AERODYNAMIC ANALYSIS OF WIND TURBINE BLADE USING CFD

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DECLARATION

I confirm this project report "Aerodynamic Analysis of Wind Turbine Blade Using CFD" results from my work aside from as cited in the references.

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Name :…………………………………

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APPROVAL

I have reviewed this report and now can be submitted to JK-PSM to be delivered back to the supervisor and to the second examiner. I believe this report is complete with respect to scope and quality for the degree of Bachelor of Mechanical Engineering award.

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Name of Supervisor : Ir. Dr. Nazri Bin Md Daud

Date :…..

ABSTRACT

Aerodynamic is a term that interprets the interaction phenomenon between air with the surface. Aerodynamic is essential because they function as a mechanism to change wind energy to electricity by using lift and drag force. In wind turbine technology, aerodynamic principles can be observed at the wind turbine blade. The wind turbine blade geometry, such as airfoil profile contributes to the highest lift and lowest drag upon air inflow. Computational fluid dynamics (CFD) approach is an effective method to investigate the lift and drag force of a wind turbine blade. This approach gives the best description of the flow around the wind turbine. Erosion is a process of eroding or being eroded by wind, water, or other natural agents. Erosion can change the blade airfoil's original shape, and it indeed influences the aerodynamic characteristic of the airfoil. Hence, this study investigates lift coefficient, drag coefficient and boundary layer thickness of two airfoil profile in 2D design and concludes the impact of erosion by referring to the lift to drag ratio value. Lift to drag ratio value can be used to monitor the airfoil efficiency. In conducting the investigation, the chosen airfoil profile will be modelled and simulated using CFD software, ANSYS Fluent. Two airfoils are selected in this study which is S809 airfoil profile and S826 airfoil profile. Boundary condition be set up in the simulation process to generate result at the end of the simulation. By knowing the lift coefficient and drag coefficient, the airfoil's performance can be analysed before and after the emerging of erosion. The lift to drag ratio for both airfoils profile decreases when erosion become worse. Heavy erosion condition for S809 airfoil, C_L/C_D value is 3.5 while for S826 airfoil, C_L/C_D value is 24.1. For light erosion condition, S809 airfoil C_L/C_D value is at 7.4 while for S826 airfoil C_L/C_D value is at 39.4. This result indicates that the airfoil's aerodynamic performance receives a significant effect by the emerging of erosion.

ABSTRAK

Aerodinamik adalah istilah yang menafsirkan fenomena interaksi antara udara dengan permukaan objek. Aerodinamik sangat penting kerana ia berfungsi sebagai mekanisme untuk menukar tenaga angin menjadi tenaga elektrik dengan menggunakan daya angkat dan daya seret. Dalam teknologi turbin angin, prinsip aerodinamik dapat diperhatikan pada bilah turbin angin. Geometri bilah turbin angin, seperti profil airfoil menyumbang kepada daya angkat yang tinggi dan daya seret yang rendah semasa aliran udara mengalir. Pendekatan dinamik bendalir berkomputer (CFD) adalah kaedah yang berkesan untuk mengkaji daya angkat dan daya seret untuk bilah turbin angin. Pendekatan ini juga mampu memberikan penerangan terbaik mengenai aliran di sekitar bilah turbin angin. Hakisan adalah proses pemisahan sebahagian bentuk objek sama ada disebabkan oleh angin, air, atau agen semula jadi yang lain. Hakisan boleh mengubah bentuk asal airfoil bilah, dan ia benar-benar mempengaruhi ciri aerodinamik airfoil tersebut. Oleh itu, kajian ini mengkaji pekali angkat, pekali seret dan aliran lapisan sempadan dua profil airfoil dalam reka bentuk 2D dan merumuskan kesan hakisan dengan merujuk kepada nilai nisbah angkat ke seretan. Nilai nisbah angkat kepada seret boleh digunakan untuk memantau kecekapan airfoil. Dalam menjalankan penyelidikan, profil airfoil yang dipilih akan dimodelkan dan disimulasikan menggunakan perisian CFD, ANSYS Fluent. Dua airfoil dipilih dalam kajian ini iaitu profil airfoil S809 dan profil airfoil S826. Keadaan sempadan ditetapkan dalam proses simulasi untuk menghasilkan keputusan pada akhir simulasi. Dengan mengetahui pekali angkat dan pekali seret, prestasi udara boleh dianalisis sebelum dan selepas berlakunya hakisan. Nisbah angkat kepada seret untuk kedua-dua profil pesawat udara berkurang apabila hakisan menjadi lebih teruk. Untuk keadaan hakisan yang teruk, nilai nisbah angkat kepada seret S809 airfoil adalah 3.5 manakala untuk nilai nisbah angkat kepada seret S826 airfoil adalah 24.1. Untuk keadaan hakisan yang sedikit, nilai nisbah angkat kepada seret S809 airfoil berada pada 7.4 manakala untuk nilai nisbah angkat kepada seret S826 airfoil adalah 39.4. Hasil ini menunjukkan bahawa prestasi aerodinamik pesawat mendapat kesan yang signifikan dengan wujudnya hakisan.

