run at a relatively high speed ratio and it also cheap due to the need only one blade (Manwell, McGowan, Rogers, 2002). But for the one blade turbine it captures less energy than two blades. It might be cheap, but it must have the same weight as one with two blades because it needs to capture the energy twice. Other than that, due to it missing blade it must balance itself by using a massive counterweight (Gipe, 2004). Two blade turbine is cheap, lighter, and operates at higher speed and due to this it cause lower-cost-transmissions compare to three blades turbine (Gipe, 2004), but they have lower moment of inertia when the blades are vertical than when they are horizontal (Manwell, McGowan, Rogers, 2002).

In most modern wind turbine, three blades is the most common used to generating electricity (Manwell, McGowan, Rogers, 2002). It is due to three blade have greater dynamic stability compare to two or single blade (Gipe, 2004). The advantage of three blades turbine is that it have constant polar moment inertia with respect to yawing. It also is independent of the azimuthal position of the rotor (Manwell, McGowan, Rogers, 2002). The characteristics make the three blades turbine operate smoothly even while yawing.

To consume the power of wind, the rotor has to have an efficient tip speed ratio. Tip speed ratio depends on the number of blades. The more the blades is the lower the tip speed ratio for that turbine should have. Meaning to this is, for turbines with the same rotor diameter, one bladed turbine needs a higher rotational speed than two bladed turbines and so on (Wizelius, 2007). To select the number of blade is depends on the design tip speed ratio (Manwell, McGowan, Rogers, 2002).

Blade can be made from almost any material. In 19th century, most European windmills made their blade out of wood ad canvas. Using wood is popular in the early farms windmills which it used wooden slats and at 1930s, wind charger used wood almost exclusively (Gipe, 2004). It can be used in small machines. For small machines, the types of wood suitable to create a blade are single planks of Sitka spruce or from wood laminate (Gipe, 2004).

Other than woods, fiberglass also can be considered as the choice of the manufacturer to build wind turbine blades. It is strong, inexpensive and good fatigue characteristics (Gipe, 2004). PVC pipe also been used in small wind turbine project.

Hub was connecting to the blades and becoming rotor part in wind turbine. The hubs transmit the transverse motion of the blade into torque (Gipe, 2004).

There are three types of hub can be considered, whether it was rigid, teetering, hinged blades (gimbaled). Rigid rotors are the best choice of wind turbine with three blades. Rigid rotors mean the blades cannot move in the flapwise and edgewise direction (Manwell, McGowan, Rogers, 2002). At the late 1930s and early 1990s, manufacturers of a medium-size wind turbine had introduced variable pitch hubs which provide more control of the rotor in high speed winds (Gipe, 2004).

2.3.2.2 Drive train

Drive train was used to transfer power from the rotor to the generator. There are three ways; first is the turbines driven the generator directly, second by using mechanical transmissions devices and few design were used hydraulic or pneumatic transmissions. By driving the generator directly with the rotor there is no need for a transmission and somehow reduces the complexity of the drive train (Gipe, 2004).

Drive train consists of gearbox, generator, shaft, mechanical breaks, and coupling. Main shaft needed to transfer of torque from the rotor to the rest of the drive train. Couplings were used to transmit torque between two shafts. Gearbox is not necessarily needed in the drive train; as mention above we might want to driven the generator directly. Its function is to increase the speed of the input shaft to the generator (Manwell, McGowan, Rogers, 2002).

To convert the mechanical energy from the rotor into electrical power was a task done by the generator. For a smaller battery charging wind turbine, shunt wound DC generator was used. Permanent magnet generator was the most frequently used in wind turbine and it also applied in small wind turbine (Manwell, McGowan, Rogers, 2002).

Mechanical brake is a disc brake that was placed on the gearbox high-speed shaft. It was fixed to the shaft (Stiesdal, 1996). As for yaw system, all horizontal axis wind turbine can yaw itself as to orient them in line with the wind direction. There are two types of yaw system, active yaw is for upwind turbine machines which they actively align the turbine. Ant the other system is free yaw which was applied to the downwind turbine machines that rely on the aerodynamics of the rotor to align the turbine (Manwell, McGowan, Rogers, 2002).

2.3.2.3 Main frame and nacelle

Nacelle is the housing for the components of the wind turbine but not included the rotor. The main frame is a structural which the component attached. It gives a rigid structure to maintain the alignment among component such as gearbox, generator, and brake. There are two types; it’s either a separate component or part of an integrated gearbox. For a nacelle cover, it provides a protection to the electrical and mechanical component in wind turbine from bad weather or sunlight etc. it is usually made from a lightweight material such as fiberglass.

2.3.2.4 Tower

There are three types of tower that can be considered for HAWT. There was free-standing lattice (truss), cantilevered pipe (tubular tower), Guyed lattice or pole. Tower is used to support the main part of wind turbine up in the air. For smaller wind turbine the tower are higher than its rotor diameter.

2.4 Summary

This chapter conclude all the data that being search for century on wind turbine. The history of wind turbine was being discussed on the first section of this chapter. Follow by the types of wind turbine and lastly the systems in wind turbine.

CHAPTER 3

BLADE DESIGN METHOD

3.1 Introductions

In this chapter, the discussion is focus on the methodology used in the project. Another focus is on the schedule on finishing the project. It was started after the student received the title and been given a briefing on how to conduct this project by the supervisor. In this chapter include the flow chart of the project from the beginning till the end of the project. Other than that, there was another flow chart showing the detail on the flow on the methodology section.

There are two types of flow chart that had been constructed in order to achieve the objective of the project. First flow chart is about the overall flow of the project while for the second flow chart is focus on the methodology that will be used in this project.

From this flow chart, the project is start with briefing with the supervisor. In this step, supervisor will explain a detail on the project.

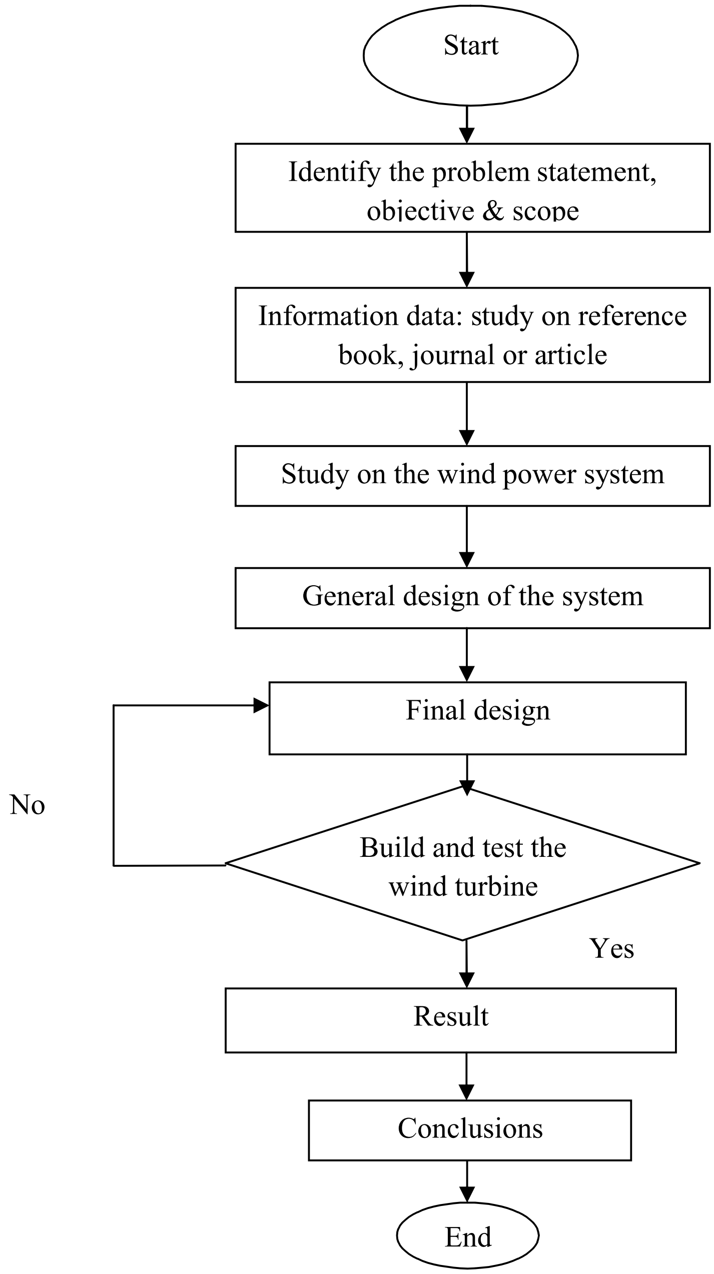


Figure 3.1: Flow chart of overall project

This project started with identifying the problem statement. After understand the problem statement. From the problem statement, suitable objective and the scope to solve the problem were being identified.

