PERFORMANCE EVALUATION OF SLOTTED AND CONTINUOUS TYPES WIND TURBINE BLADE

SARAH NARIMAH NOORAZYZE BT ZAINAL RAMLAN NOORAZYZE

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Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

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ABSTRACT

Nowadays, wind turbine became one of the largest energy suppliers of energy in world. The focal point in the wind turbine system is where the wind is harvested and converted into useable energy by the wind turbine blade. This study emphasized on determining the performance of continuous and slotted type of 5 meter diameter wind turbine blades for low wind speed in Malaysia. The Autodesk Inventor 2013 software was used as to develop the three dimensional model NACA 4412 airfoil blades with and without slot before evaluation of aerodynamic characteristics by using ANSYS software. This evaluation of aerodynamic characteristics of the slotted wind turbine blades with different slot configurations is believed could to benefit the material weight reduce its cost as it is constantly rising. Blades with lighter material would produce wind turbines with low rotational inertia and therefore would yield better energy performance at lower wind speeds. The aerodynamic results shows an increased value of lift coefficient with the increasing value of angle of attack (0° - 30°).

ABSTRAK

Pada masa kini, turbin angin menjadi salah satu pembekal terbesar tenaga di dunia. Tumpuan utama dalam sistem turbin angin di mana angin dituai dan ditukar menjadi tenaga yang boleh digunakan ialah bilah turbin angin. Kajian ini akan memberi penekanan dalam menentukan prestasi bilah turbin berdiameter 5 meter iaitu bilah asal dan bilah yang telah dislotkan bagi kelajuan angin rendah di Malaysia. Proses merekabentuk bilah model NACA 4412 dengan dan tanpa slot ini adalah menggunakan perisian Autodesk sebelum penilaian ciri-ciri aerodinamik dengan menggunakan perisian ANSYS. Kajian aerodinamik dilakukan terhadap bilah berslot ini adalah pada pelbagai konfigurasi dipercayai dapat memberi manfaat kepada penggunaan bahan mentah yang lebih ringan dan sekaligus merendahkan kos bahan yang semakin meningkat dari hari ke hari. Bilah yang ringan juga dipercayai dapat menghasilkan momen inersia yang rendah sekaligus mmenghasilkan lebih banyak tenaga pada kelajuan angina yang rendah. Keputusan aerodinamik menunjukkan nilai peningkatan pekali daya angkat meningkat apabila sudut angin semakin meningkat (0 ° - 30°).

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LIST OF SYMBOLS AND ABBREVIATIONS

α - Angle of attack

η - Efficiency

C_D - Drag coefficient

C_L - Lift coefficient

D - Drag

L - Lift

F - Force

N - Number of slot

HAWT - Horizontal Axis Wind Turbine

VAWT - Vertical Axis Wind Turbine

CHAPTER 1

INTRODUCTION

Wind turbines which were known as windmills many years ago was constructed from wood, cloth and stone for the purpose of pumping water or grinding corn are used as now used to extract the energies [1]. Nowadays, wind turbines became one of the largest suppliers of energy in the world. The focal point in the wind turbine system where the wind is converted into useable energy is the wind turbine blade. As the wind turbines in global energy production grow, wind turbines optimization becomes much more important [2, 3]. Wind turbines technology is one of the cleanest energy production machines [4], as they only require wind energy and maintenance to produce power. However the usage of wind turbine in Malaysia is still low compared to other countries like Spain, Denmark and China. This is likely due to the low rate of wind speed in most areas in Malaysia.

1.1 Research background

Wind speed in most area in Malaysia is low and inconsistent. Furthermore, wind turbine for low wind speed is currently much expensive than high speed wind turbine as the output is lesser than the financial installation [5]. Thus, in order for wind energy to be competitive in the market and to enhance its usage, it is important that its weight and cost to be minimized through blade design optimization [6 – 8]. If its power capability is equal, then the cost of material could be reduced and there will be more wind turbine usage in Malaysia. Currently, the wind blade is smooth and having a continuous surfaces which need higher cost in material and production As the speed of wind in Malaysia is low (between 5-17m/s), few consideration are needed as to enhance the wind harvested. Besides the design optimization which many other studies have done, the multi-rotor could be used in enhancing the wind harvested and this study is intended to design slotted blade. The slotted blade is proposed to reduce the overall weight of wind turbine rotor. The effect of number of slot and slot distance to the aerodynamic performance of the blade will be also evaluated using ANSYS software in this study. It is expected the slotted type wind turbine blade may benefits weight and cost reduction without compromising the performance of the wind turbine system. At the end of the study, the optimum slot configuration for wind turbine blade will be proposed.

1.2 Problem statement

Nowadays, many wind turbines are using composite as it is cheaper and have higher flexibility than other materials. However it has more weight and needs special labour fabrication techniques to make the known wind turbine blades which are relatively costly [9], and there may be some quality control issues [10]. The low speed wind in Malaysia caused unworthy installation of wind turbine in most area because of its performance rate and cost. To overcome these disadvantages, this study will evaluate a performance of slotted wind turbine blade. It is expected the slotted type wind turbine blade may benefits weight and cost reduction without compromising the performance of the wind turbine system.

1.3 Objective

The objectives of this study are:

a) To determine the performance of slotted type wind turbine blade

b) To propose an optimum slot configuration for wind turbine blade

1.4 Scope of study

The study will emphasize on determining the performance of continuous and slotted type of 5 meter diameter wind turbine blades for low wind speed in Malaysia. Following are the scopes of the study:

i. Development of 3D model of the wind turbine rotor blades with and without slot by using Autodesk Inventor 2013 software.

ii. Evaluation of aerodynamic characteristics (using ANSYS software) of the continuous and slotted wind turbine blades.

iii. Evaluation of aerodynamic characteristics of the slotted wind turbine blades with different slot configurations.

CHAPTER 2

LITERATURE REVIEW

2.1 Wind turbine

For human development to continue, we will ultimately need to find sources of renewable or virtually inexhaustible energy. We need to imagine, what will humans do for the next 250,000 years or so after they are depleted? Even the most apparently "inexhaustible" sources like fusion involve the generation of large amounts of waste heat; enough to place damaging stress on even a robust ecosystem like Earth's, at least for the organisms that depend upon stability of the system to survive. At this point, wind gets a lot of attention.

