

BLADE DESIGN FOR WINDMILL GENERATOR

MUHAMMAD FITRI BIN MOHAMED HASSAN

UNIVERSITI MALAYSIA PAHANG

BLADE DESIGN FOR WINDMILL GENERATOR

MUHAMMMAD FITRI BIN MOHAMED HASSAN

Report submitted in partial fulfillment of the requirements
for the award of Bachelor of Mechatronics Engineering

Faculty of Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project in my own opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechatronic Engineering.

Signature :

Name of Supervisor: PROF. IR. DR. SHAH NOR BIN BASRI

Position :

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name : MUHAMMAD FITRI BIN MOHAMED HASSAN

ID Number : FB09023

Date :

Acknowledgments

In the name of Allah, the Most Gracious and the Most Merciful. Alhamdulillah, all praises to Allah, whom with His willing giving me the opportunity to complete this Final Year Project report. I am grateful and would like to express my sincere gratitude and appreciation to my supervisor, Professor Ir. Dr. Shah nor Bin Basri for his supervision and support till the end of my project.

I would like to thanks to all my lecturer for their kindness, encouragement and moral support during this project development. Thanks also to all my friends that have been teaching me how to use Solidworks and Ansys software.

ABSTRACT

Windmill has been introduced since 1891 to generate electricity. In 1990s the windmill energy has been growing rapidly and it's been focus on how to make it more useful in our daily life. Windmill is for water pumping and generator application. Blade is the most important part in windmill and it has its own characteristic based on application. Aerofoil blade is the most new design for windmill generator that has the same character as aeroplane wing.

ABSTRAK

Kincir Angin telah diperkenalkan sejak 1891 untuk menjana tenaga elektrik. Pada 1990-an tenaga kincir angin telah berkembang dengan pesat dan ia telah diberi tumpuan kepada bagaimana untuk menjadikannya lebih berguna dalam kehidupan seharian kita. Kegunaan kincir angin adalah untuk pam air dan penjana elektrik berdasarkan permintaan dan keupayaan untuk digunakan di sesuatu tempat. Bilah kipas merupakan bahagian yang paling penting dalam kincir angin dan ia mempunyai ciri-ciri tersendiri berdasarkan permintaan. Bilah Aerofoil adalah reka bentuk yang paling baru untuk penjana kincir angin dimana mempunyai ciri-ciri yang sama seperti sayap kapal terbang.

TABLE OF CONTENTS

SUPERVISOR’S DECLARATION	ii
STUDENT’S DECLARATION	iii
ACKNOWLEDGEMENTS	iv
ABSTRACT	v
ABSTRAK	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	xi
LIST OF FIGURES	xii
CHAPTER 1: INTRODUCTION	
1.1 Project Motivation	1
1.2 Project Background	1
1.3 Problem Statement	2
1.4 Objectives of Project	3
1.5 Project Scopes	3

CHAPTER 2 LITERATURE REVIEW

2.1	How the Turbine Works	4
2.2	Type of Turbine Design	5
2.2.1	Number of Blade	6
2.2.2	Horizontal Axis Wind Turbine	7

CHAPTER 3 METHODOLOGY

3.1	Introduction	9
3.2	Studies on Blade Design	10
3.2.1	Wind Power	10
3.2.2	Solidity	11
3.2.3	Tip Speed Ratio	12
3.3	Design Blade with Software	12
3.3.1	Computer Aided Design	12
3.4	Analysis Method	14
3.4.1	Computational Fluid Dynamic (CFD)	14

CHAPTER 4 RESULTS AND DISCUSSION

4.1	Introduction	20
4.2	Streamline Velocity	20
4.3	Velocity Contour	21
4.3.1	Velocity Contour for Profile 1	21

4.3.2	Velocity Contour for Profile 2	23
4.4	Blade Pressure	24
4.5	Graphical Result	25
CHAPTER 5 CONCLUSION AND RECOMMENDATIONS		
5.2	Conclusion	27
5.3	Recommendation	27
REFERENCES		28

LIST OF TABLES

Table No.	Title	Page
2.1	Selected Reynolds Number	7
3.1	Blade Parameter	14
3.2	Mesh Information	15
3.3	Domain Physics for CFD	17
3.4	Boundary Physics for CFD	19

LIST OF FIGURES

Figure No.	Title	Page
1.1	Pou La Cour's first electricity producing wind turbine in 1891 in Askov, Denmark (Golding, 1977)	2
2.1	Lift and drag vectors	50
2.2	Blade at low, medium and high angle of attack	5
2.3	Maximum power coefficients of a three-blade optimum function of the Sliding Ratio	8
3.1	Flow Chart	10
3.2	Aerofoil Profile 1	13
3.3	Aerofoil Profile 2	13
3.4	Enclosure Detail	14
3.5	Meshing	15
3.6	Fluid Flow Set-up	16
3.7	Blade Detail	16
4.1	Streamline velocity for Profile 1	20
4.2	Streamline velocity for Profile 2	21
4.3	Velocity Contour at 30% cross section for Profile 1	21
4.4	Velocity Contour at 50% cross section for Profile 1	22
4.5	Velocity Contour at 70% cross section for Profile 1	22

4.6	Velocity Contour at 30% cross section for Profile 2	23
4.7	Velocity Contour at 50% cross section for Profile 2	23
4.8	Velocity Contour at 70% cross section for Profile 2	24
4.9	Blade Pressure for Profile 1	24
4.10	Blade Pressure for Profile 2	25
4.11	Velocity versus Chart Count	25
4.12	Pressure versus Chart Count	26

CHAPTER 1

INTRODUCTION

1.1 Project Motivation

Most of windmill is commercially available but these are too costly. Moreover, windmill is widely use in the area which is in high speed of wind energy. Windmill with low speed design will be cheaper than high speed design.

So, it is important to build low speed windmill that available at low cost for personal or community usage. This low speed windmill should be built with high performance condition and then apply at potential area.

1.2 Project Background

Development of windmill either to generate electricity or water pump was due to concern on environmental issues for clean power generation. Furthermore, in some areas, windmill was used for these purpose if they are available cheaply and applicable to local condition in order to reduce their utility bills and contribute to the nation's energy supply.

Wind energy was rapidly growing in 1990's, but it is not really distributed around the world. Nowadays, a lot of researches have been done to develop windmill blade structure. Windmill blade was designed probably is to use wind energy which is free energy and apply it in our daily live.

The rotor blade plays the main role in windmill to transfer the maximum wind power to the motor. Previously, in the early development of windmill, type of blade designs for example rectangular, trapezoid and sickle-shaped have been used for windmill. Lately, the design of windmill blade has been focus on aerofoil shape that

equivalent with aeroplane wing. The manufacturer believes that this design is the latest design with highest performance.

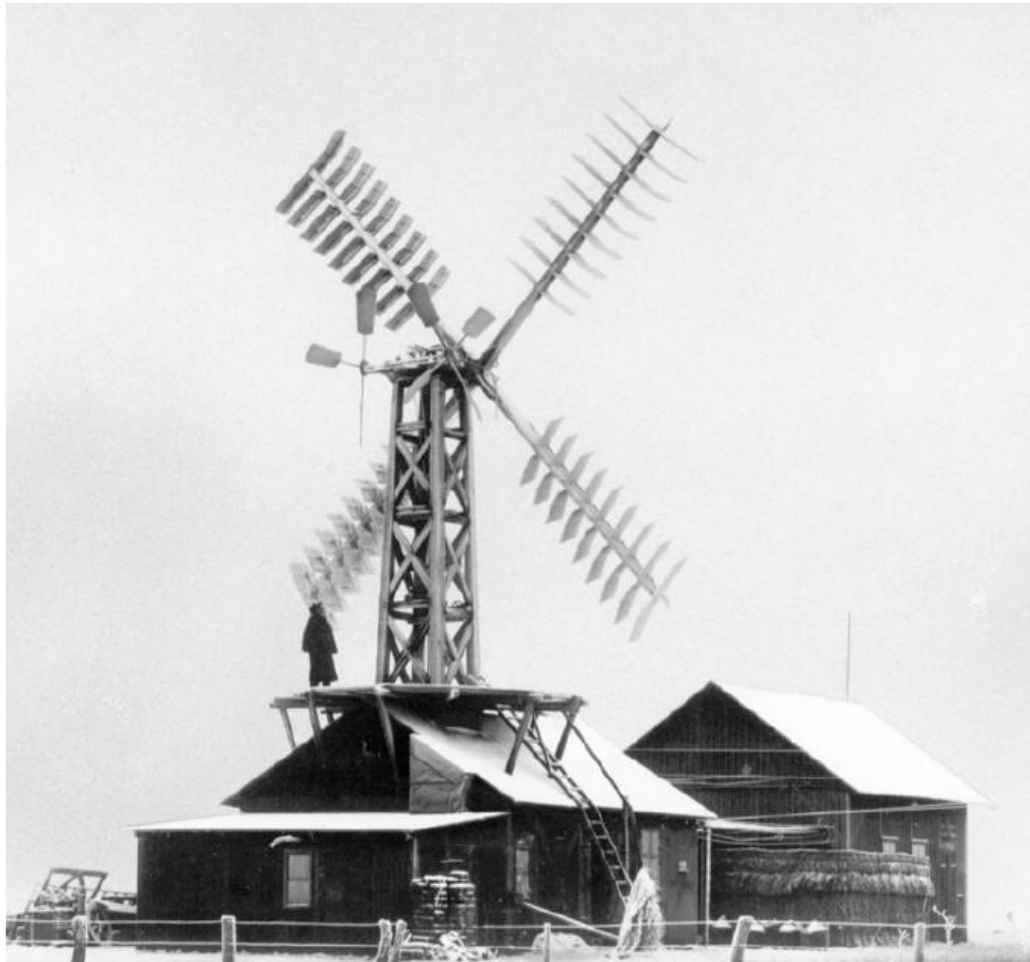


Figure 1.1: Pou La Cour's first electricity producing wind turbine in 1891 in Askov, Denmark (Golding, 1977)

1.3 Problem Statement

1. Basically, the different shape or design of blade would give difference velocity result. Each design have its own characteristic. So, which design have higher velocity when the wind energy exerted on the blade.