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LIST OF ABBEREVATIONS

HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
3D	3 Dimension
2D	2 Dimension
CFD	Computational Fluid Dynamic
BEM	Blade Element Momentum
kW	Kilowatt
UTeM	Universiti Teknikal Malaysia Melaka
NACA	National Advisory Committee for Aeronautics
DU	Delft University
NREL	National Renewable Laboratory
SIMPLE	Semi-Implicit Method for Pressure Linked Equations
SST	Shear Stress Transport Model
BL	Boundary Layer
AEP	Annual Energy Production

LIST OF SYMBOLS

ρ	=	density of air
A	=	area surface
C_L	=	lift coefficient
C_D	=	drag coefficient
V	=	flow velocity
L	=	lift
D	=	drag
l	=	length
Re	=	Reynolds Number
μ	=	Dynamic viscosity

CHAPTER 1

INTRODUCTION

1.1 Background

In this era of technology, many countries start using wind turbine as their source of energy. A wind turbine is well known as an environmentally friendly technology, and it is accepted as an alternative of energy source (Ali Cemal et al., 2018). Albania and Kosovo plan to build a 1 kW wind turbine off-grid at a strategic location (Qafleshia et al., 2015). The trend toward wind turbine energy comes out because the wind is more predictable, and the price of wind technology is estimated to drop for the next few years (Mohammadreza et al., 2016).

Based on Mehmet & Sezayi (2018), a wind turbine is a machine that obtains kinetic wind energy and switches it to rotational mechanical energy, then converts it to electrical energy by the generator. There are several types of wind turbine technology, such as are Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Horizontal axis wind turbine blade HAWT is the top choice to be applied in wind energy industry rather than vertical axis wind turbines (Mohammadreza et al., 2016) as major horizontal-axis-wind-turbine (HAWT) plant operate in Megawatt range (Yilei He & Ramesh K. Agarwal, 2014). Due to this reason, Horizontal Axis Wind Turbine (HAWT) be applied in this study.

The wind turbine blade applied aerodynamic behaviour to make it rotate in generating electricity as referred to Figure 1.1. The term aerodynamic means the reaction behaviour between air with solid surface (Pop et al., 2016). In the wind turbine industry, aerodynamic characteristics were used to change wind energy to electricity by using lift and drag force on the wind turbine blade. Wind turbine blade was sensitive to the changes in aerodynamic behaviour because lack of aerodynamic could reduce energy efficiency (Majid Asli et al., 2014). To tackle this issue, some researchers such as Sharifi & Nobari's (2013), focused on aerodynamics of the blade to study horizontal-axis-wind-turbine (HAWT) performance.

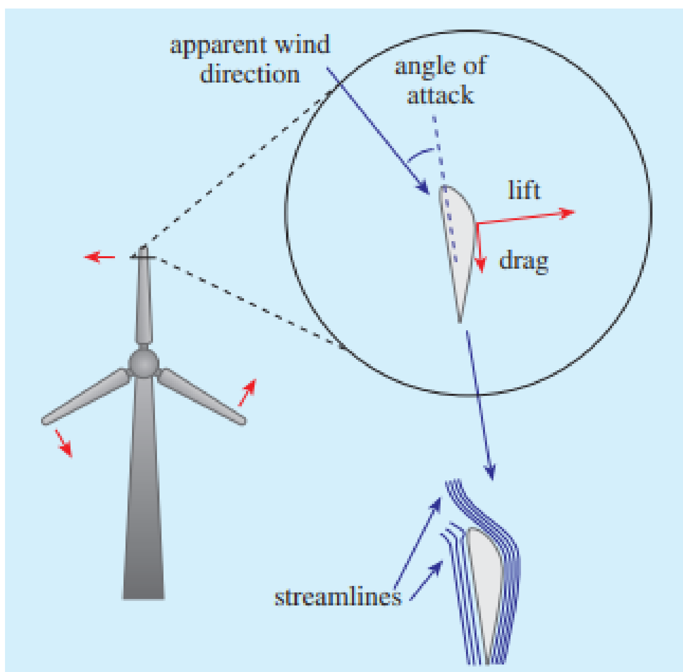

Figure 1.1: Schematic view of the operation of a wind turbine (Appleyard, 2009).