2.1.1 History of wind turbine

Since early recorded history, wind has been harvested to mill grains, power ships and even to generate electricity, starting in the 1930s. But as energy demand climbs, so have efforts to turn wind into a viable option for producing electricity on a large scale. Wind energy propelled boats along the Nile River as early as 5000 B.C. By 200 B.C., simple windmills in China were pumping water, while vertical-axis windmills with woven reed sails were grinding grain in Persia and the Middle East.

In the 1940s the largest wind turbine of the time began operating on a Vermont hilltop known as Grandpa's Knob. This turbine, rated at 1.25 megawatts in winds of about 30 mph, fed electric power to the local utility network for several months during World War II [8].

New ways of using the energy of the wind eventually spread around the world. By the 11th century, people in the Middle East were using windmills extensively for food production; returning merchants and crusaders carried this idea back to Europe [11]. The Dutch refined the windmill and adapted it for draining lakes and marshes in the Rhine River Delta. When settlers took this technology to the New World in the late 19th century, they began using windmills to pump water for farms and ranches, and later, to generate electricity for homes and industry.

The popularity of using the energy in the wind has always fluctuated with the price of fossil fuels. When fuel prices fell after World War II, interest in wind turbines waned. But when the price of oil skyrocketed in the 1970s, so did worldwide interest in wind turbine generators. The wind turbine technology R&D that followed the oil embargoes of the 1970s refined old ideas and introduced new ways of converting wind energy into useful power. Many of these approaches have been demonstrated in "wind farms" or wind power plants — groups of turbines that feed electricity into the utility grid [12].

Today, the lessons learned from more than a decade of operating wind power plants, along with continuing R&D, have made wind-generated electricity very close in cost to the power from conventional utility generation in some locations. Wind energy is the world's fastest-growing energy source and will power industry, businesses and homes with clean, renewable electricity for many years to come. At present, wind turbines can be catalogue into four areas [13]:

1. Light home wind turbines : 1.5kW – 10kW
2. Medium and on grid wind turbine: 10kW – 100kW
3. Large and on grid wind turbine: 100kW – 1500kW
4. Larger and on grid wind turbine: ≥ 1.5MW

2.1.2 Advantages and challenges of wind energy

Basically wind energy is fueled by the wind, so it's a clean fuel source. Wind energy doesn't pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas [8]. Wind turbines don't produce atmospheric emissions that cause acid rain or greenhouse gasses. According to the American Wind Energy Association [14] "*On average, each MWh of electricity generated in the U.S. results in the emission of 1,341 pounds of carbon dioxide* (CO^2)*, 7.5 pounds of sulphur dioxide* (SO^2) *and 3.55 pounds of nitrogen oxides (NOx). Thus the 10 million MWh of electricity generated annually by U.S. wind farms represents about 6.7 million tons in avoided* CO^2 *emissions, 37,500 tons of* SO^2 *and 17,750 tons of NOx. This avoided* CO^2 *equals over 1.8 million tons of carbon, enough to fill 180 trains, each 100 cars long, with each car holding 100 tons of carbon every year. And unlike most other electricity sources, wind turbines do not consume water".*

Wind power is a free and inexhaustible source of energy. Wind is actually a form of solar energy; winds are caused by the heating of the atmosphere by the sun, the rotation of the earth, and the earth's surface irregularities. Unlike fossil fuels such as coal and oil, which exist in a finite supply and which must be extracted from the earth at great environmental cost, wind turbines harness a boundless supply of kinetic energy in the form of wind. Adding to this, wind energy could be harvest from anywhere; urban, rural, offshore or even on the mountains.

However, wind turbine must compete with conventional generation sources on a cost basis. Depending on how energetic a wind site is, the wind farm may or may not be cost competitive. Even though the cost of wind power has decreased dramatically in the past 10 years, the technology requires a higher initial investment than fossil-fueled generators [9].

Good wind sites are often located in remote locations, far from cities where the electricity is needed. Transmission lines must be built to bring the electricity from the wind farm to the city. Wind resource development may compete with other uses for the land and those alternative uses may be more highly valued than electricity generation.

Although wind power plants have relatively little impact on the environment compared to other conventional power plants, there is some concern over the noise produced by the rotor blades, aesthetic (visual) impacts, and sometimes birds have been killed by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.

2.2 Horizontal and Vertical Axis Wind Turbine

There are two major types of wind turbines: horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). These turbines are named based on their rotor shaft location and the wind direction is shown as in Figure 2.1 [4, 12].

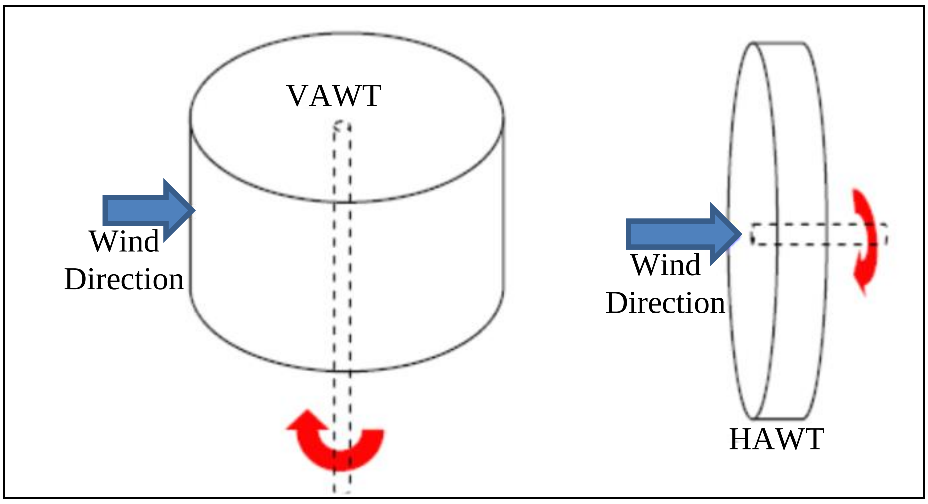


Figure 2.1: Alternative Configurations for Shaft and Rotor Orientation [4, 12].

Horizontal axis wind turbines (HAWT) have a horizontal rotor shaft and an electrical generator at the top of its tower as in Figure 2.2 [15]. HAWT is almost parallel to the wind stream and it has some distinct advantages such as low cut-in wind speed and easy furling [16, 17]. In general, they show relatively high power coefficient. However, the generator and gearbox of this axis of rotation horizontal to the ground and almost turbines are to be placed over the tower which makes its design more complex and expensive [16, 18].