In literature review section, the focus is on the aerodynamics concept that being applied o the previous blade shape. Three shape of aerofoil has been chosen to be tested on the CFD. Another research is on the forces that acting on the blade. Focus is on the lift forces because this focus is the most important part of the design of aerofoil. Lift force is the force that will cause the blade to move (rotate).

The research is also focus on the average wind speed at Kuantan along September in 2009. The wind speed was taken from the website of the Weather Underground.

Table 3.1: Wind Speed at Kuantan along September 2009

1/9	**2/9**	**3/9**	**4/9**	**5/9**	**6/9**	**7/9**
1.11 m/s	1.11 m/s	1.11 m/s	1.39 m/s	1.11 m/s	2.22 m/s	1.39 m/s
8/9	**9/9**	**10/9**	**11/9**	**12/9**	**13/9**	**14/9**
1.11 m/s	1.67 m/s	11.11 m/s	1.39 m/s	1.94 m/s	1.39 m/s	0.83 m/s
15/9	**16/9**	**17/9**	**18/9**	**19/9**	**20/9**	**21/9**
1.11 m/s	1.39 m/s	1.11 m/s	0.83 m/s	0.83 m/s	1.11 m/s	1.11 m/s
22/9	**23/9**	**24/9**	**25/9**	**26/9**	**27/9**	**28/9**
1.39 m/s	1.39 m/s	1.67 m/s	1.39 m/s	1.11 m/s	1.11 m/s	1.39 m/s
29/9	**30/9**					
1.11 m/s	1.39 m/s					

+

Date (September 2009)	Wind speed

Second flow chart is focus on the detail in the methodology section. In this flow chart, the step was started with designing the wind turbine in Computational Aided design (CAD) SolidWorks. After designing on SolidWorks, the project continue with analysis on Computational fluids dynamics (CFD); Cosmos Floworks. The analysis will be repeated in order to get the best design and the result will be obtained. If the shape of design cannot be approved the step goes back to the design step. When the optimized design had been chosen we proceed with the discussion.

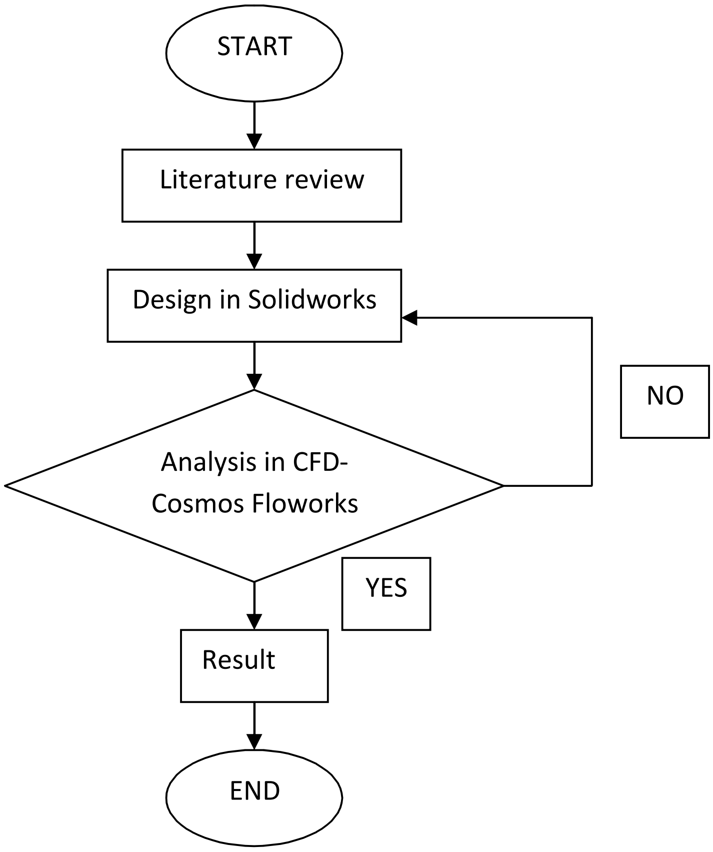


Figure 3.2: Flow Chart of the methodology

3.2 Designs in SolidWork

As mentioned on the previous section. There are three different shape of airfoil that been chosen in this project. There is flat bottom type, curved bottom type, symmetrical type. The design will have a little bit different from the example because the radius will not being used in the design. The shape was altered to have only straight line design due to the consideration of material selection.

3.2.1 Basic dimension

Table 3.2: Basic dimension on the design

Type of dimension	Dimension (mm)
Cord length	150
Span Length	500
Thickness	30

The project were about to discuss small wind turbine that have 1m high tower. The assumption made that the length of blade is the same with the span length. For small wind turbine, in order for the wind turbine giving its optimum performance the rotor blade radius should be halved of the tower high.

3.2.2 Material selection

Table 3.3: Material selection

Type	Properties
Woods-Cedar	470 kg/m

For small wind turbine, the blade can be made from almost any material because one does not have to worry about the fatigue effect of the material. From plastic PVC, wood, steel metal or aluminum; the most popular used is wood due to its strength, also wood will not facing so much problem when exposed to the surrounding compare to the other material.

3.3 Design type and proposed final design

In this section, discussion is about the three basic type of airfoil and the modified design that been used in the project

3.3.1 Flat type bottom

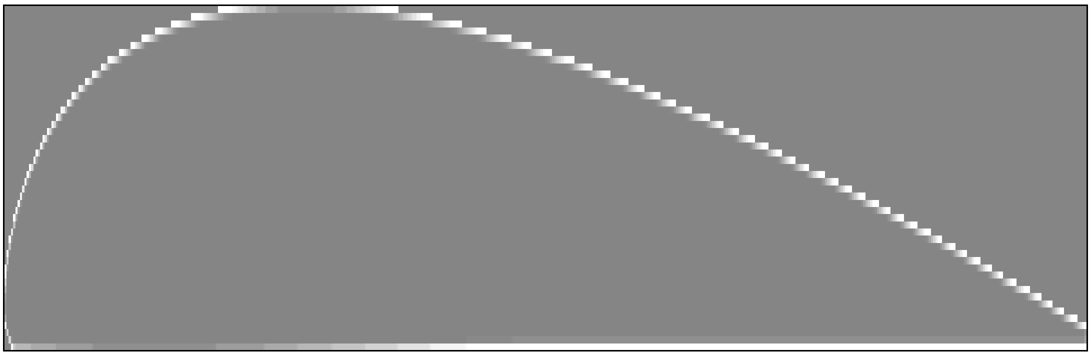


Figure 3.3: Example of flat Bottom Type (Johnson, 2002-2009)

For flat bottom, the example is shown above. As mentioned at previous section, the design will be modified due to the material selection for the blade wind turbine.

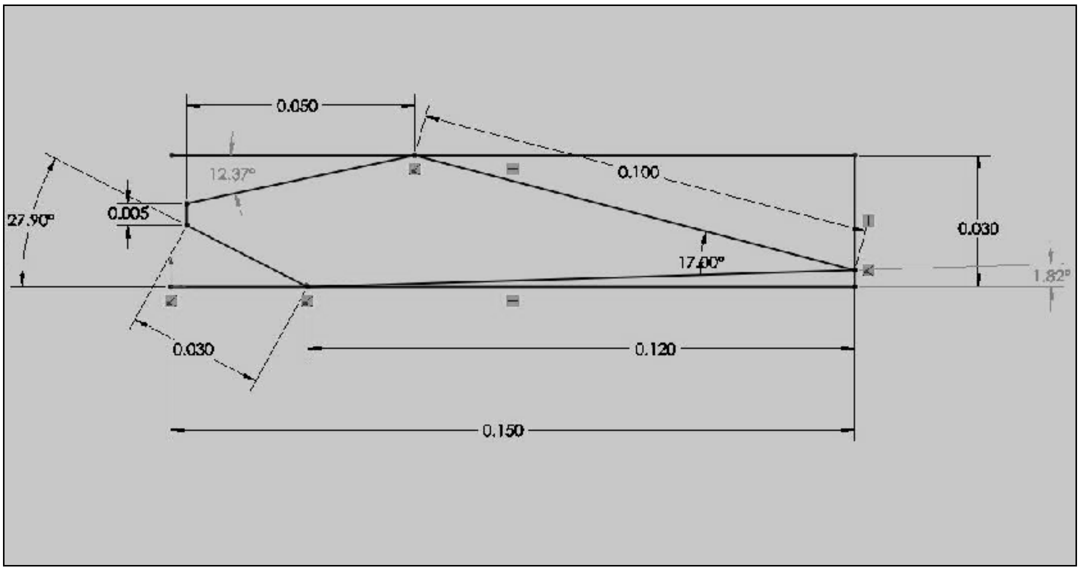


Figure 3.4: After modification flat bottom type design

The basic dimension already been stated in the previous section. For the overall dimension, it could be found on the figure 3.4. as mention, the modified design will not applied any radius and as can be seen the design having a straight line.