2. Cross section along the tapered blade will not have the same velocity. The different is because of difference chord line length. Therefore, which chord length at each cross section have the higher velocity value.

1.4 Objective of Project

1. To determine the air flow velocity around the blade with difference cross section.
2. To analyze the velocity of air passing through the difference design of blade.

1.5 Scope of the Project

There are variable of blade design available through the manufacturer. This project mainly will focus on the two type of blade design. It will discuss the higher velocity value between two designs of aerofoil shape.

Then, the cross section along the blade need to be compared and identify the highest velocity between both designs.

CHAPTER 2

LITERATURE REVIEW

2.1 How the Turbine Works

Wind turbine blades are design to generate the maximum power from the wind at minimum cost. Basically the blade shape design based on aerodynamics and structural requirements. The material chosen and the manufacturing process will decide how ideal the blade design aerodynamically.

Wind turbine blades work just like an aeroplane wing by generating lift due to their shape. The more curved side generates low air pressure while on the other side the high pressure pushes the airfoil. The result shows that the lift force is perpendicular to the direction of the air flow. Wind power was determined by the wind flow around the blade turbine. As the blade turned, the angle of wind attack increases until it reaches the optimum angle of attack to generate the maximum lift force. Drag force increase as the angle of attack reach its maximum angle and make the blade stalls and the lift force will also decreases. Each type of aerofoil turbine blade has its own lift and drag coefficient determined by different angle of attack.

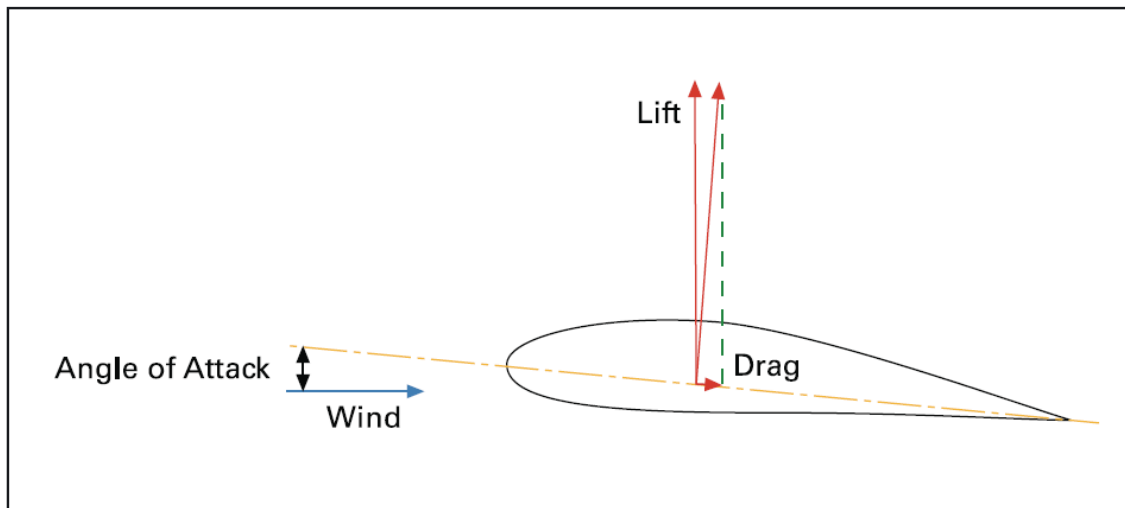


Figure 2.1: Lift and drag vectors. [1]

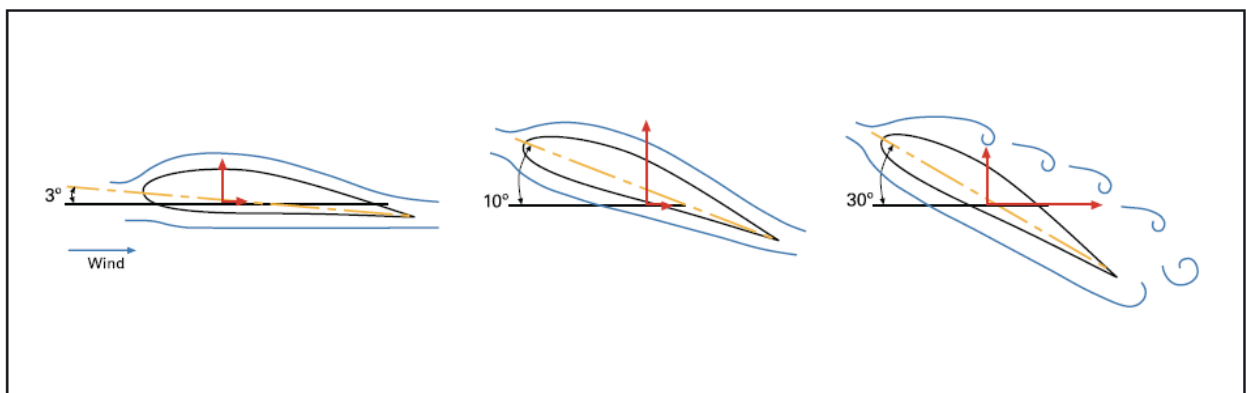


Figure 2.2: Blade at low, medium and high angle of attack. [1]

2.2 Type of Turbine Design

The best design required for wind turbine blade is the aerofoil shapes which are similar with aeroplane wings. This aerofoil shape would probably increase the efficiency of wind turbine and minimize the wind power loss by an oscillating wind turbine. Furthermore, in order to deliver the maximum output power was based on how efficient the turbine can capture the wind energy with the most minimum loss energy. Lift and drag force is one of

the most important characters to analyze for start-up motion of the blade and how it's going to continue oscillating. Generally the best lift and drag characteristic are obtained by thin aerofoil shape for high sliding ratio, its thickness around 10-15% of its “chord” length [1] [2]. Chord is the length across the blade, in the wind flow direction. Aerofoil structural should be able to support for lift, drag and gravitational forces acting on it. Therefore aerofoil needs to be thicker at the most bending forces acts which locate near the blade root where the blades attach to the hub.

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

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

Therefore, sliding ratio can defined as,

$$\epsilon = \frac{C_L}{C_D} = \frac{L}{D}$$

2.2.1 Number of Blade

A greater number of blades increase the weight to be turned by the turbine [3]. On the other hand, more blades provide a greater available surface area for the wind to push, so it would produce more turning power [3]. Having fewer blades could be beneficial because it will not be as heavy, and will be easier to turn than a greater number of blades, but it will also be somewhat inefficient because it produces less turning power [3].

2.2.2 Horizontal-Axis Wind Turbine

Nowadays, aerodynamically design of all Horizontal-Axis-Wind-Turbine (HAWT) performed different numerical studies range from Blade Element Momentum theory (BEM) integrated by Computational Fluid Dynamics (CFD) to full 3D-Navier-Stokes models [2]. The simulation for two-dimensional (2D) computations were carried out at low Reynolds numbers at average speed 11 m/s in Egypt and also Hoogendoorn et al. done simulations for high Reynolds number ($Re > 10^6$) for wind turbine profile NACA 0008 and NACA0012 [2]. Wilson et al. (1976) have determined the maximum turbine power coefficient, C_p with an optimum blade design but with a finite number of blades and aerodynamic drag [2]. Their result obtained the accuracy is around 0.5% for tip speed ratio from 4 to 20, sliding ratio from 25 to infinity and from 1 to 3 blades where:

Table 1: Selected Reynolds numbers for the study at different wind speeds [2].