HAWT also have the ability to collect maximum amount of wind energy for time of day and season and their blades can be adjusted to avoid high wind storm. Wind turbines operate in two modes namely constant or variable speed [19, 20]. For a constant speed turbine, the rotor turns at constant angular speed regardless of wind variations. One advantage of this mode is that it eliminates expensive power electronics such as inverters and converters. Its drawback however, is that it constraints rotors’ speed so that the turbine cannot operate at the peak efficiency in all wing speeds. For this reason, a constant wind speed turbine produces less energy at low wind speeds than does a variable wind speed turbine which is designed to operate at a rotor speed proportional to the wind speed below its rated wind speed [21].

Vertical axis wind turbine (VAWT) as in Figure 2.2 are designed with vertical rotor, a generator and gearbox which are placed at the bottom of the turbine, and a uniquely shaped rotor blade is designed to harvest the power of the wind no matter which direction it blows. The most obvious benefit of Vertical turbine is that they don’t need to be oriented towards to wind because they can capture wind energy from all directions. Unfortunately the vertical designs have weakness due to pulsatory torque, which occurs during every rotation and the large flexing moments of the blades themselves. This pulsatory torque creates unwanted vibrations on the rotor of the turbine and this stress can result in damage to the turbine.

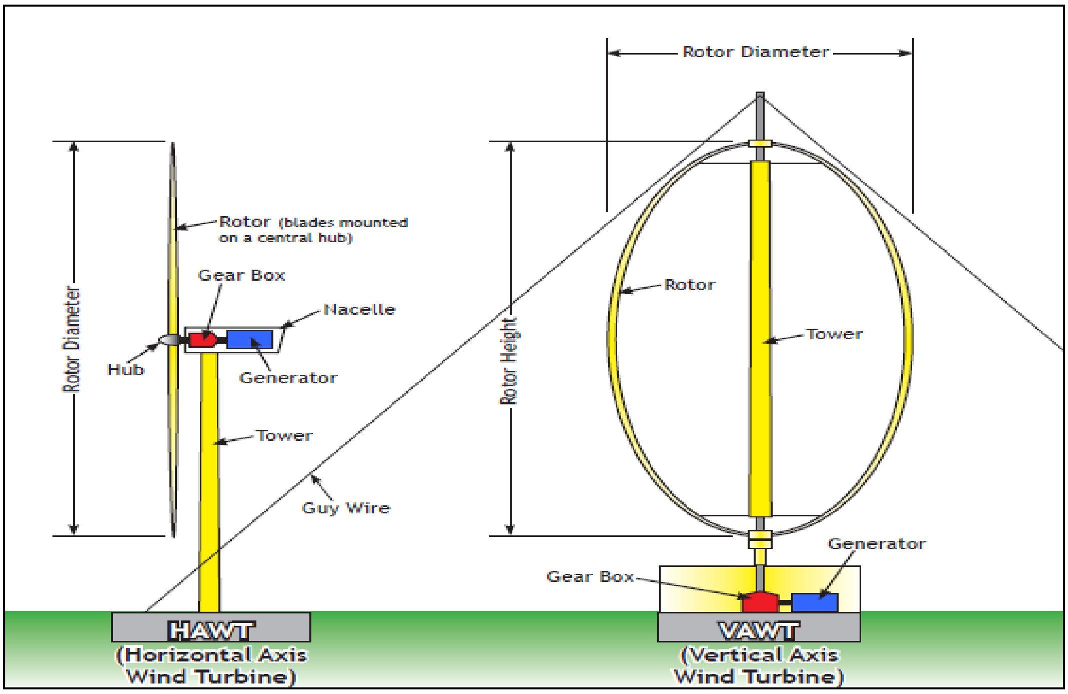


Figure 2.2: Horizontal Axis and Vertical Axis wind turbine [1]

2.3 Characteristic of Wind Speed in Malaysia

Malaysia consists of the Peninsular Malaysia and a part of Borneo Island. The Peninsular Malaysia in situated between 10 N and 70 N latitude, under the tropical climate. Most towns in the peninsular experience high temperature and humidity throughout the year without remarkable variations. However, there is a seasonal climatic change, which is dominated by the monsoon. Though the wind over the country is generally light and variable, there are, however, some uniform periodic changes in the wind flow patterns.

Based on these changes, four seasons can be distinguished, namely, the southwest monsoon, northeast monsoon and two shorter periods of inter-monsoon seasons. The southwest monsoon season is usually established in the latter half of May or early June and ends in September. The prevailing wind flow is generally south-westerly and light, below 7.72 m/s. The northeast monsoon season usually commences in early November and ends in March. During this season, steady easterly or north-easterly winds of 10 m/s to 17 m/s prevail. The east coast states of

Peninsular Malaysia where the wind may reach 15.46 m/s or more during periods of strong surges of cold air from the north (cold surges). During the two inter-monsoon seasons, the winds are generally light and variable. During these seasons, the equatorial trough lies over Malaysia.

It is worth mentioning that during the months of April to November, when typhoons frequently develop over the west Pacific and move westwards across the Philippines, south-westerly winds over the northwest coast of Sabah and Sarawak region may strengthen to reach 10.29 m/s or more.

2.4 Characteristic of wind turbine blade

Main role of wind turbine is to extract energy from the wind. Different factor affect the efficiency of wind turbine blades. If the blades are not turning, they are not creating energy.

As reported in many research publications, the effectiveness of wind energy conversion systems are dependent on a wide range of factors including the wind-speed characteristics, the wind turbine generator design parameters etc. [8]. Many methods and research has been done as to gain the optimum output based on the blade design, specifications, and perfect location to build the wind turbine and so on. This research will be focus on slotted wind blade design and determining if its result is equal to the continuous wind blade design for low wind speed which averagely in Malaysia is between 5 – 17 m/s as most of the wind resources are using propeller type wind turbine, with low power output efficiency around 20% only due to shape, design, and other factors.

2.4.1 Placement

The location of a wind turbine will affect the efficiency of the blades. The amount of wind activity is paramount to the operation of the blades. The more wind, the more energy created because the blades require a constant wind. Many wind turbines get placed along the coast, flat land masses, mountain ranges with large gaps and hills that have round tops. These areas provide the blades with a more consistent wind source. Usually, the higher the turbine, the more energy it can capture because wind speeds increase with elevation increase and; scientist does estimate 12% for this increase [22].