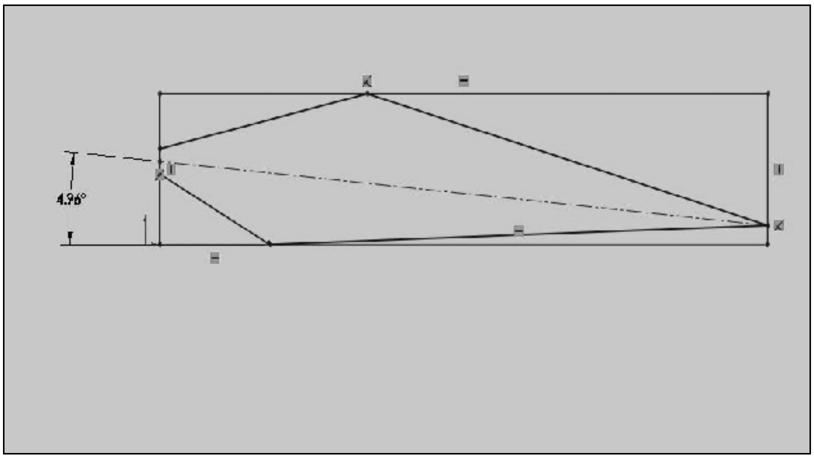


Figure 3.5: Angle of the design from the cambered line

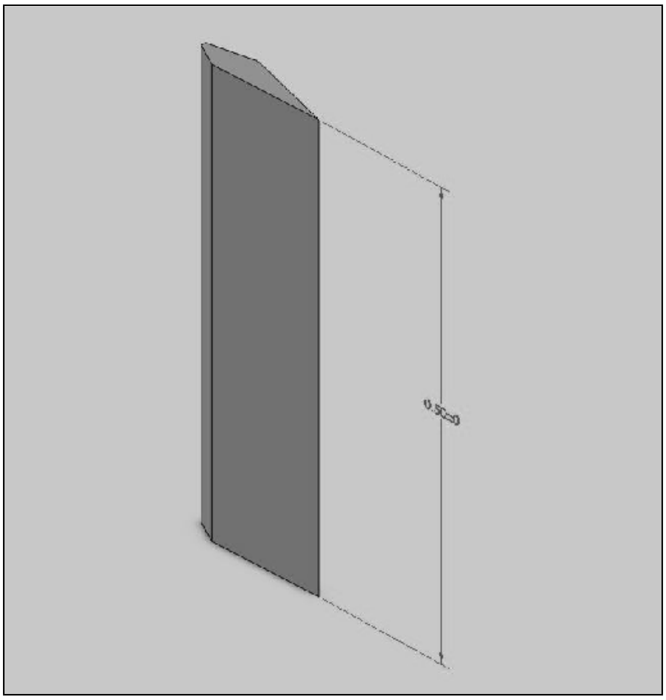


Figure 3.6: Span Length

3.3.2 Curved bottom type

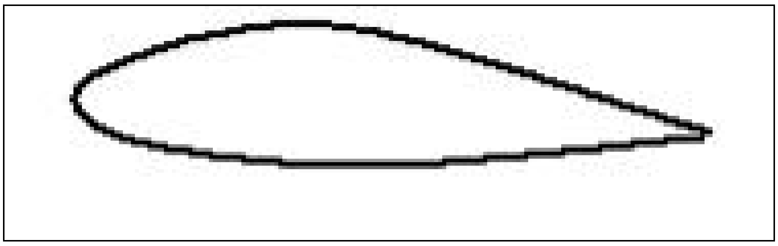


Figure 3.7: curved bottom type

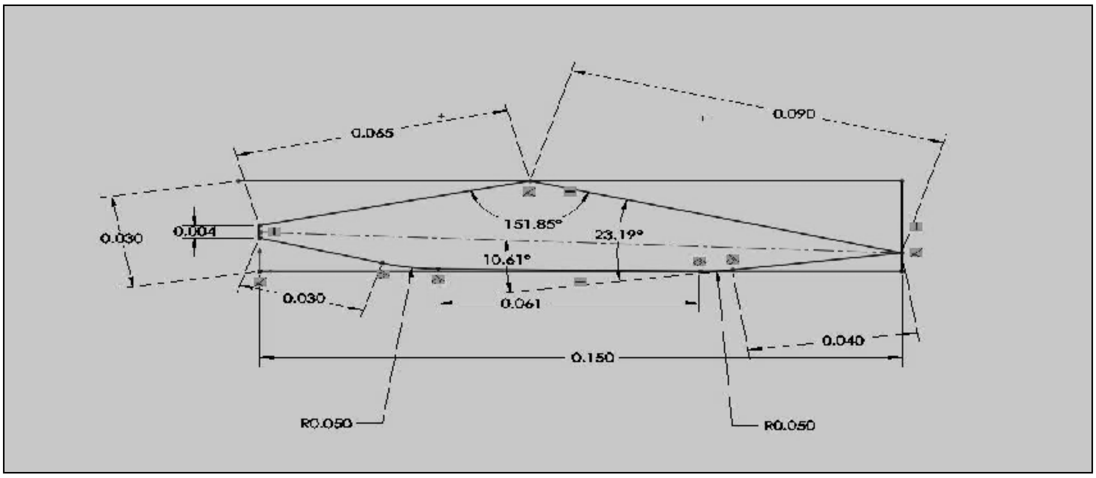


Figure 3.8: overall dimension for curved bottom

For the curved bottom, we also applied a straight line design, but at the same type we applied the radius on the bottom side of the design in order to get the curved bottom. The radius is small and overall dimension can be seen in figure 3.8.

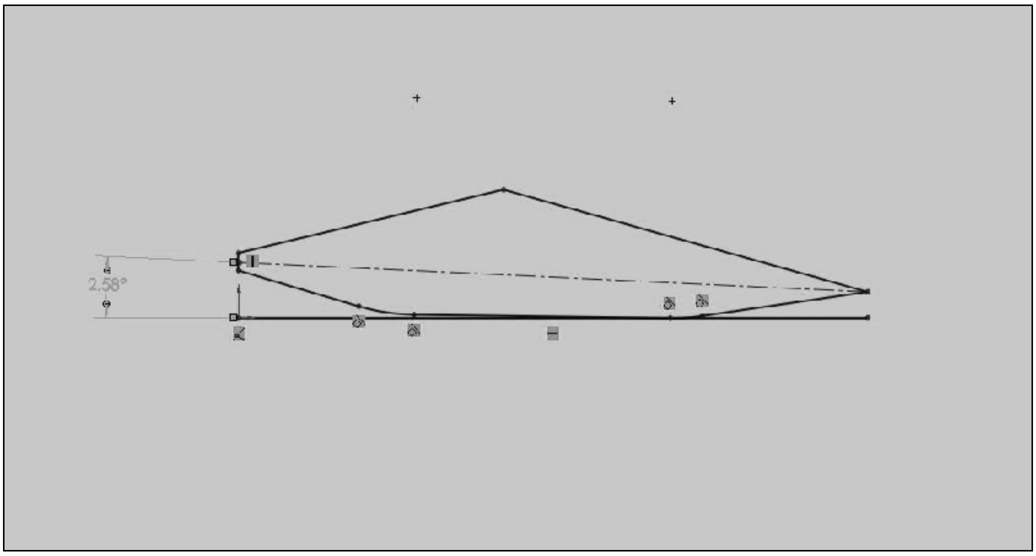


Figure 3.9: angle of the curved bottom from the cambered line (dashed line)

The span length was still the same as the type bottom design, only the angle will be different due to its different shape.

3.3.3 Symmetrical type

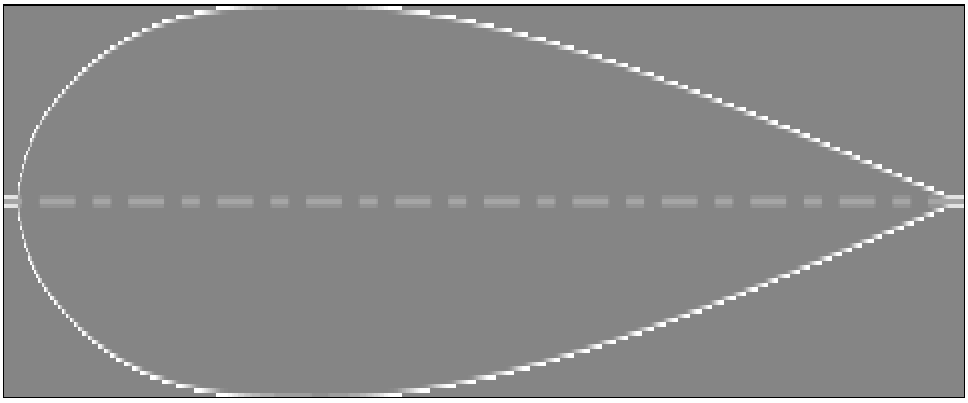


Figure 3.10: Example of symmetrical type (Johnson, 2002-2009)

Figure 3.10 above is the example of the symmetrical type of airfoil. Same with the other two designs the modification will be applied to the basic design of airfoil.