Wind speed (m/s)	Reynolds numbers (Re)
5	3.21E + 05
7	4.36E + 05
9	5.61E + 05
11	6.85E + 05
13	8.10E + 05
15	9.35E + 05

Table 2.1: Selected Reynolds Number

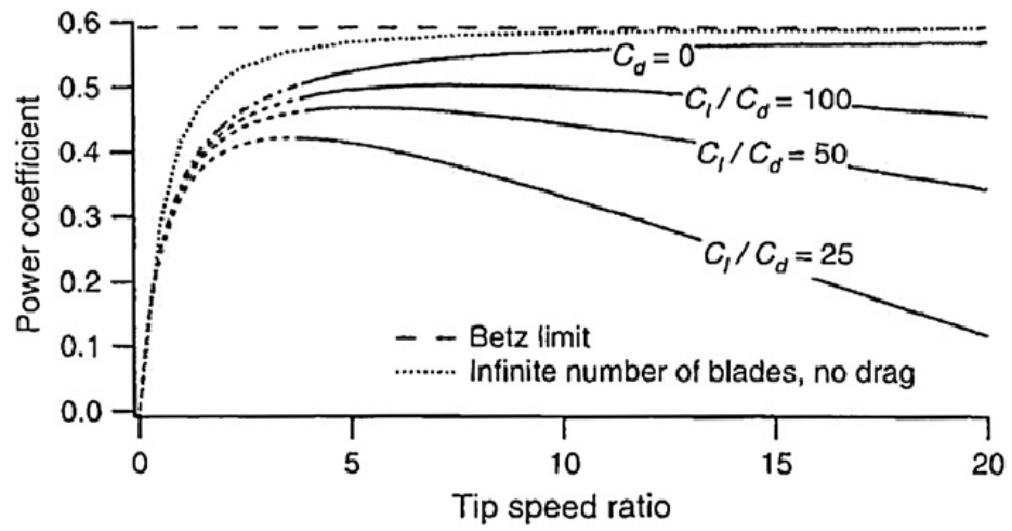


Figure 2.3: Maximum power coefficients of a three-blade optimum function of the sliding ratio.

CHAPTER 3

METHODOLOGY

3.1 Introduction

On methodology part, it will describe about how the project will be conduct in step by step flow. This flowchart consists planning from starting till the end of the project process. This part will explain briefly about how the blade have been design and what type of software have been used.

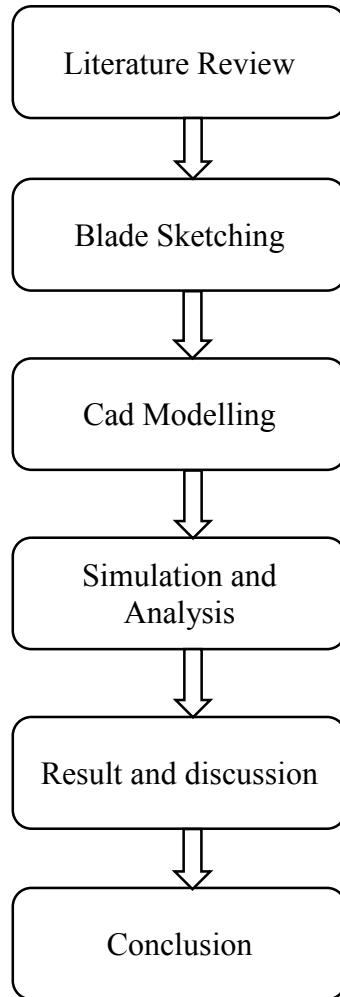


Figure 3.1: Flow chart

3.2 Studies on Blade Design

3.2.1 Wind power

The power contained in the wind is the kinetic energy of the flowing air mass per unit time. If v_{wind} is the velocity of the wind, A is the rotor swept area and ρ is the density of air, then Kinetic energy of the wind is given by

$$KE = \frac{1}{2}mv_{wind}^2 \quad (1)$$

Volume of air passing through swept area per unit time = Av_{wind}

Mass flow rate = ρAv_{wind}

c_p = power coefficient

Wind Power $P = \frac{1}{2}(\text{mass flow rate})c_p v_{wind}^2$

$$P = \frac{1}{2}\rho A v_{wind}^3 \quad (2)$$

3.2.2 Solidity

The solidity of a wind rotor is the ratio of the projected blade area to the area of the wind intercepted (Bhadra S N, 2010). The projected blade area over here refers to the blade area met by the wind or projected in the direction of the wind. The area of the wind intercepted is also called the swept area.

$$\text{Solidity} = \frac{\text{Projected blade area}}{\text{Rotor sweep area}} \quad (3)$$

For high-speed horizontal-axis machines, solidity is between 0.01 and 0.1 (Bhadra S N, 2010). Solidity has direct relationship between speed and torque. High solidity rotors have high torque and low speed which suitable for work like pumping water. Low solidity rotors have high speed and low torque. This is typically suited for electrical power generation.

3.2.3 Tip Speed Ratio

Tip speed ratio (TSR) is the speed of the blade at its tip divided by the speed of the wind.

$$\lambda = \frac{2\pi RN}{v} \quad (4)$$

where λ is the tip speed ratio, R is the radius of the swept area, N is the rotational speed, and v is the free wind speed.

If the TSR does not achieve 1, it means a lot of drag force acting on the blade. If TSR is above 1, that means there is lift force involve rotating the blade faster than the wind speed. Modern wind turbines have higher TSR values like 5.

For a particular generator, if the blade was set to spin at too low, then it might not catch up with the wind that passes through the blade. If the blade rotates too fast then the blade will travel through turbulence air. It happens because the blade travels through the air of the blade in front of it just pass through and the fresh air not yet reaches that area.

The tip speed ratio will be low as they operate at low speed. On the other hand, in high speed horizontal-axis rotor type, the TSR can reach values as high as 9.

3.3 Design Blade with Software

Blade profile for both aerofoil design have been designed in Solidwork. All the specification have been determine in Solidwork. Then, aerodynamic analysis will be done in ANSYS software.

3.3.1 Computer Aided Design

There are two types of blade shape that has been designed by using Solidwork which is aerofoil shape. Both of these blade have difference chord length and thickness. These design have been set-up at only 15 degree angle of attack.