2.4.2 Number of Blades

One major importance in wind turbine design is its number of blades. Number of blade is greatly influencing the horizontal axis wind turbines (HAWT). The most common number used are two and three blades. Some HAWTs may have more than three blades, and normally because they using for low speed wind turbines [18] and most of the present commercial turbines used for electricity generation have three blades [12].

It is known that more blades provide a greater available surface area for the wind to push, so it would produce more turning power but in the same time a greater number of blades increase the weight to be turned by the turbine. This mean that the smaller number of rotor blades, the faster the wing turbine rotate to extract the maximum power from the wind [23]. As this study is to seek the performance of slotted and continuous types of wind turbine, thus this research will set the number of blade to three only.

In the same time, wind blades must be placed properly to work efficiently. When the blades are spaced to close together, the turbulence affects the efficiency of blades. The upwind designed blades will affects the downwind designed blades by reducing each other’s speed and wind load must be greater to turn the blades to each design. The turbulence forces these design to work against each other when they are close together.

2.4.3 Blade profile

The efficiency of the rotor largely depends on the blade’s profile in increasing the lift to generate sufficient torque [23, 24]. Parameters associated with blade geometry optimization are important, because once optimized, shorter rotor blades would produce power comparable to larger and less optimized blades [25].

The size of a blade makes differences in their efficiency. The larger blades produce more kinetic energy through one rotation of the blades than the smaller blades [19]. Smaller blades only have a certain amount of surface area on the face of the blades. The larger blades have a greater surface area, allowing them to work more efficiently [1]. In some case, however, the smaller length of the blades, the better it will catch wind at slower speeds [22]. The solution is to make sure small wind turbine rotors have a good start up response in order to generate maximum power [26].

2.4.4 Material

Material selection is one of the important matters in designing and producing product, including wind turbines. A right material selection could help the wind turbine possess the high stiffness, low in density, long fatigue life, being non-corrosive and the most important being productive as it should be [27]. The material chosen must also be readily available (in large quantity), easy to machine and perform safely and also the cost of material [8, 28, 29]. Blades with lighter material would produce wind turbine with low rotational inertia and yield better energy performance at lower wind speeds [26].

Furthermore, lightweight designs can benefit the entire wind turbine through decreased mass-induced loads. Indeed, the cost of the rotor may represent 20% of the total, but decreasing the mass can have a significant effect by reducing the materials demand [6]. As for that reason, aluminium has been set as the material for this type of blade in this study. Other than its property reason, the state of Sarawak itself in Malaysia has one of the biggest aluminium smelter plant.

2.5 Airfoil concepts

The word is an Americanization of the British term aerofoil which itself is derived from the two Greek words Aeros ("of the air") and Phyllon ("leaf"), or "air leaf". An airfoil is defined as the cross section of a body that is placed in an airstream in order to produce a useful aerodynamic force in the most efficient manner possible. It supposed to either generate lift or minimize drag when exposed to a moving fluid. The cross sections of wings, propeller blades, windmill blades, compressor and turbine blades in a jet engine, and hydrofoils are example of airfoils.

2.5.1 NACA 4412

NACA airfoils are airfoil shapes for aircraft wings develop by National Advisory Committee for Aeronautics (NACA). The shapes of NACA airfoils (Figure 2.3) are 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. Basically, the NACA four digit wing sections define the profile by [30]:

1. First digit describing the maximum camber as percentage of the chord
2. Second digit describing the distance of maximum camber from the airfoil leading edge in tens of percents of the chord.
3. Last two digits describing maximum thickness of the airfoil as percent of the chord.

Thus, NACA 4412 has a maximum camber of 4% located 40% (0.4 chords) from the leading edge with a maximum thickness of 12% of the chord.

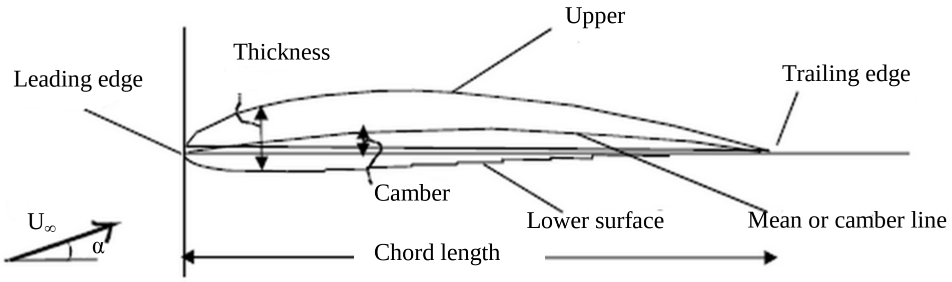


Figure 2.3: NACA4412 airfoil's geometry [31]

2.5.2 Lift (C_L) and Drag (C_D) coefficient

Just like an aeroplane wing, wind turbine blades work by generating lift due to their shape. As shown in Figure 2.4, the more curved side generates low air pressures while high pressure air pushes on the other side of the aerofoil. The net result is a lift force perpendicular to the direction of flow of the air [3, 7, 17, 32, 33, 34]. The lift coefficient is a dimensionless coefficient that relates the lift generated by a lifting body to the density of the fluid around the body, its velocity and an associated reference area.

Drag is the force parallel to the wind flow (Figure 2.4) and drag coefficient is a dimensionless number used in aerodynamics to describe the drag of a shape. This number is independent of the size of the object and is usually determined in a wind tunnel. Basically the drag will increase together with the increasing value of lift force [31]. For a wind blade operate efficiently, the drag value should be low. If the aerofoil shape is good, the lift force is much bigger than the drag, but at very high angles of attack, especially when the blade stalls, the drag increases dramatically. So at an angle slightly less than the maximum lift angle, the blade reaches its maximum lift/drag ratio. The best operating point will be between these two angles.

Since the drag is in the downwind direction, it may seem that it wouldn’t matter for a wind turbine as the drag would be parallel to the turbine axis, so wouldn’t slow the rotor down. It would just create “thrust”, the force that acts parallel to the turbine axis hence has no tendency to speed up or slow down the rotor. When the rotor is stationary (e.g. just before start-up), this is indeed the case. However the blade’s own movement through the air means that, as far as the blade is concerned, the wind is blowing from a different angle. This is called apparent wind. The apparent wind is stronger than the true wind but its angle is less favourable: it rotates the angles of the lift and drag to reduce the effect of lift force pulling the blade round and increase the effect of drag slowing it down. It also means that the lift force contributes to the thrust on the rotor. The result of this is that, to maintain a good angle of attack, the blade must be turned further from the true wind angle.