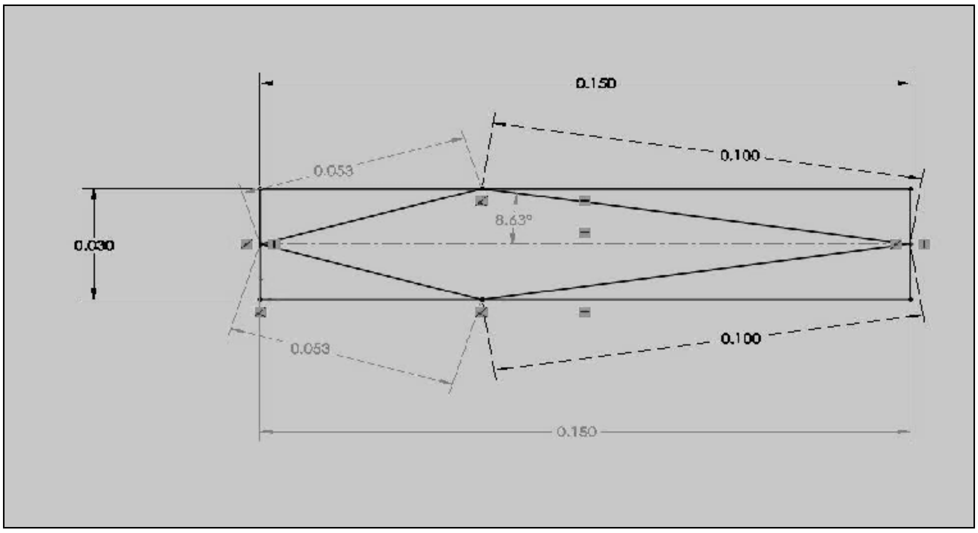


Figure 3.11: Overall dimension for the modified design of symmetrical type

Figure 3.11 shown the overall dimension of the modified design applied in symmetrical type. As for this type, there will be no angle applied on the cambered line due to its symmetry shape. The span length is the same with the previous two.

3.4 Analysis in CFD

- Analysis CFD
    - Analysis type: External flow
    - Fluid type: Air
    - Pressure: 101.3 kPa
    - Temperature: 283 K
    - Wind speed: 4.28 m/s (Weather Underground)

The parameter being search is Lift and Drag force. By using CFD-Cosmos Floworks, the design was test with the above boundary condition. The pressure and the temperature used is a standard value. And the assumption made for the computational domain; which the assumption is to assume the blade already being installed at the roof of a house with the roof high is 4 m from the ground. The figure was shown below. The direction of wind attack is from x direction.

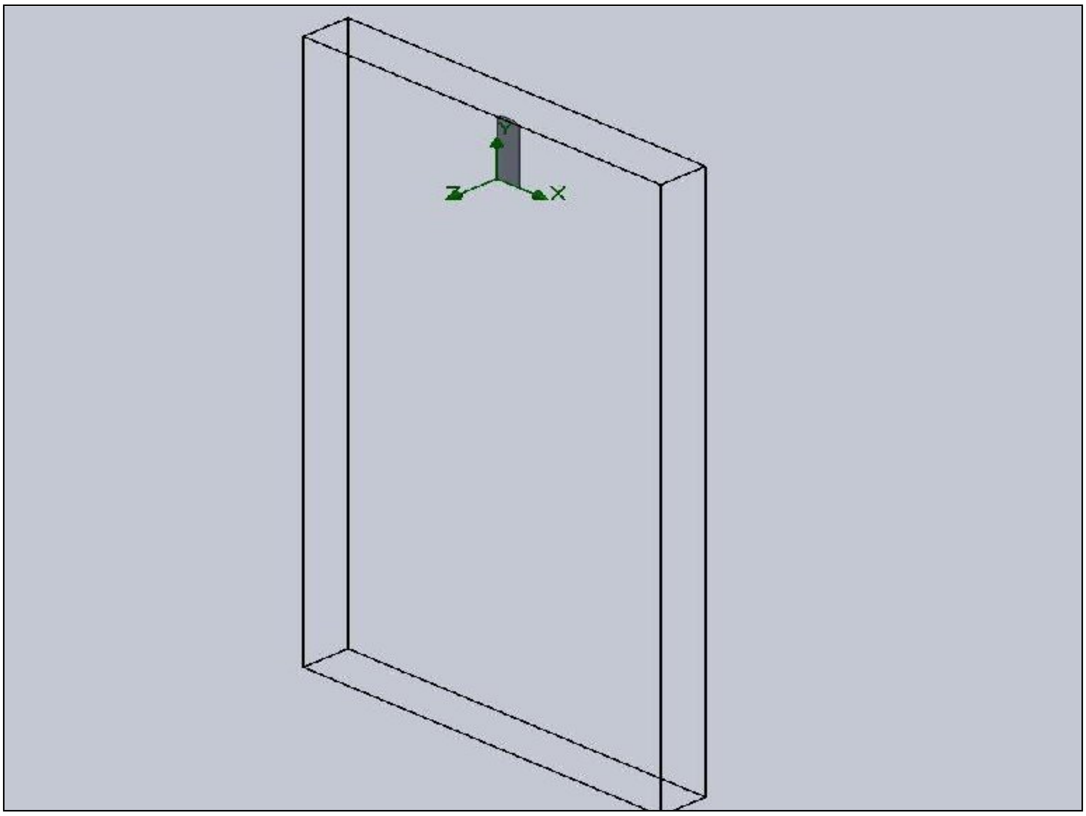


Figure 3.12: Computational Domain

Figure above is about the computational domain that being used in this analysis.

3.5 Summary

This chapter concludes all the method that being used in order to finish the project. Designing a shape in Solidworks and simulation analysis in CFD are the main method in this project.

CHAPTER 4

RESULT AND DISCUSSION

For this chapter, it was devoted to the output of the project and the analysis and discussion of the result for better enhancement in the future.

4.1 Introduction

The purpose of this chapter is to analyze and discussed the result of the project. The result was determined using comparison method among the three shape design with the design that does not apply any aerodynamics concept in it. As mention before, the parameters being search in CFD is Lift force and the drag force.

Lift force was known as a force that acts perpendicular to the oncoming airflow. Lift force also can be said as a consequence of the unequal pressure on the upper and the lower airfoil surfaces. It was used to help the blade rotate on its rotation plane. The higher the lift is the better.

As for the drag force, it was defined as a force that acts parallel to the direction of the oncoming airflow. The drag force happen because of the viscous friction forces at the surface of the airflow and to unequal pressure on the airfoil surfaces facing toward and away from the oncoming flow. In aerodynamic concept and also based on blade element theory, the lower the drag is better because the drag can cause a stalling during rotation.

In order to make the final decision for this project, for the design shape that produce higher lift force with low drag force can be stated as the best design. the comparison will be made between the chosen design with the design without any aerodynamics concept in it. The calculation of drag percentage reducing will be made to make the project having the precise result. Also calculation of lift to drag ratio will be calculated, as the higher the lift to drag ratio the better the performance is.