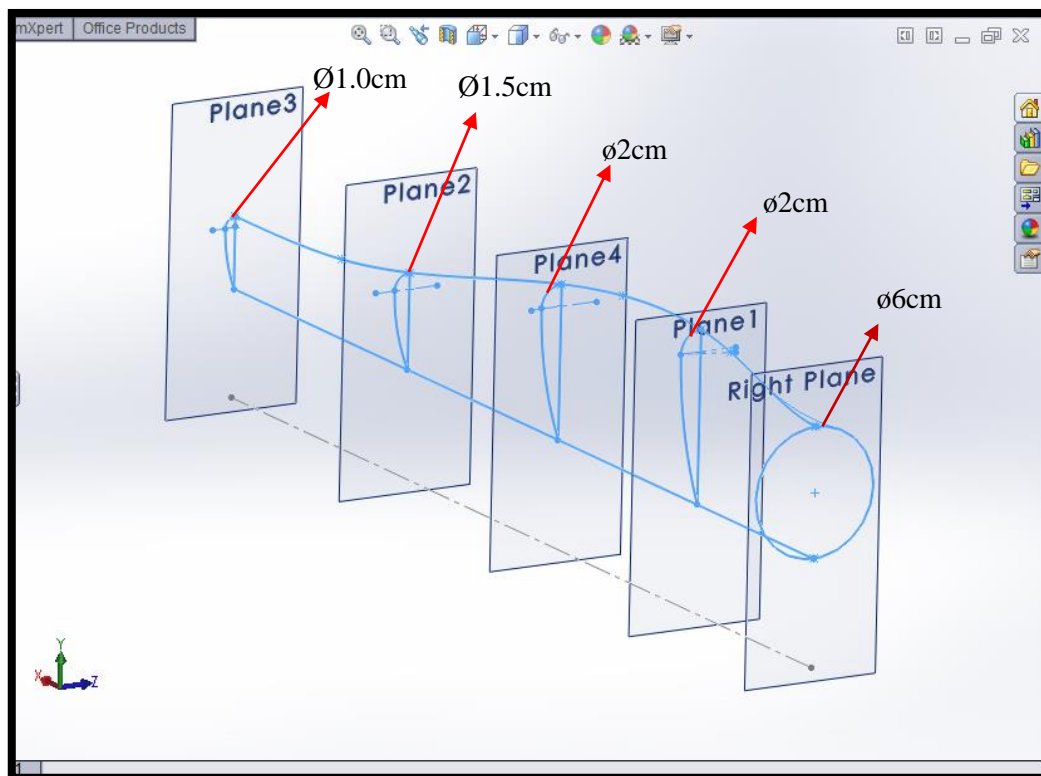


Figure 3.2: Aerofoil Profile 1

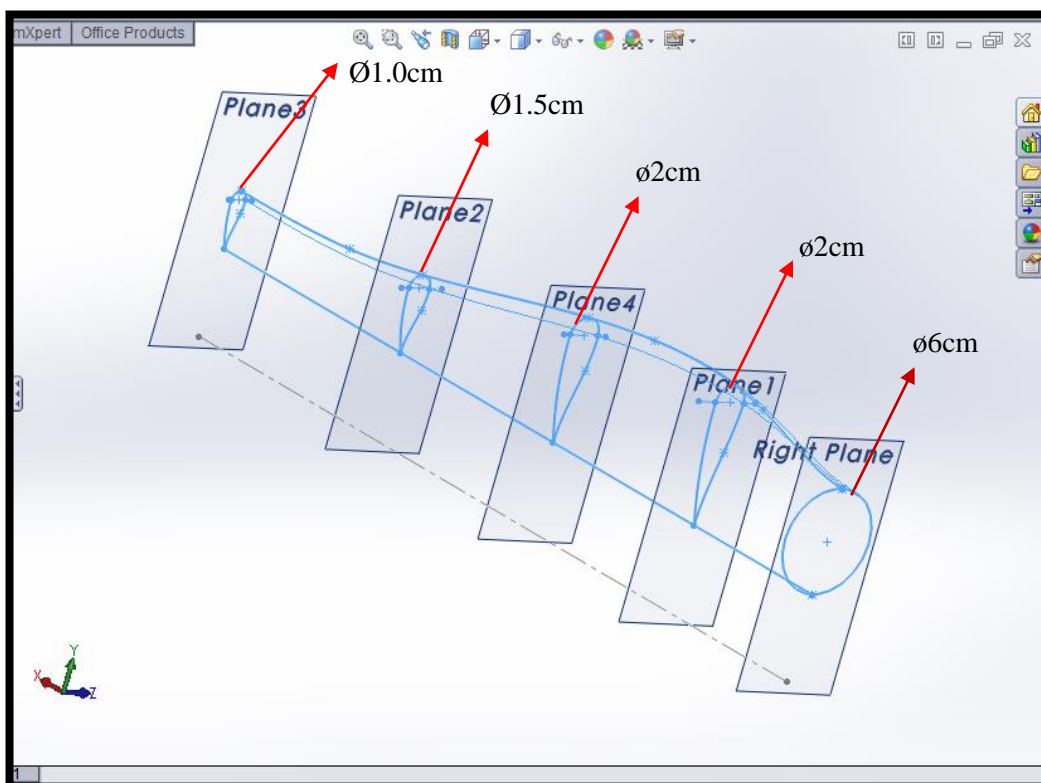


Figure 3.3: Aerofoil Profile blade 2

Specification	Profile 1			Profile 2		
Cross Section	30%	50%	70%	30%	50%	70%
Distance	15cm	25cm	35cm	15cm	25cm	35cm
Chord length	7.99cm	6.49cm	4.41cm	7.99cm	6.49cm	4.41cm

Table 3.1: Blade Parameter

3.4 Analysis Method

3.4.1 Computational Fluid Dynamic (CFD)

There are many CFD software use, for example PHOENIX, STAR-CD and so on. Does not matter what type of CFD software is, the main processes of simulation are the same [7].

All the set up and analysis result in this thesis is from ANSYS software. Both design have been set-up in ANSYS and they have the same set-up characteristic.

Step 1: Boundary Set-up

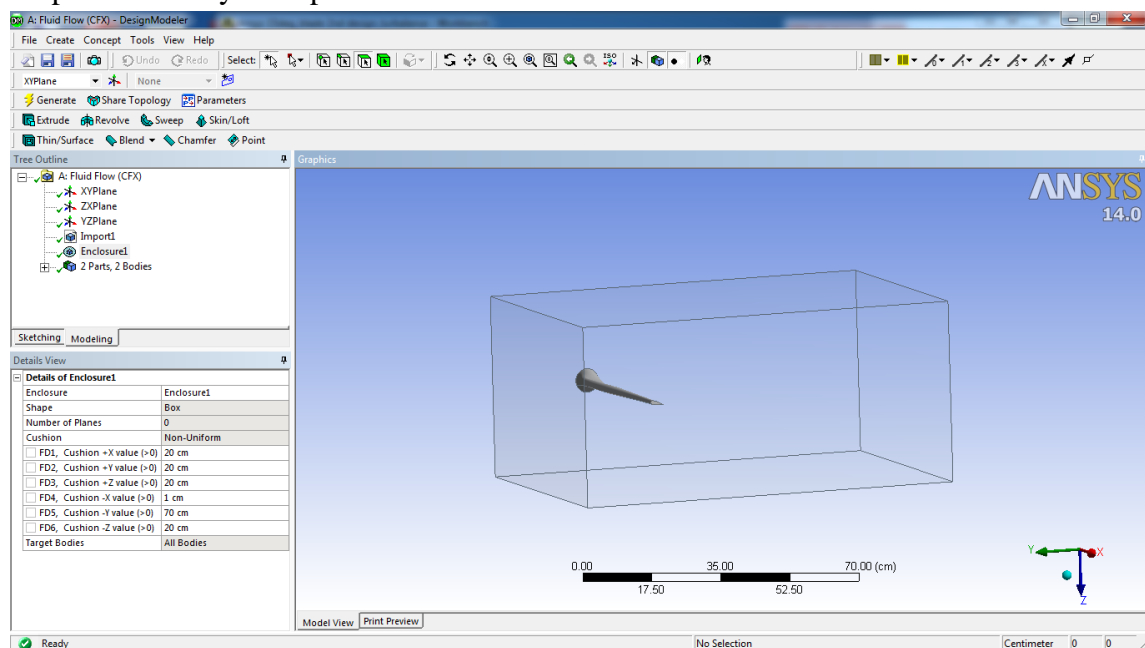


Figure 3.4: Enclosure Detail

Step 2: Mesh Set-up

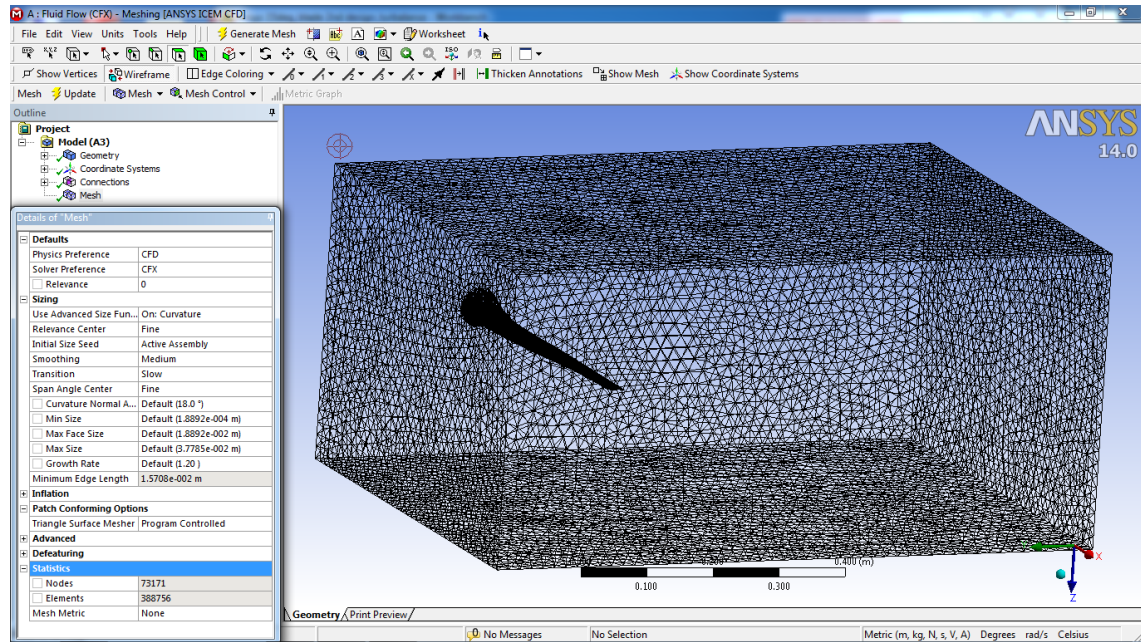


Figure 3.5: Meshing

Domain	Nodes	Elements
Default Domain / Air	58168	313516
Domain 1/ Blade	8362	7056
All Domains	66530	320572