The effect of wind blows also affects the propulsion for horizontal and vertical axis wind turbine as in Table 2.1 while Table 2.2 show the types of wind turbine used globally and types of propulsion. In this study, lift coefficient (C_L) and drag coefficient (C_D) were to be acquiring using ANSYS Fluent software.

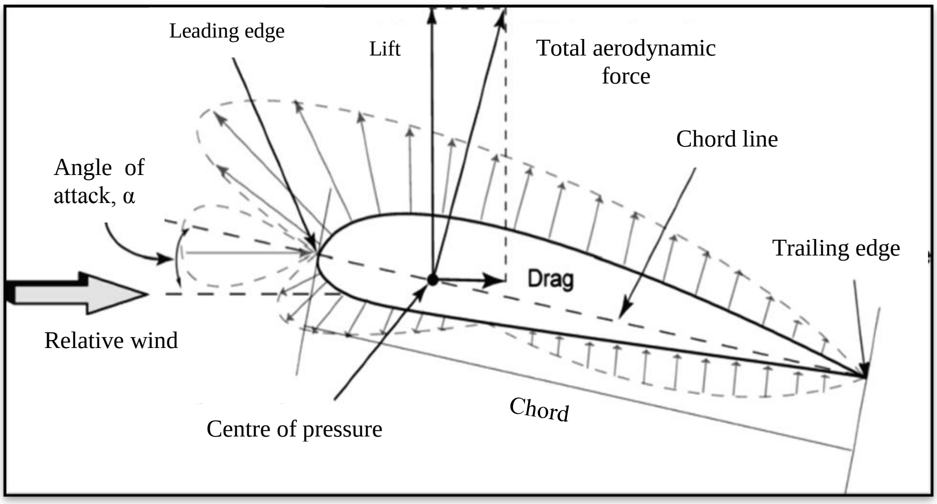


Figure 2.4: Airfoil Concepts [3, 7, 17, 32, 33, 34].

Table 2.1: The two mechanism of propulsion compared

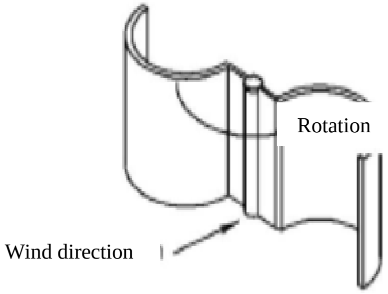
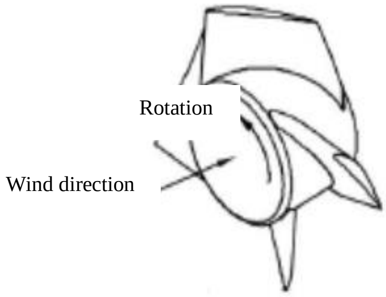
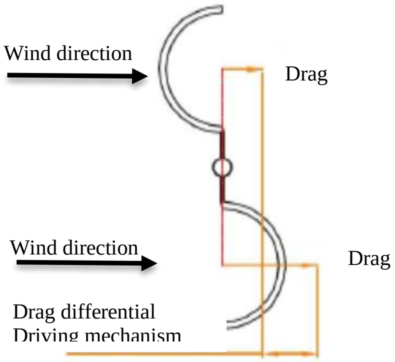
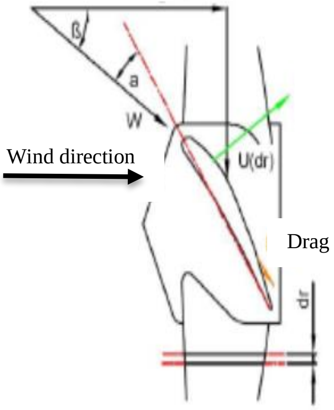
Drag	Lift
	
	

Table 2.2: Modern and historical rotor design [1, 9]

<table>
<tr><th>Design</th><th>Orientation</th><th>Use</th><th>Propulsion type</th><th colspan="2">Peak efficiency</th></tr>
<tr><td>Savonius rotor</td><td>VAWT</td><td>Historic Persian windmill to modern day ventilation</td><td>Drag</td><td colspan="2">16%</td></tr>
<tr><td>Cup</td><td>VAWT</td><td>Modern day cup anemometer</td><td>Drag</td><td colspan="2">8%</td></tr>
<tr><td>American farm windmill</td><td>HAWT</td><td>18th century to present day, farm use for pumping water, grinding wheat, generating electricity</td><td>Lift</td><td colspan="2">31%</td></tr>
<tr><td>Dutch windmill</td><td>HAWT</td><td>16th century, used for grinding wheat</td><td>Lift</td><td colspan="2">27%</td></tr>
<tr><td>Darrieus Rotor (Egg Beater)</td><td>VAWT</td><td>20th century, electricity generation</td><td>Lift</td><td colspan="2">40%</td></tr>
<tr><td rowspan="4">Modern Wind Turbine</td><td rowspan="4">HAWT</td><td rowspan="4">20th century, electricity generation</td><td rowspan="4">Lift</td><td>Blade Qty</td><td>η</td></tr>
<tr><td>1</td><td>43%</td></tr>
<tr><td>2</td><td>47%</td></tr>
<tr><td>3</td><td>50%</td></tr>
</table>

2.5.3 Angle of Attack (α)

The lift and drag coefficients are strongly dependent on angle of attack and less dependent on Reynolds number. Reynolds number effects are particularly important in the region of maximum lift coefficient just prior to stall. Basically, the lift force increases as the blade is turned to present itself at a greater angle to the wind. This is called the angle of attack. At very large angles of attack the blade “stalls” and the lift decreases again. So there is an optimum angle of attack to generate the maximum lift.

In fluid dynamics, angle of attack (α) is the angle between a reference line on a body (often the chord line of an airfoil) and the vector representing the relative motion between the body and the fluid through which it is moving. In aerodynamics, angle of attack specifies the angle between the chord line of the wing of a fixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere; as shown in Figure 2.5.