4.2 Simulation result

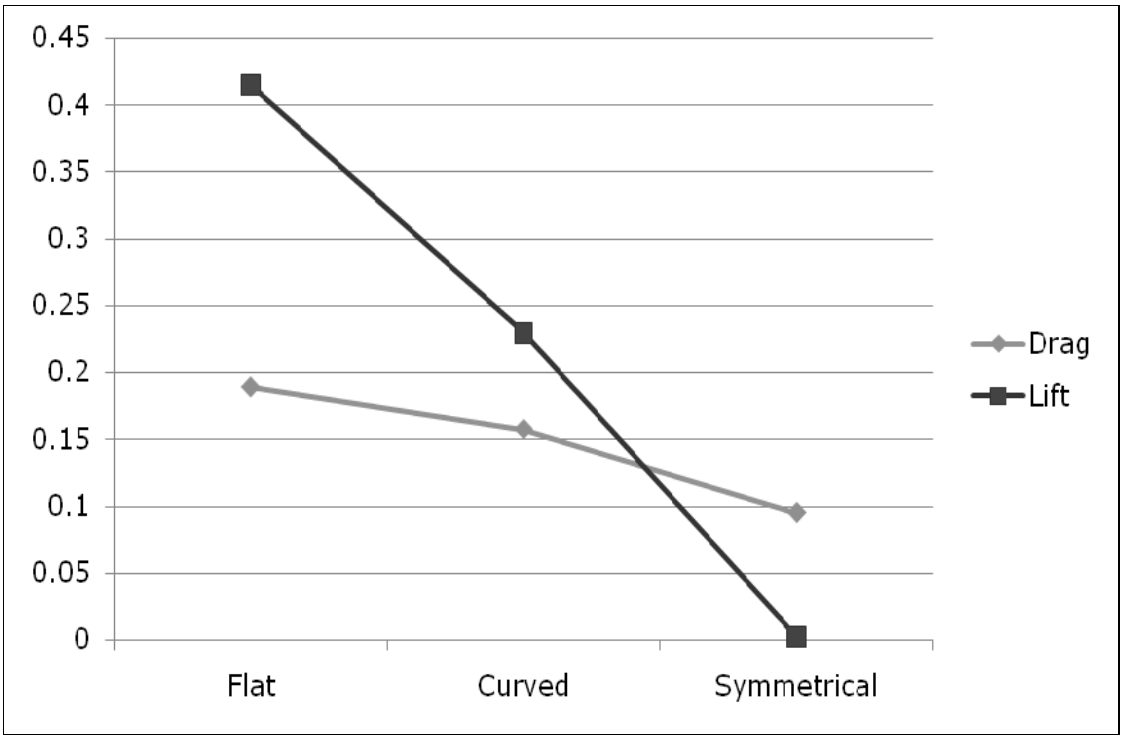
On this section, the result will be analyzed after the design being simulate in the Cosmos Floworks software.

Table 4.1: Drag and lift force analysis

Force	Rectangular	Flat bottom	Curved bottom	Symmetrical
Drag	0.4579N	0.1893N	0.1576N	0.0949N
Lift	2.074x10-5N	0.4149N	0.2292N	0.0022N

From the table above, the analysis was done by comparing the results gain for each shape design. From table 4.1 above, the result shows that for the flat bottom it has the higher Drag force, D_f= 0.1893N, followed by the curved bottom with D_f=0.1576N and the shape with the lower drag force is symmetrical that is D_f=0.0949N. For the rectangular shape above, it was to prove that the design without aerodynamic concept was unacceptable in designing the blade wind turbine.

For the lift force, Flat bottom also produce higher lift compared to the other two designs. From this table, the design shape for symmetrical type can now be rejected as the drag force produced is higher than the lift force.



Graph 4.1: Graph Drag and Lift force vs. the design shape

From the graph above, the differences of lift force produce by each of the design was very high. For the flat bottom that produces the higher lift force can be state as the most acceptable design comparing to the other two.

After the result being analyzed, to make sure the result is precise the results now are being calculated.

The calculation is based on how much percentage that the new design can reduce the drags force from the old design (rectangular shape). The drag coefficient will first being calculate using the below equation.

$$C_D = \frac{D}{\frac{1}{2}\rho v_\infty^2 A}$$

eq 4.1

ρ=1.225kg m^{-3}

V=4.28m/s

Table 4.2: Frontal area for three designs

Shape design	Rectangular	Flat bottom	Curved bottom
Frontal area, A	0.015 m^2	0.0425 m^2	0.0495 m^2

Table above is for the frontal area for three different shape designs. The frontal area will be used to calculate the drag coefficient.

Table 4.3: Drag coefficient for three design

Shape design	Rectangular	Flat bottom	Curved bottom
Drag coefficient, C_D	2.7207	0.3970	0.2838

The table above shows the drag coefficient for each three designs after being calculate using the eq 4.1.

$$\frac{C_{D_R} - C_D^*}{C_{D_R}} \times 100\% \qquad \textit{percentage reducing formula}$$

eq 4.2

Table 4.4: Percentage of drag reducing

Shape design	Rectangular	Flat bottom	Curved bottom
Percentage of reducing, %	100%	85.408%	89.569%

For the table above, the percentage of drag coefficient reducing is almost the same with these two different designs. Even though the curved bottom reduced more drag compare to the flat bottom, but the flat bottom produce higher lift force, thus the analysis proceed to the next step which in this step the lift to drag coefficient ratio is the main parameter. As mention above, the higher the lift to drag coefficient ratio the better the performances of the blade will be.

Table 4.5: Lift, Drag coefficient, Lift to drag coefficient ratio

Shape design	Flat bottom	Curved bottom
Lift coefficient, C_L	0.8700	0.4127
Drag coefficient, C_D	0.3970	0.2838
Lift-drag coefficient ratio, C_L/C_D	2.1914	1.4542

Based on the table above, flat bottom shape produce more lift to drag coefficient ratio compared to the curved bottom. Based on the result and the analysis above, the best shape design for this project is the flat bottom which the lift force is higher with lower drag force and higher lift to drag coefficient ratio compared to the curved bottom.

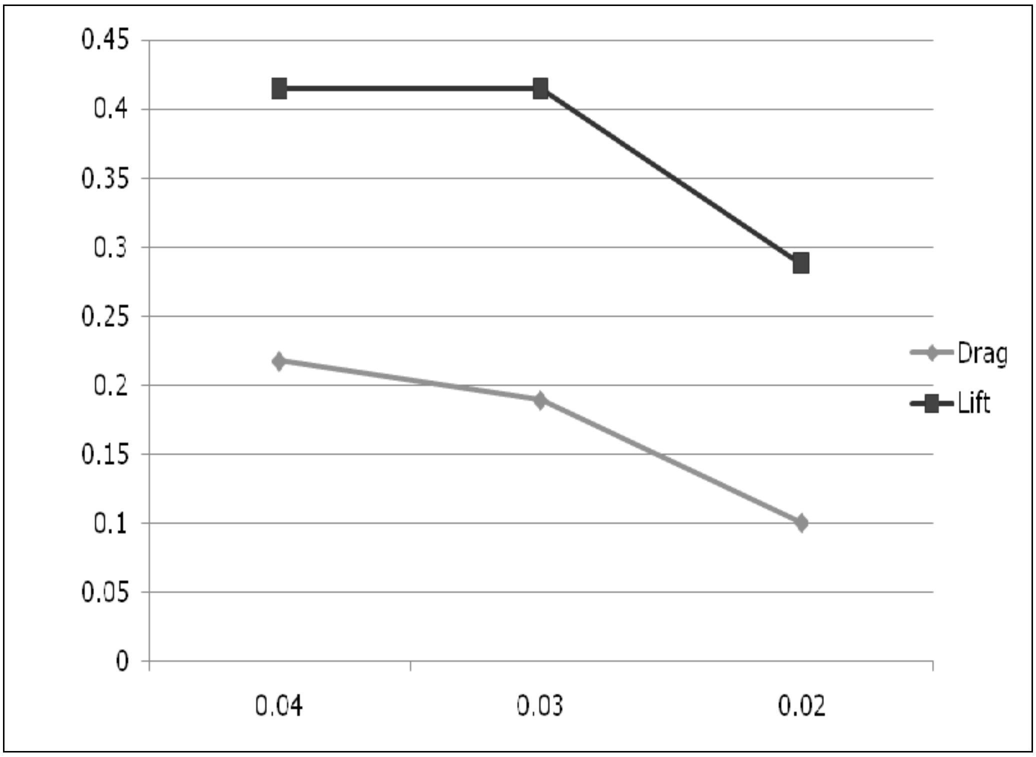
After choosing the flat bottom as the best design for the blade, the next step is to determine the best thickness for the blade itself. The same analysis was done to three new designs. The new design was using flat bottom as an example. Only the thickness will be varying for this step.

The same concept is still the same with the above analysis. With three different thicknesses with the same design, the design will be simulate on CFD to find the parameters of lift force and drag force.

Table 4.6: Lift and drag force for three different thicknesses

Force/thickness	0.04m	0.03m	0.02m
Drag	0.2177N	0.1893N	0.1003N
Lift	0.4149N	0.4149N	0.2879N

Table 4.6 shown the result after the simulation was done. From the table, can be seen that for the thickness= 0.04m can produce 0.4149N lift force with 0.2177N drag force. For the thickness= 0.03 m, the data was taken from the previous analysis. As for the thickness= 0.02 m, the drag force= 0.1003 N and the lift force= 0.2879 N. for this analysis, the thickness of 0.04 m was rejected due to it drag force which is higher than the other two thickness design.