Table 3.2: Mesh Information

Step 3: Inlet, outlet and wall setting

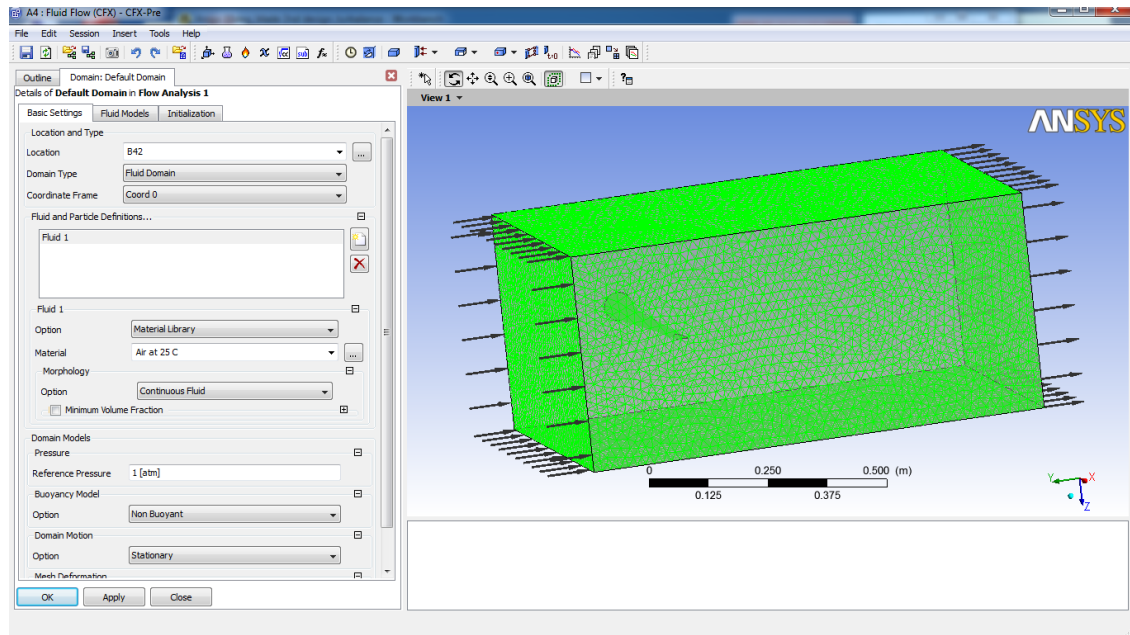


Figure 3.6: Fluid Flow Set-up

Step 4: Blade Set-up

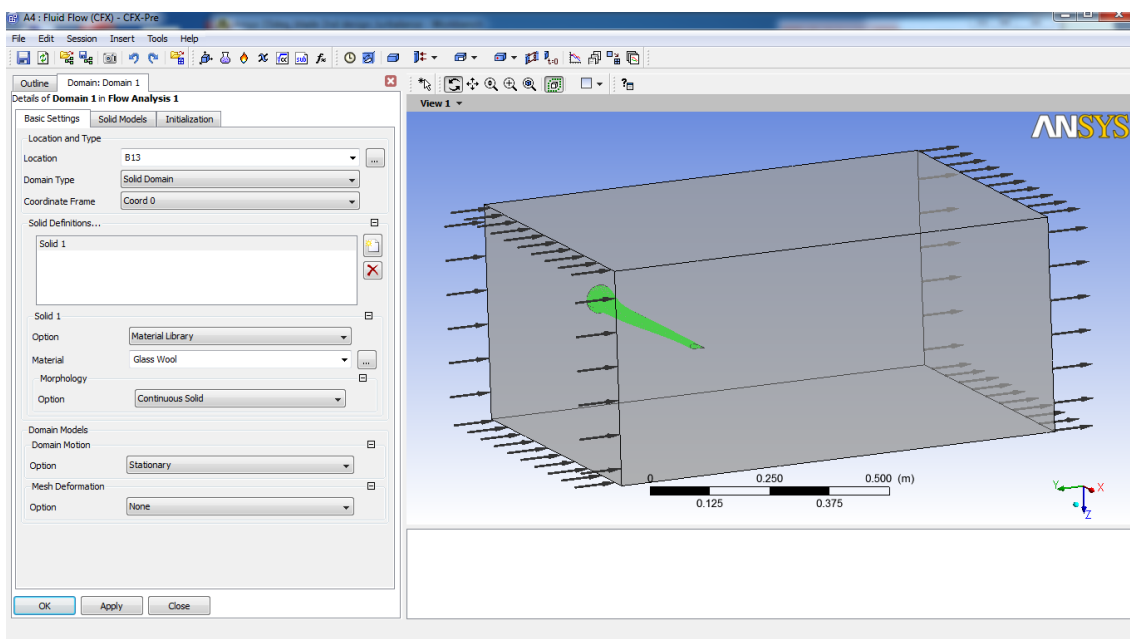


Figure 3.7: Blade Detail

Domain - Default Domain (Air)	
Type	Fluid
Location	B42
<i>Materials</i>	
Air at 25 C	
Fluid Definition	Material Library
Morphology	Continuous Fluid
<i>Settings</i>	
Buoyancy Model	Non Buoyant
Domain Motion	Stationary
Reference Pressure	1.0000e+00 [atm]
Heat Transfer Model	Isothermal
Fluid Temperature	2.5000e+01 [C]
Turbulence Model	k epsilon
Turbulent Wall Functions	Scalable
Domain - Domain 1 (Blade)	
Type	Solid
Location	B13
<i>Settings</i>	
Domain Motion	Stationary

Table 3.3: Domain Physics for CFD

Domain	Boundaries	
Default Domain(Air)	Boundary - Inlet	
	Type	INLET
	Location	F45.42
	<i>Settings</i>	
	Flow Regime	Subsonic
	Mass And Momentum	Normal Speed
	Normal Speed	2.5000e+00 [m s ⁻¹]
	Turbulence	Medium Intensity and Eddy Viscosity Ratio
	Boundary - Outlet	
	Type	OUTLET
	Location	F47.42
	<i>Settings</i>	
	Flow Regime	Subsonic
	Mass And Momentum	Static Pressure
	Relative Pressure	1.0000e+00 [Pa]
	Boundary - Default Domain Default	
	Type	WALL
	Location	F43.42, F44.42, F48.42, F49.42, F50.42, F51.42, F52.42
	<i>Settings</i>	
	Mass And Momentum	No Slip Wall
	Wall Roughness	Smooth Wall
	Boundary - Wall	
	Type	WALL
	Location	F46.42
	<i>Settings</i>	
	Mass And Momentum	No Slip Wall
	Wall Roughness	Smooth Wall

Domain 1(Blade)	Boundary - Domain 1 Default	
	Type	WALL
	Location	F14.13, F15.13, F16.13, F17.13
	<i>Settings</i>	
	Heat Transfer	Adiabatic

Table 3.4: Boundary Physics for CFD

After completed setting, then running the software to get the analysis result. All analysis result have been display in Chapter 5.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will discuss about the analysis from both aerofoil design. The result display is all from ANSYS software. This chapter will be focus on the velocity. It will discuss about the difference of air velocity between these two types of aerofoil design and also the velocity of air pass through at difference cross section. Then it will discuss about how the pressure and velocity related.

4.2 Streamline Velocity

Diagram below shows there is difference velocity value for both streamline and there is the difference velocity which is Profile 2 have higher streamline velocity than Profile 1.