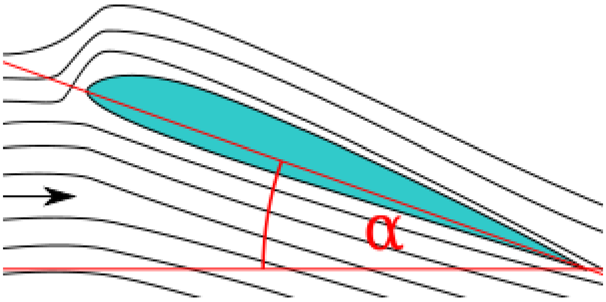


Figure 2.5: Angle of Attack

The critical angle of attack is the angle of attack which produces maximum lift coefficient. This is also called the "stall angle of attack". Below the critical angle of attack, as the angle of attack increases, the coefficient of lift (C_L) increases [11,31]. This dynamic stall changes as the sudden changes of the wind direction leading to changes of angle of attack [35].

At the same time, above the critical angle of attack, as angle of attack increases, the air begins to flow less smoothly over the upper surface of the airfoil and begins to separate from the upper surface [4]. On most airfoil shapes, as the angle of attack increases, the upper surface separation point of the flow moves from the trailing edge towards the leading edge. At the critical angle of attack, upper surface flow is more separated and the airfoil or wing is producing its maximum coefficient of lift. As angle of attack increases further, the upper surface flow becomes more and more fully separated and the airfoil/ wing produces less coefficient of lift [36].

2.5.4 C_L, C_D and α for NACA4412

As previous research has been done on NACA4412 (r = 5m), the maximum lift coefficient is 1.25 at 12° of angle of attack [31]. Previous research also shown that for radius 5 metre of NACA4412 blade, the C_L will increase until 13° angle of attack, but then it decrease while C_D at lowest value at 0 degree angle of attack. In one of previous study which using NACA 4412 with a flip, the Jang Cory S. [37] found that lift and drag coefficient value is 1.4 and 0.04 respectively and estimated the best angle of attack as 4 degrees.

2.6 Bernoulli theorem

Figure 2.4 shows the forces acting on airfoil when it is placed in airstream. When an airfoil is placed in a wind stream, air passes through both upper and lower surfaces of the blade. Due to the typical curvature of the blade, air passing over the upper side has to travel more distance per unit time than that passing through the lower side. Thus the air particles at the upper layer move faster. According to Bernoulli's theorem, this should create a low-pressure region at the top of the airfoil. This pressure difference between the upper and lower surfaces of the airfoil will result in a force, F. The component of this force perpendicular to the direction of the undisturbed flow is called the lift force, L. The force in the direction of the undisturbed flow is called the drag force, D. In this study, lift coefficient (C_L) and drag coefficient (C_D) will be determined using ANSYS Fluent software.

CHAPTER 3

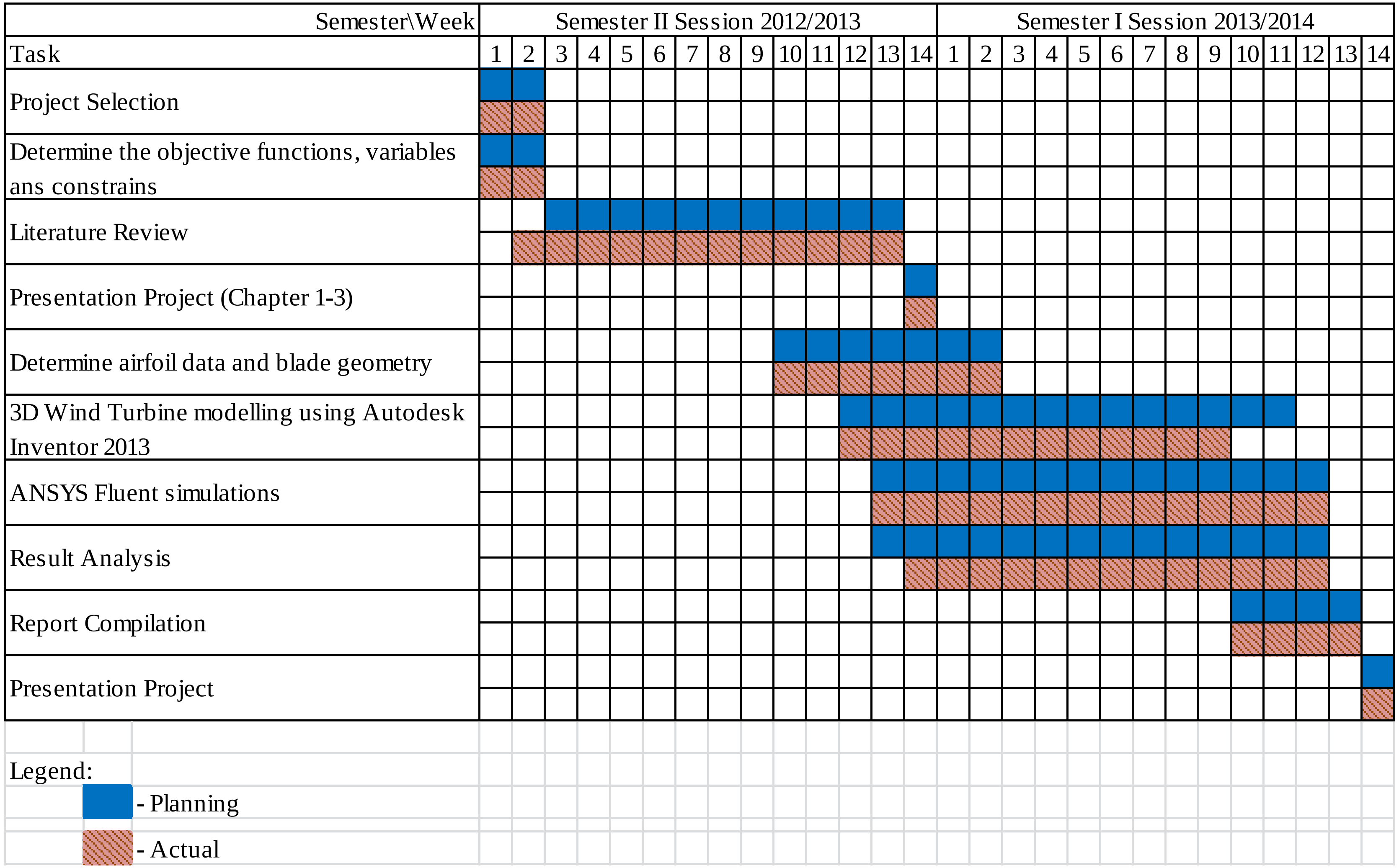
METHODOLOGY

3.1 Introduction

This chapter will cover the details explanation of methodology that is being used to complete and achieve the project objectives. The planning schedule has been made in the early stage as presented in Figure 3.1 and Figure 3.2 as to make sure the project is done systematically.