Graph 4.2: Drag and lift forces vs. the thicknesses

From the data that been collected, the result is, the best shape design for small blade wind turbine is using flat bottom type with thickness= 0.03m, chord length= 0.15m, and the span length or the blade length= 0.5m. For this type of shape design, it can produce 0.4149N of lift force with 0.1893N drag force. The lift to drag coefficient ratio= 2.1914.

4.3 Summary

Overall of this chapter, conclude and discuss all the data gain after running a simulation Cosmos Floworks. The best design was being chose, after several consideration based on analysis and calculation.

CHAPTER 5

CONCLUSION

In this chapter, it concludes all the information that being collect and analyze on the previous chapter. The result being concludes for further research in the future.

5.1 Conclusion

This chapter was written in order to make a further review for the result and summarize all the work and the data and consolidate the discussion and conclusion that already been make at the end of every chapter in this report.

For the best shape design of small blade wind turbine that can give higher performances is the flat bottom type design. This type of shape can give higher lift force, that will be used to make the blade move thus rotate on its rotation plane and can capture the wind energy. The percentage of reduction for it drag coefficient from the shape that does not applied any aerodynamic concept in it is almost reach 100% reduction, percentage of reduction= 85.408%.

Furthermore, the best thickness for this type of shape design is =0.03m. based on the result, for this thickness it can produced lift force= 0.4149N, with lower drag force that is 0.1893N. the drag coefficient is lower= 0.3970, with higher lift to drag coefficient ratio= 2.1914.

Finally, this project does give new prospect to the small blade wind turbine industry. It can help people to make their own small wind turbine by giving them a review on what factor that can affect their wind turbine performance. After knowing the factor, they should know on how to choose the best shape design for their small blade wind turbine thus helping them to get more power from the wind energy even with just a small wind turbine.

5.2 Recommendation

For the future review, there is several ways to test the blade performance. There are:

- The best way to test the blade performance is to build the small blade wind turbine itself then test with real wind speed. Trial and error steps are needed in order to find the best result.
- Another way is to test the blade in a wind tunnel.
- The development of software has now increased in the market. One of the best software that can used to simulate the blade performance is CFD fluent analysis.

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APPENDIX A

Analysis in CFD

Table A1: Analysis result in CFD for Flat Bottom type

flat.SLDPRT [Default (2)]

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Drag	[N]	0.0482937	0.18930126	0.044942107	3.449905265	0	Yes	3.260604	0
Lift	[N]	-0.179444	-0.414899407	-6.105715405	-0.114627021	0	Yes	5.690816	0

Iterations: 26

Analysis interval: 0

The above table gain after running a simulation on Cosmos Floworks. This result is for the flat bottom type.

Table A2: Analysis in CFD for curved bottom type

curved.SLDPRT [Default (1)]

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Drag	[N]	0.042115121	0.157565175	0.040249018	3.178909092	0	Yes	3.021343917	0
Lift	[N]	-0.10057169	-0.229184902	-3.98916735	-0.048223842	0	Yes	3.759982447	0

Iterations: 29

Analysis interval: 0

This result is for curved bottom type.

Table A3: Analysis in CFD for curved bottom type

symmetrical.SLDPRT [Default (1)]

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Drag	[N]	0.029481875	0.09489804	0.029406245	2.617859295	0	Yes	2.522961255	0
Lift	[N]	-0.00045484	-0.002186913	-0.047654019	0.039279293	0	Yes	0.037626352	0

Iterations: 43

Analysis interval: 0

Result above is for symmetrical shape design.

Table A4: Analysis in CFD for flat bottom type with 0.04m thickness

Part1.SLDPRT [Default (1)]

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Drag	[N]	0.103807919	0.217679044	0.074351704	4.4814663	0	Yes	4.26378726	0
Lift	[N]	-0.167541706	-0.414873273	-6.53324801	-0.167541706	0	Yes	6.11837474	0

Iterations: 34

Analysis interval: 0

Above table is for the flat bottom type for 0.04 m thickness. This result is for the second simulation after flat bottom being decided to be the best shape that allowed blade to perform on its optimum performance.

Table A5: Analysis in CFD for flat bottom type for 0.02m thickness

Part1.SLDPRT [Default (1)]

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Drag	[N]	0.026924149	0.083989532	0.024286791	2.691089709	0	Yes	2.6071002	0
Lift	[N]	-0.05597091	-0.194096882	-5.18235057	-0.055970914	0	Yes	4.9882537	0

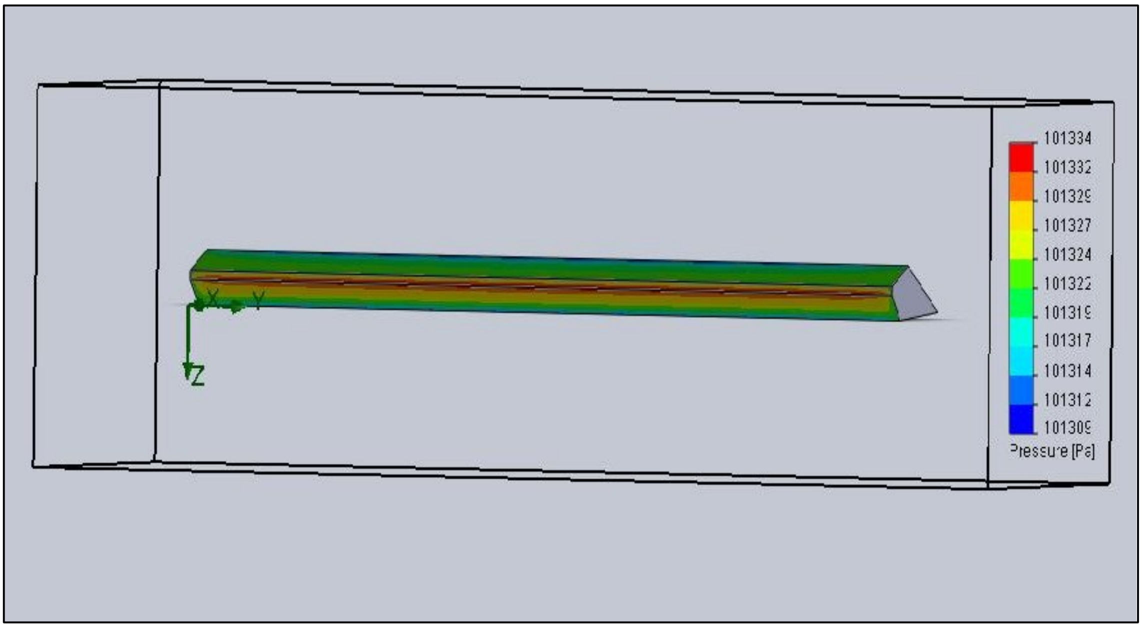
Iterations: 52

Analysis interval: 0

APPENDIX B

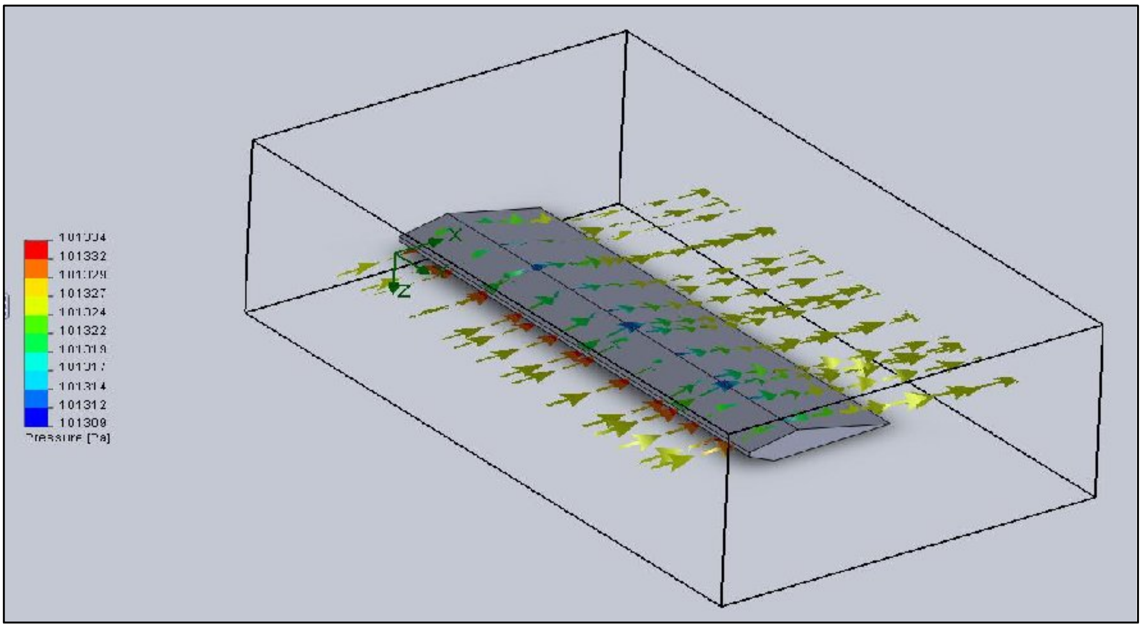
Analysis flow in CFD

Table B1: Flow contour for flat bottom



Flow contour or flat bottom. The red color showed the part on this design that facing higher pressure after being attacked by the wind.