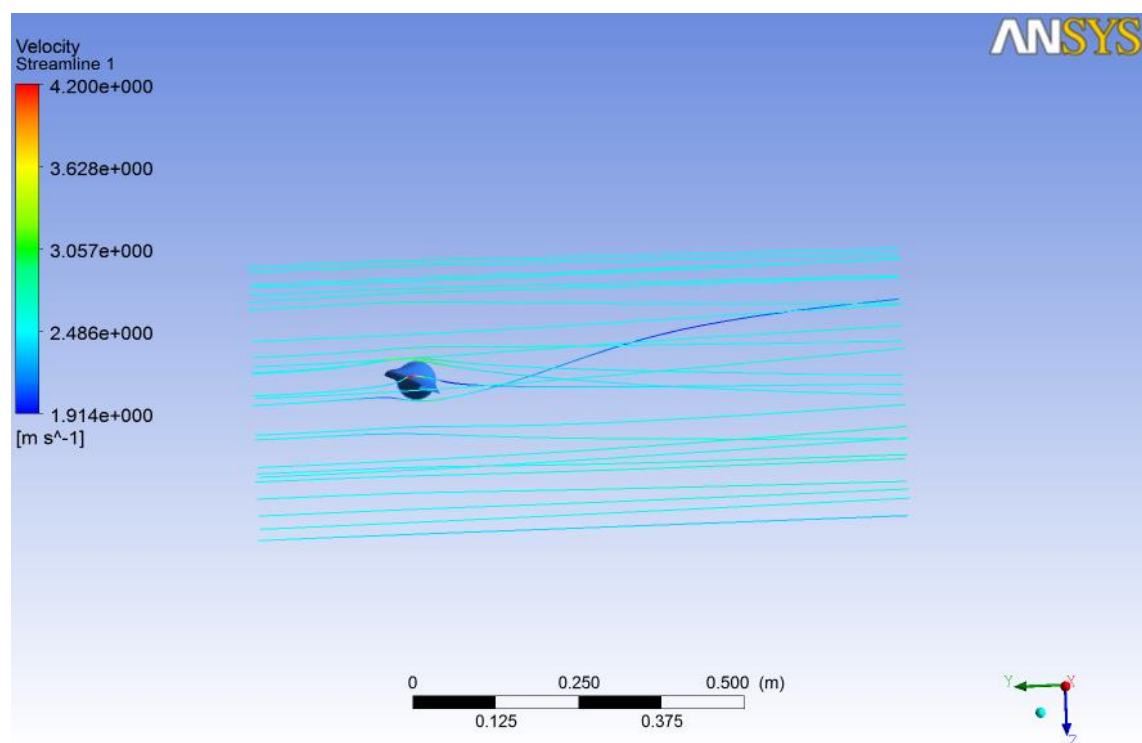


Figure 4.1: Streamline velocity for Profile 1

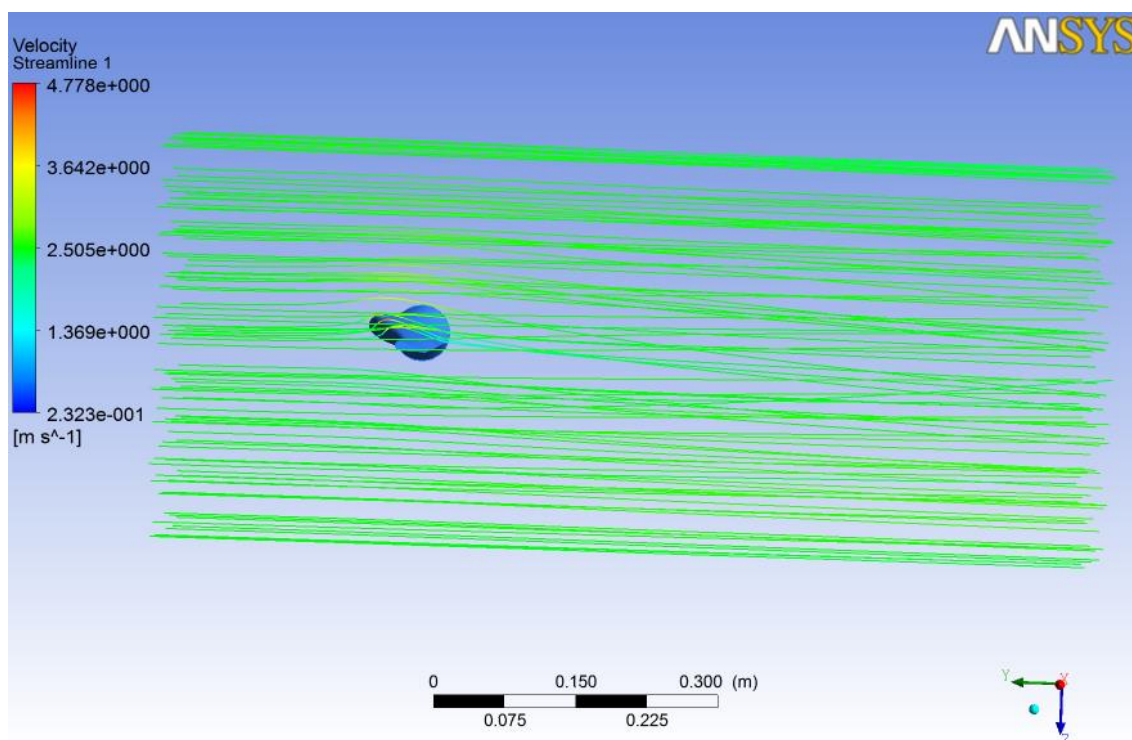


Figure 4.2: Streamline velocity for Profile 2

4.3 Velocity Contour

4.3.1 Velocity Contour For Profile 1

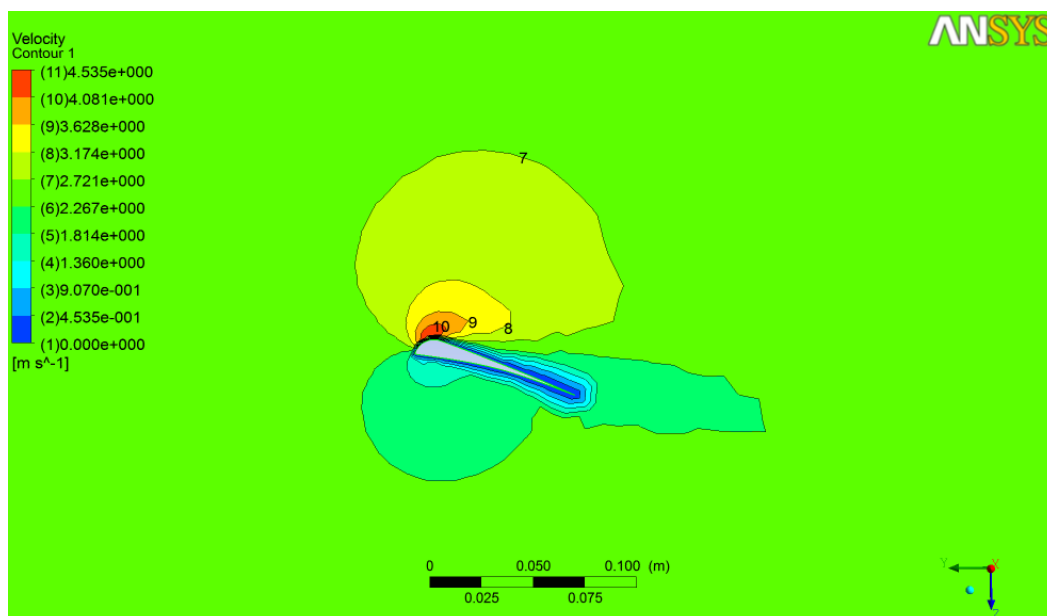


Figure 4.3: Velocity Contour at 30% cross section

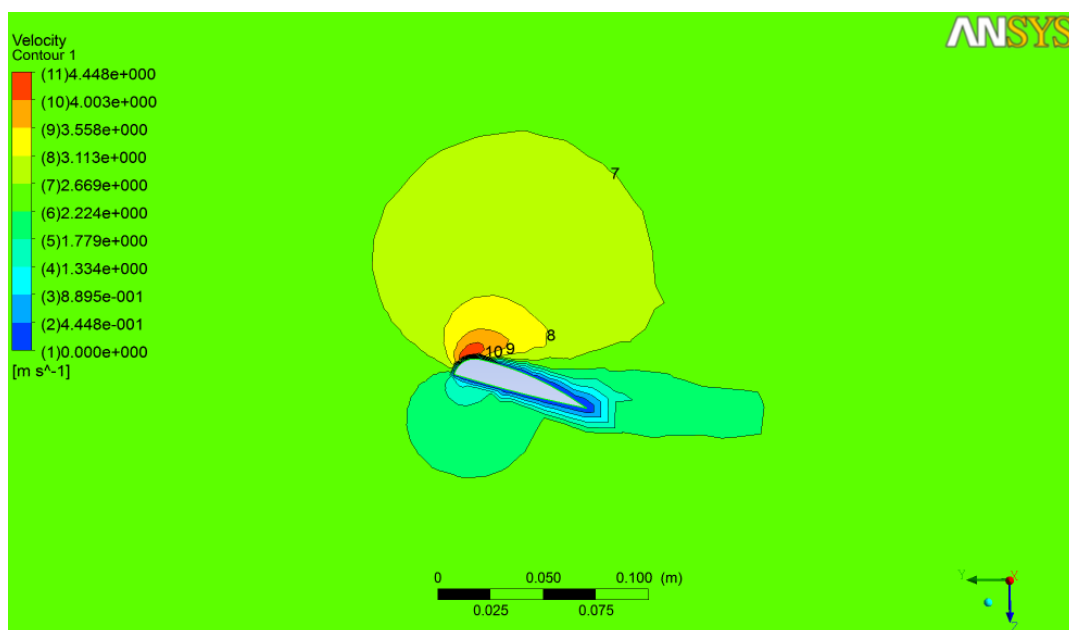


Figure 4.4: Velocity Contour at 50% cross section

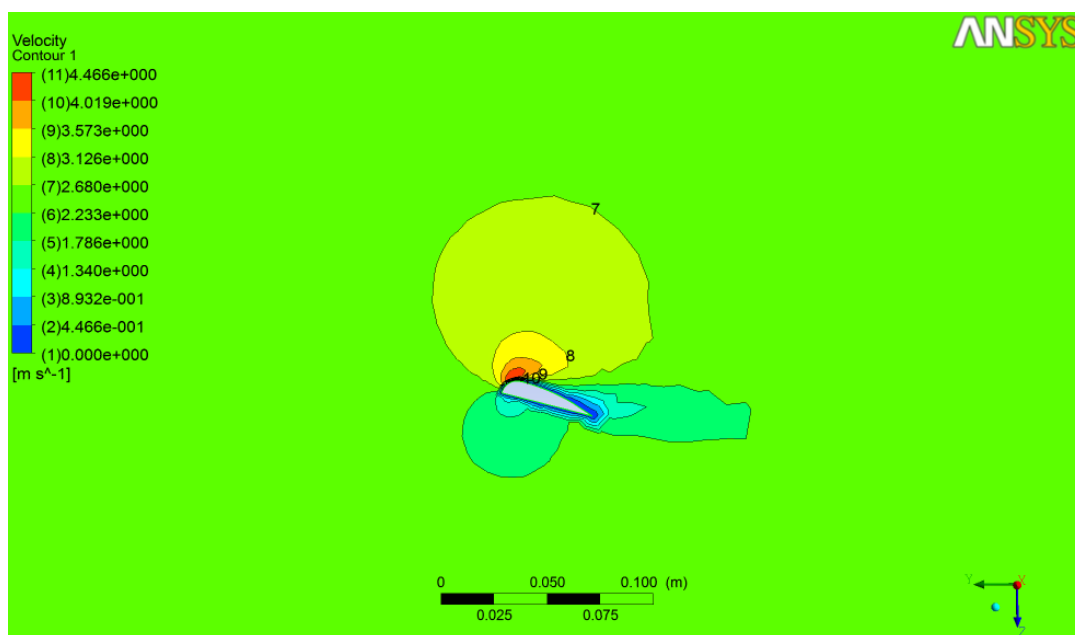


Figure 4.5: Velocity Contour at 70% cross section

4.3.2 Velocity Contour For Profile 2

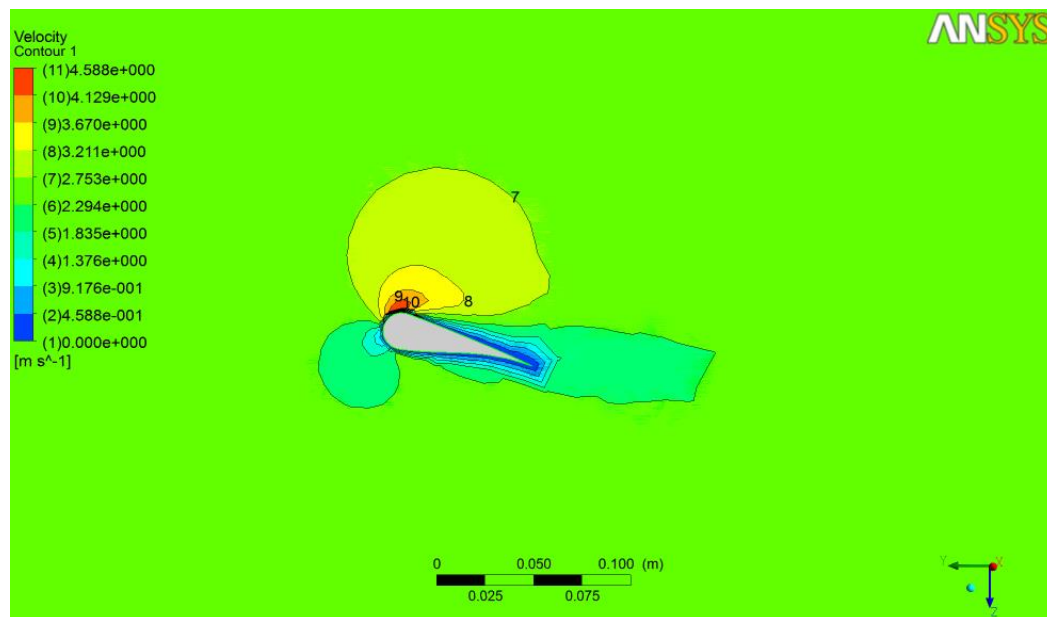


Figure 4.6: Velocity Contour at 30% cross section

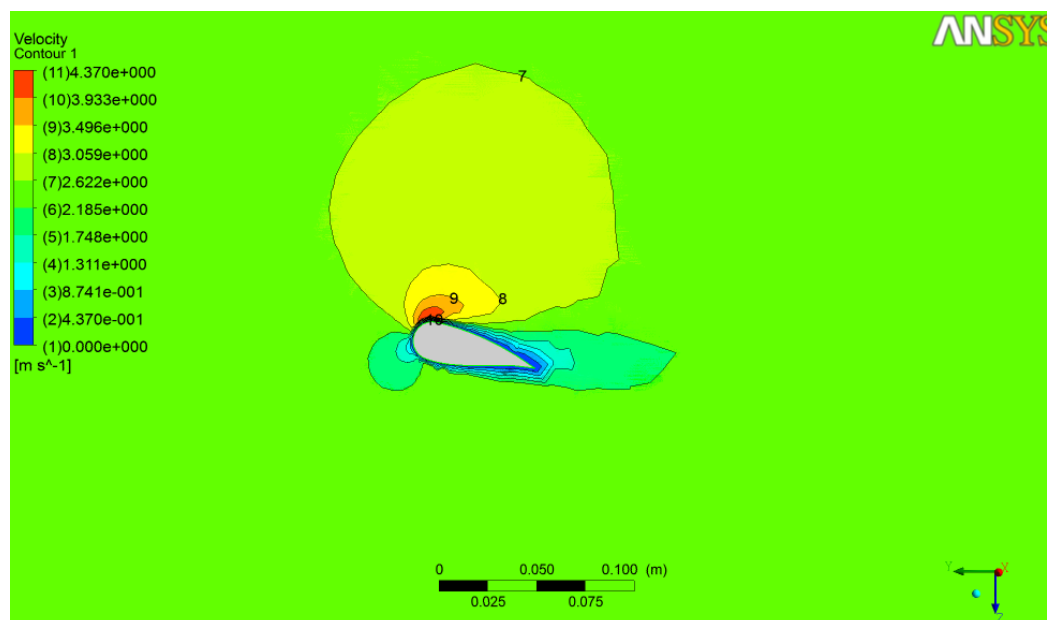


Figure 4.7: Velocity Contour at 50% cross section



Figure 4.8: Velocity Contour at 70% cross section

4.4 Blade Pressure

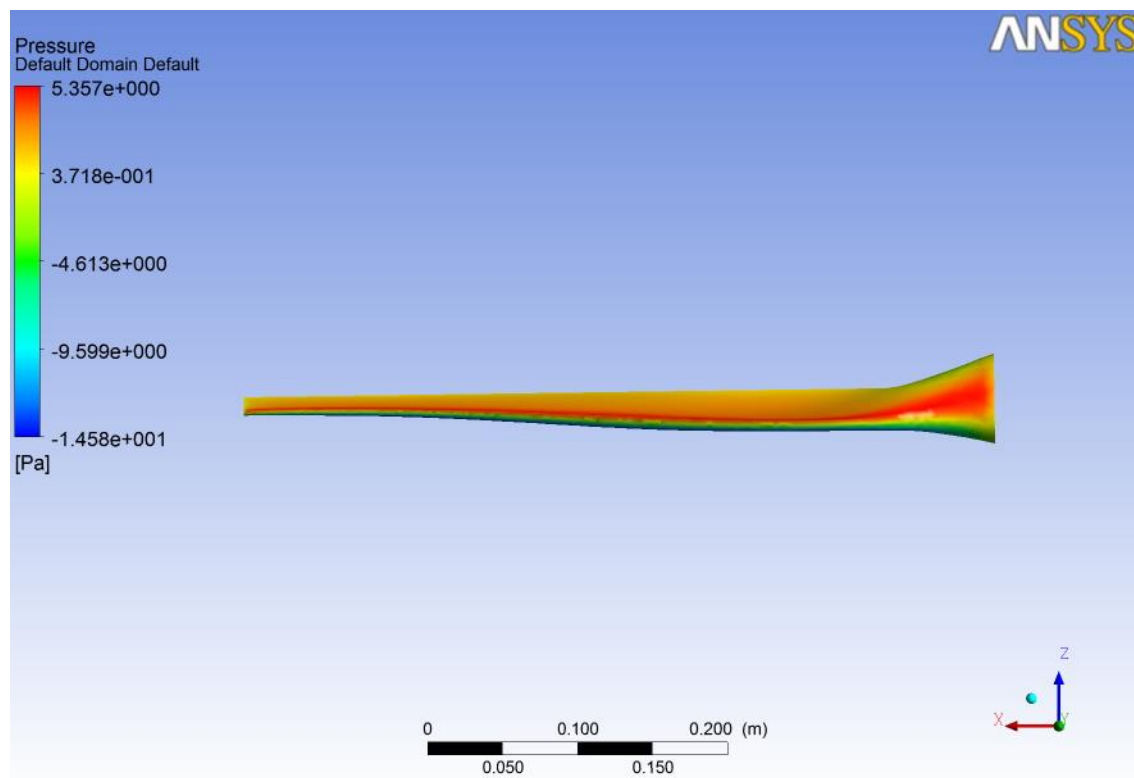


Figure 4.9: Blade Pressure for Profile 1

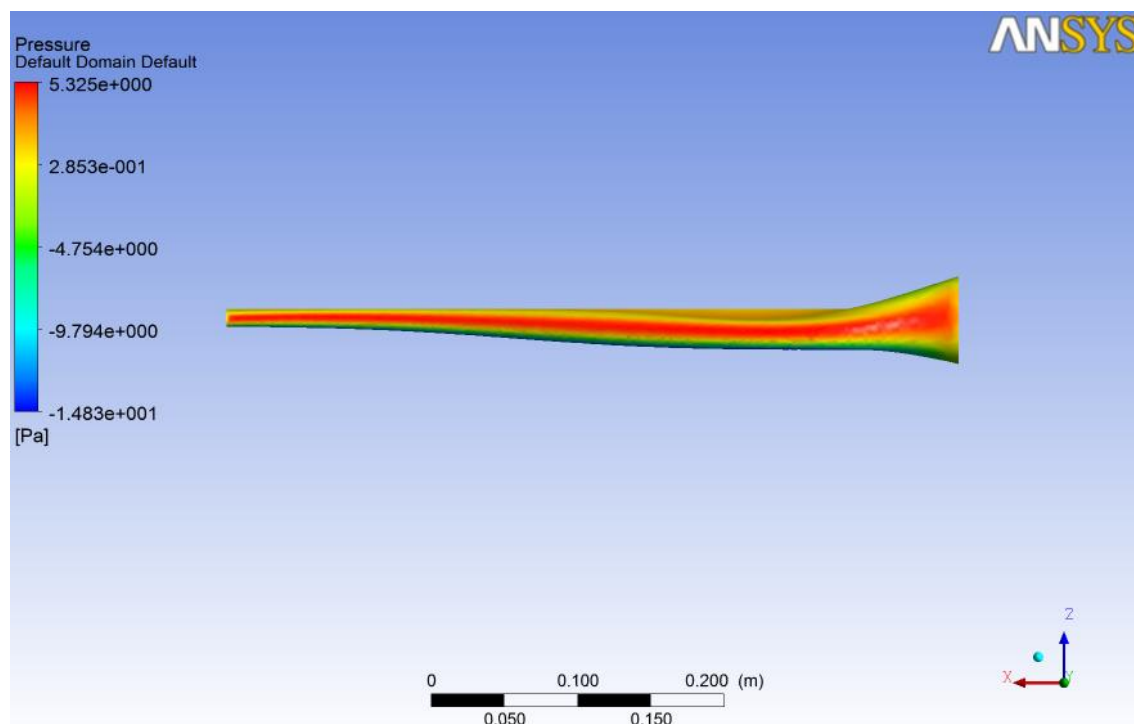


Figure 4.10: Blade Pressure for Profile 2

4.5 Graphical Result