Several approaches are being used to obtain the result and finding of this project. This project is based on current situation in Malaysia which has a slow speed wind and to enhance the usage of wind turbine in Malaysia. Thus this project is to determine the performance of continuous and slotted wind blade and in the same time to discover the optimum number for slotted wind blade. This designing process will be done using Autodesk Inventor 2013.

After all the detailed drawings are completed, the design will then be processed and subjected to the flow analysis using ANSYS software based on the standard size of wind tunnel.



Semester\Week	Semester II Session 2012/2013														Semester I Session 2013/2014													
Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Selection	🟦	🟦																										
	▨	▨																										
Determine the objective functions, variables ans constrains	🟦	🟦																										
	▨	▨																										
Literature Review			🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															
		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨															
Presentation Project (Chapter 1-3)														🟦														
														▨														
Determine airfoil data and blade geometry										🟦	🟦	🟦	🟦	🟦	🟦	🟦												
										▨	▨	▨	▨	▨	▨	▨												
3D Wind Turbine modelling using Autodesk Inventor 2013												🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			
												▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨					
ANSYS Fluent simulations													🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
													▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
Result Analysis													🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
														▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
Report Compilation																								🟦	🟦	🟦	🟦	
																								▨	▨	▨	▨	
Presentation Project																												🟦
																												▨

Legend:
🟦 - Planning
▨ - Actual

Figure 3.1: Project Gantt Chart

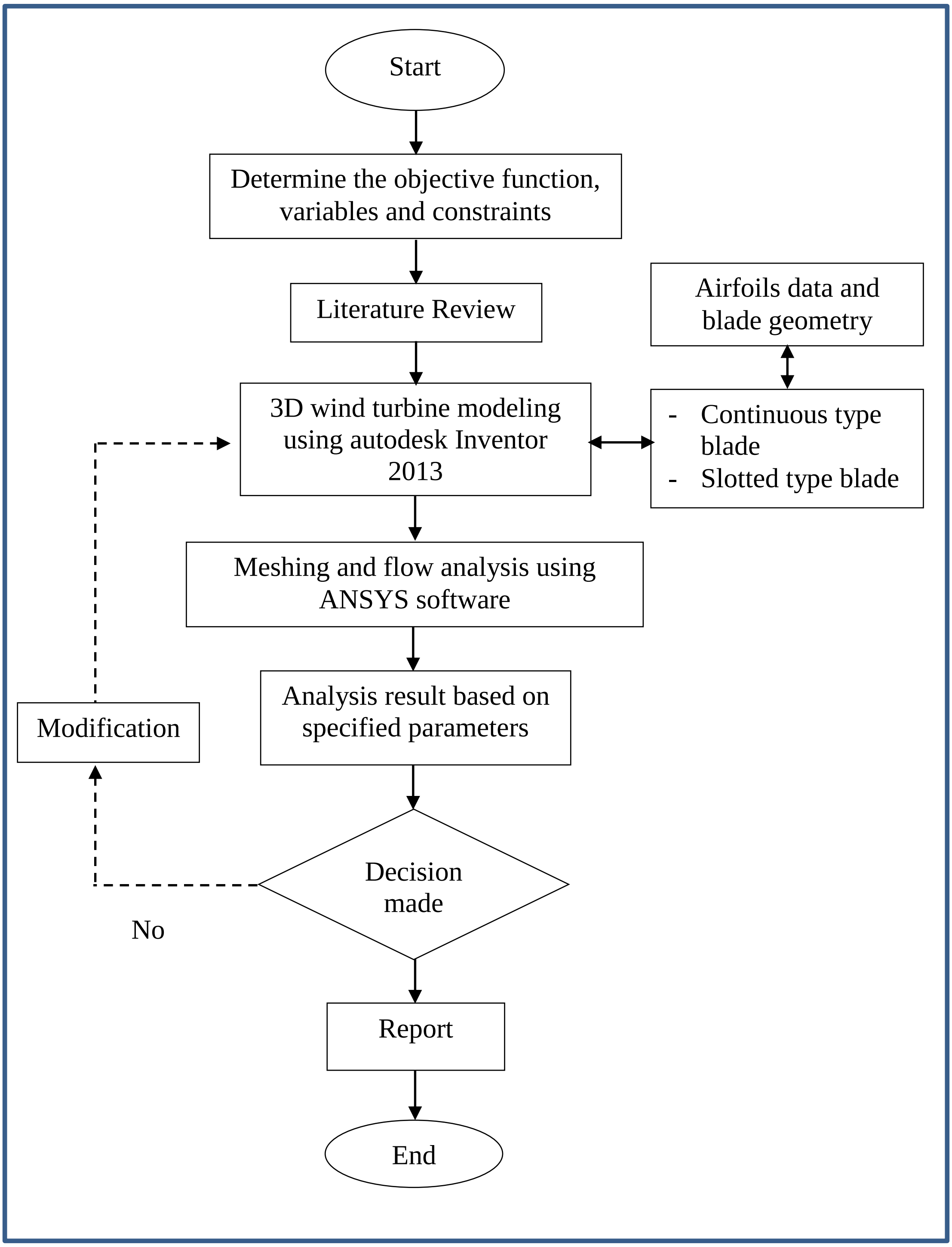


Figure 3.2: Project Flow Chart

3.2 Starting the project

The project starts with title selection given by project coordinator and the discussion with the supervisor. It is important to understand the problem and come out with solutions. For this project, it has found that Malaysia lacks the usage of wind turbine because of slow speed and inconsistent wind. Thus, by using 5 meter rotor diameter horizontal axis wind turbine, the objectives of this project is to determine either the slotted wind turbine is capable to achieve the efficiency of continuous blade; and in the same time, the new blades' design will be much lighter in weight since the blade is slotted. Figure 3.3 is the solid continuous blade type NACA 4412 and the new blades' design applying horizontal and vertical type of slotting as shown in Figure 3.4 and Figure 3.5. Based on these two designs, the optimum number of slots and size of slots and size between slots will be determined in this study.