Table B2: Flow trajectories for flat bottom



This figure shows the flow for the wind across the shape design.

Table B3: Flow contour for curved bottom

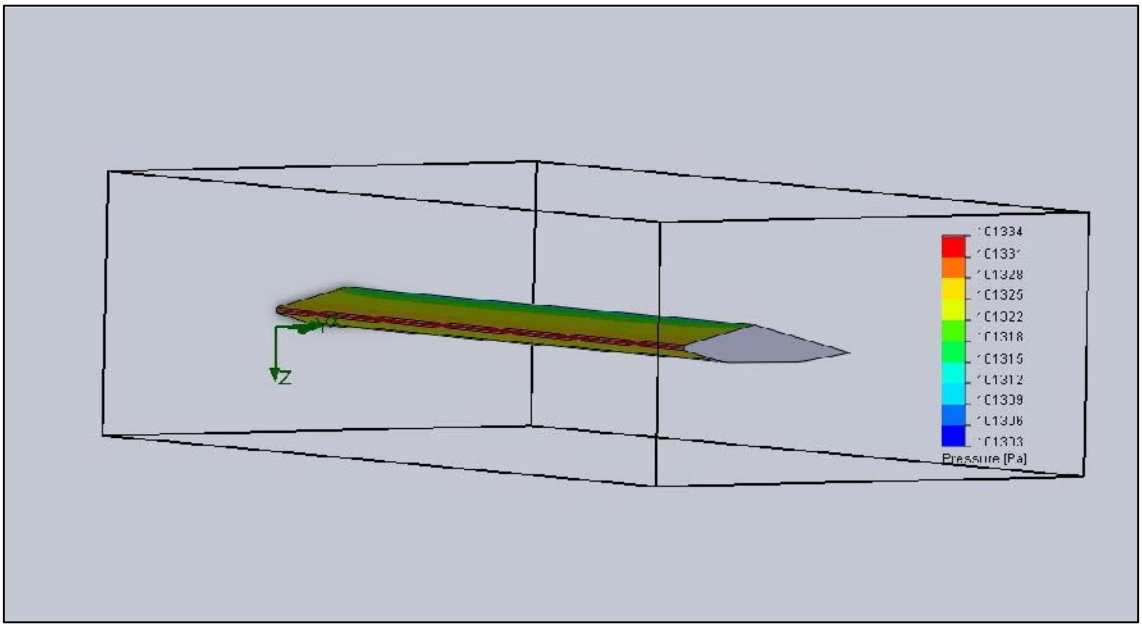


Table B4: Flow trajectories for curved bottom

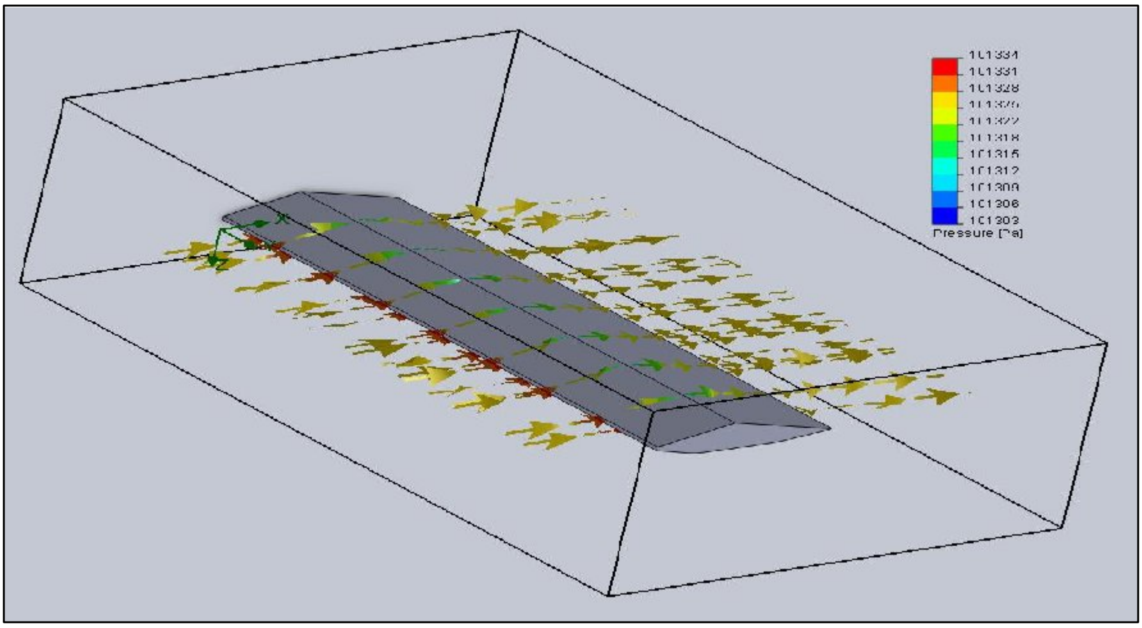


Table B5: Flow contour for symmetrical

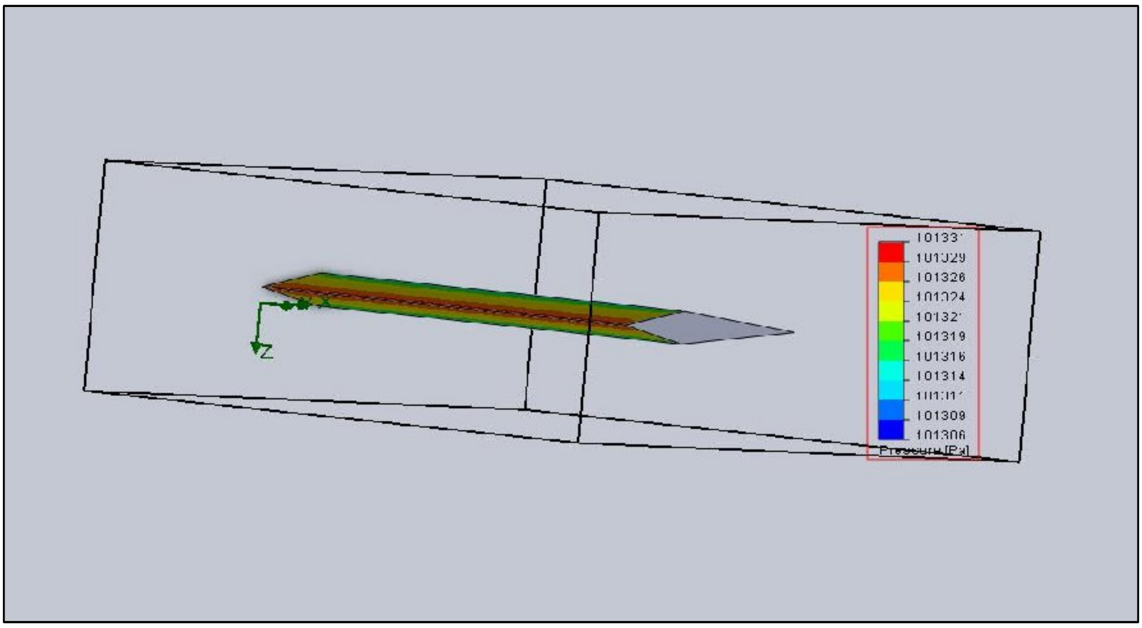


Table B6: Flow trajectories for symmetrical