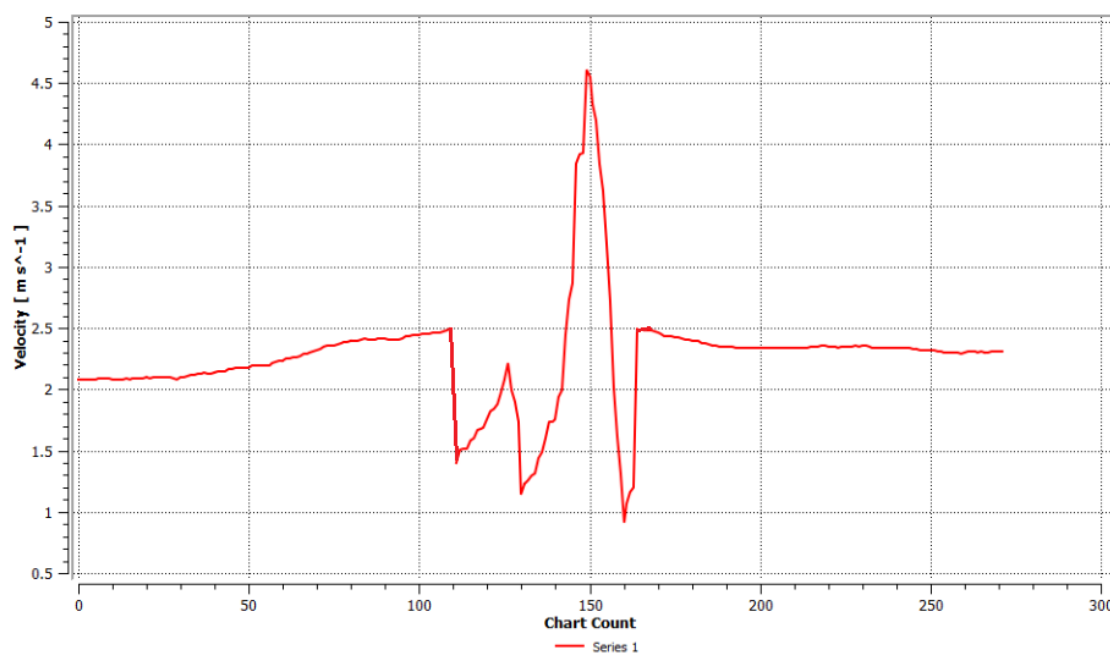


Figure 4.11: Velocity versus Chart Count

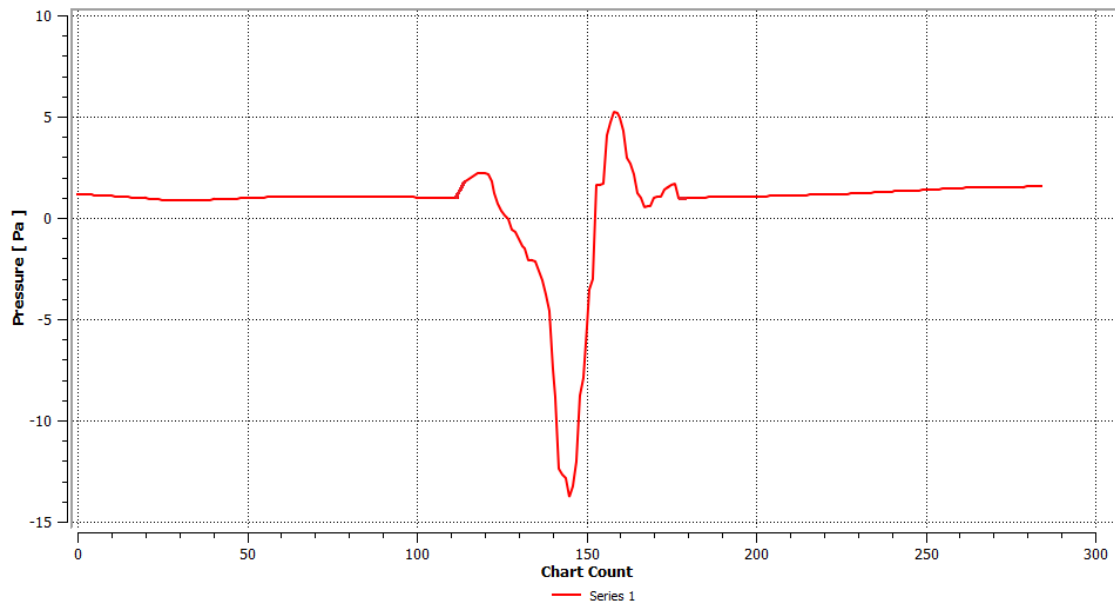


Figure 4.12: Pressure versus Chart Count

Figure 4.9 shows that the velocity of the fluid increase to the peak value as it touch the blade, but for pressure, the Figure 4.10 shows the pressure is extremely decrease as it touch the blade. Due to the curvature of the Aerofoil, the higher velocities and acceleration over the top of the aerofoil requires a pressure above the aerofoil lower than the ambient pressure. This pressure difference results in an upward lifting force on the aerofoil.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Profile 1 have higher velocity at 50% and 70% of blade section while Profile 2 have higher velocity at 30% of blade section. Streamline velocity shows that profile blade 2 have higher velocity than profile 1. This difference occur because of the shape of the blade and the thickness along the blade.

5.2 Recommendation

This design is only focus on 15 °angle of attack .This study should focus on different angle of attack for example 20 °, 25 ° or other angle of attack to determine which angle is more efficient for each blade. Then, combine each cross section that have higher velocity value to make a new blade shape.

REFERENCE

- [1] WE Handbook-2- Aerodynamics and Loads 1

- [2] Mohamed A. Sayed, Hamdy A. Kandil , Ahmed Shaltot. Energy Conversion and Management. Aerodynamic analysis of different wind-turbine-blade profiles using finite-volume method,7-8.

- [3] Anish Bhattacharya, THE EFFECT OF BLADE ANGLE AND SIZE ON WIND TURBINE PERFORMANCE, 8th Grade, Unity Point School District 140.

- [4] Bhadra S N, K. D. (2010). Wind Electrical Systems. Oxford University Press.

- [5] R Vijay, Aditya Kumar Sethi, Pitch Control of Horizontal Axis Wind Turbine. Thesis of Bachelor of Technology in Electrical Engineering, retrieve 2011 from Department of Electrical Engineering National Institute of Technology, Rourkela