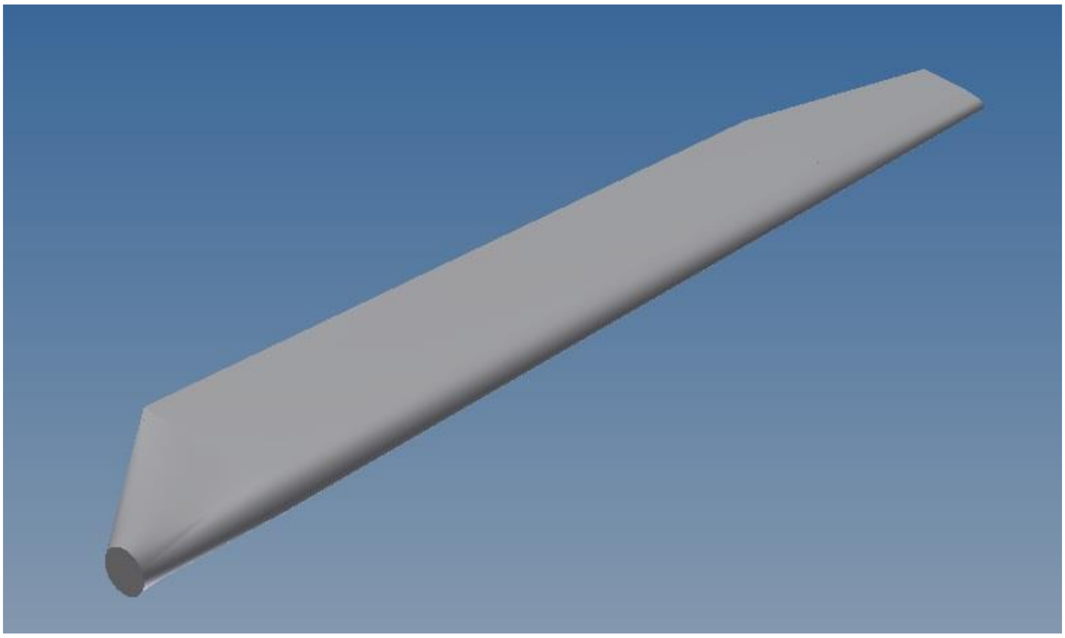


Figure 3.3: Solid continuous blade

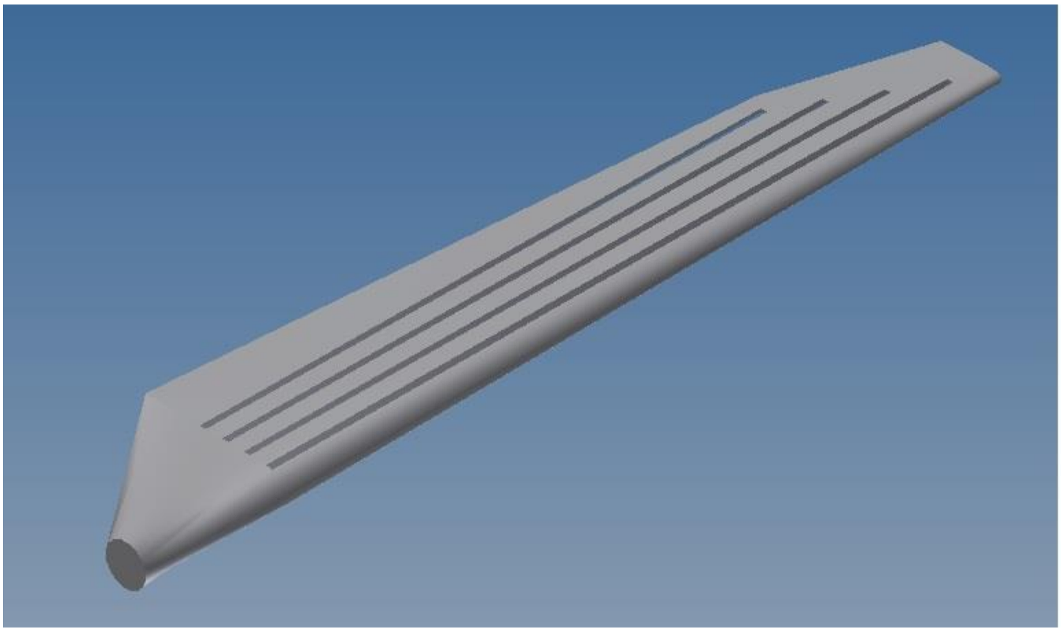


Figure 3.4: Horizontal slotted blade design

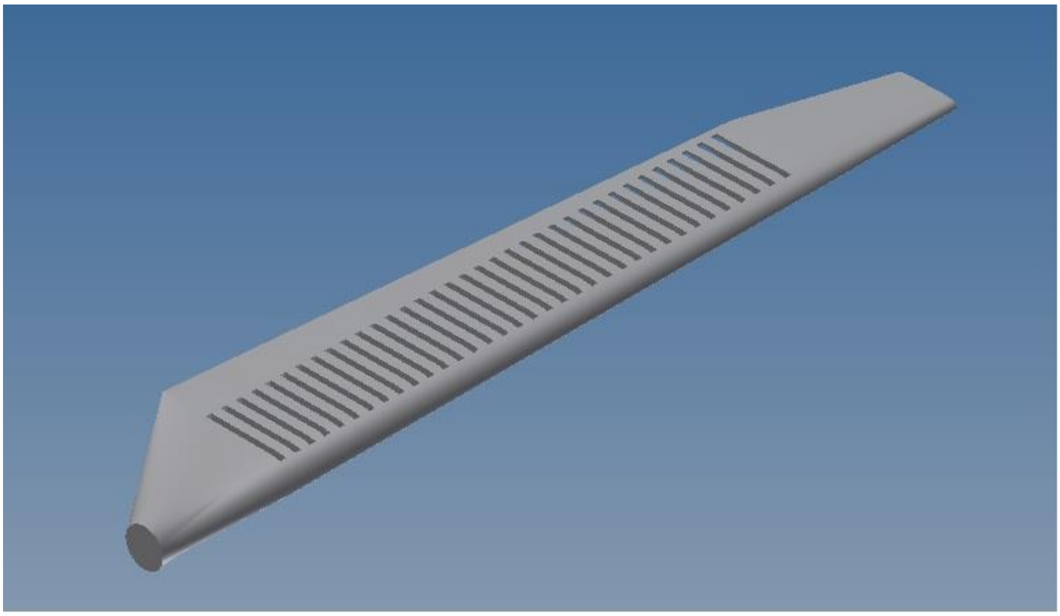


Figure 3.5: Vertical slotted blade design

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