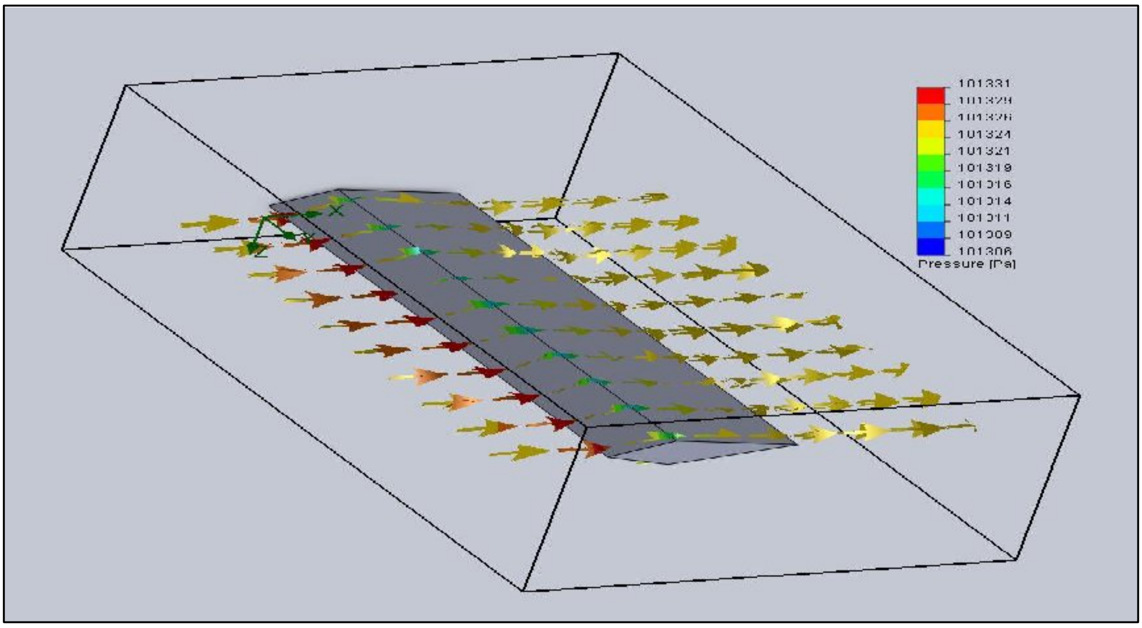


Table B7: Flow contour for flat with 0.04m thickness

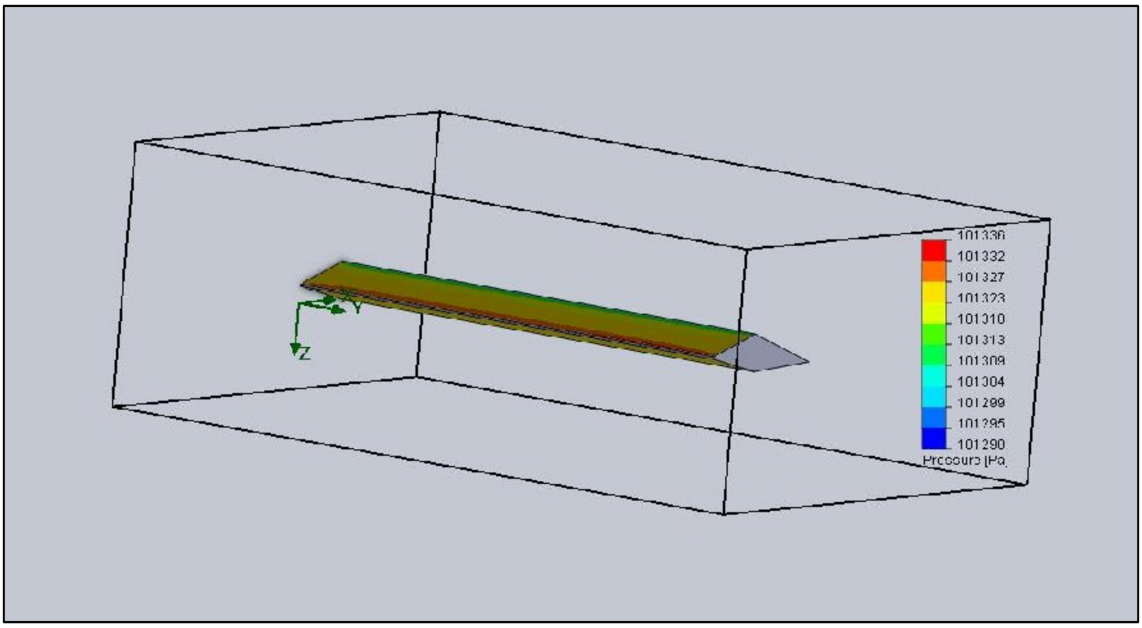


Table B8: Flow trajectories for flat bottom with 0.04 m thickness

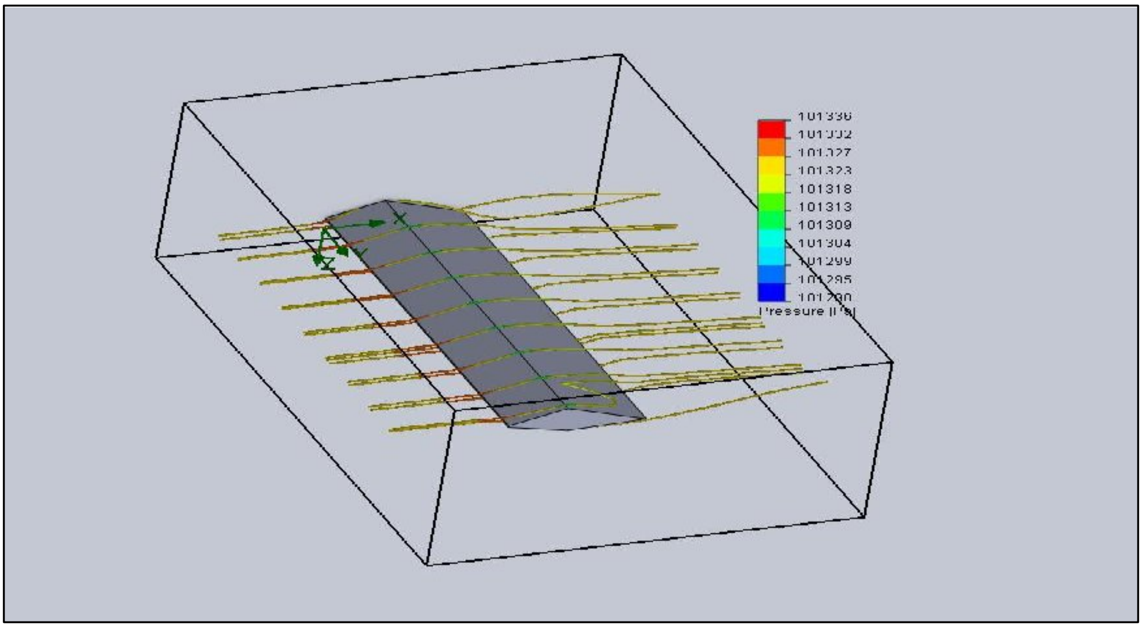


Table B9: Flow contour for flat with 0.02m thickness.

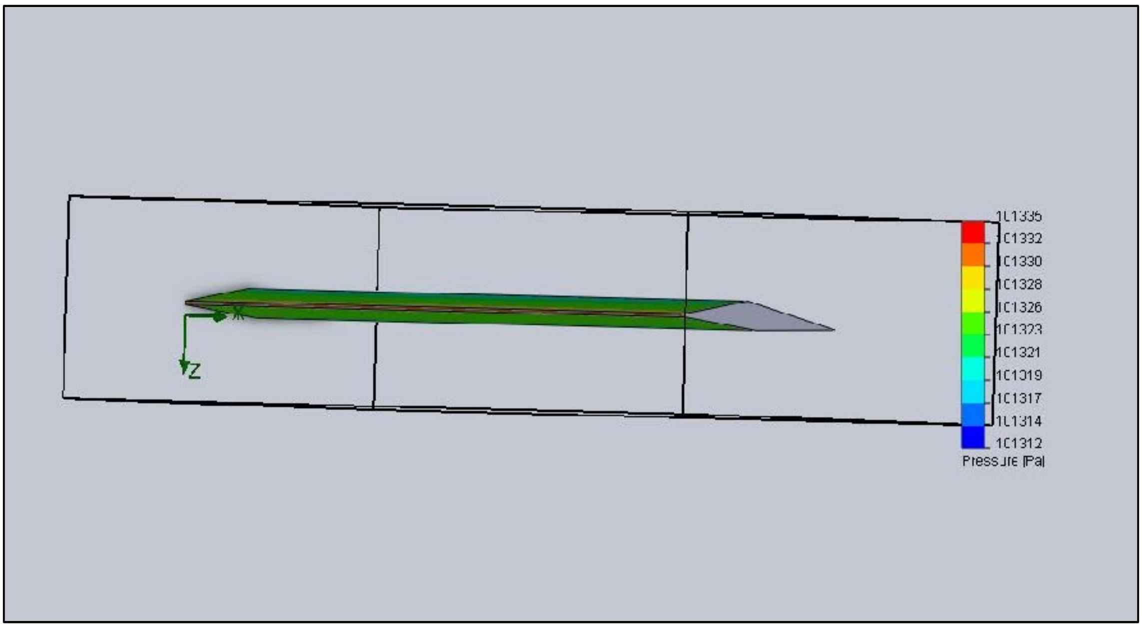


Table B10: Flow trajectories for flat bottom with 0.02 m thickness