Geometry of a wind turbine blade is based on the shape of airfoil geometry. Airfoil is an advanced kind of geometry that is specially built to generate the highest lift and lowest drag forces upon air inflow. The special features at airfoil as be shown in Figure 1.2 aim to produce high aerodynamic performance, such as high maximum lift-to-drag ratio and low noise (Jianhua Xu et al., 2019). Therefore, a high maximum lift to drag ratio is the main objective in designing an airfoil to create a better power from wind flow (Xingxing Li et al., 2020). In recent years, many researchers study airfoil performance to get high output power such as Karim Oukassou et al. (2019), which used ANSYS Fluent 16.2. simulation software for NACA0012 and NACA2412 airfoil.

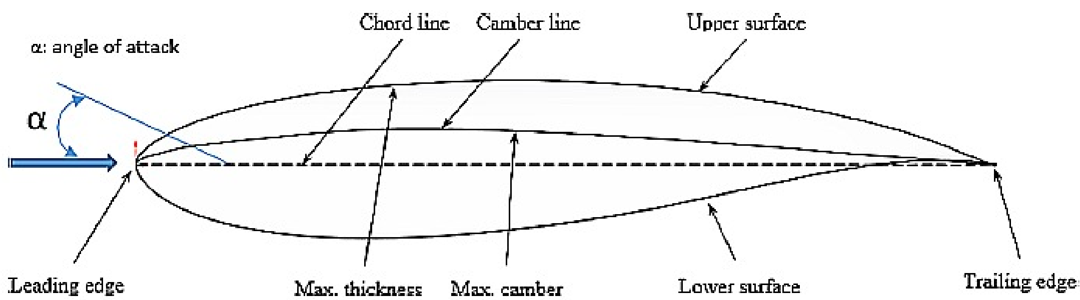

Figure 1.2: S833 airfoil geometry with parameters (Burak Çanakçı et al., 2020).

In operating a wind turbine, many obstacles need to be tackled specifically on the wind turbine blade. One of them is an erosion that appears on the blade structure, as shown in Figure 1.3. Erosion can be defined as a small damage on airfoil shape due to several factors that give impact to the wind turbine performance. Stated by Zhang S. et al. (2015) and Oka Y. & Miyata

H. (2009), an erosion will show up at some wind turbine blade after two years been used. This erosion mainly occurs because of nature as an example, sand storms, ice snow and rain (Zidane et al., 2016; Sagol et al., 2013). The existence of erosion is terrible for a wind turbine blade because the erosion will reduce the blade surface quality thus give more significant resistance to aerodynamic performance (Zidane et al., 2016; Sagol et al., 2013). The lower aerodynamic performance be produced by the wind turbine blade; the lower power can be generated.

Figure 1.3: Leading edge erosion of a rotor blade (J. Liersch & J. Michael, 2014).

There are many methods in analyzing erosion effect on aerodynamic behaviour of a wind turbine blade. One of them is using Computational Fluid Dynamic (CFD). Rapid involvement of technology had made CFD method suit in handling aerodynamic problems such as boundary layer transition, dynamic stall, inflow turbulence and rotational effects. Xin Cai et al. (2013), stated that CFD method is cheaper than other methods. The number of users using CFD method has also increased over the last decades in analyzing turbines blade performance (Keck & R.-E, 2013). Some researchers had applied CFD method to get detail information regarding the wind turbine blade. One of them is Lee et al. (2016), who use CFD simulation to examine a wind turbine's aerodynamic performance with two different blades. CFD simulations also can be applied to estimate 2D airfoil lift and drag coefficients at a different angle of attack and the 3D wind turbine torque and power values with different tip speed ratio values (Mehmet & Sezayi, 2018). Due to the advantages of CFD method, this method was used in this research.

1.2 Problem Statement

A study related to erosion effect on aerodynamic of wind turbine blade is still lacking. Although the number of studies related to erosion effect is not too much, yet it is still an important aspect that needs to be focus on because almost all wind turbine blade will face erosion problem when it been used after several periods. A survey conducted by EDP Company identified that 174 blades out of 201 blades in 67 wind turbines face erosion problem which approximately 87% of inspected blades (Han et al., 2018). The emerging of erosion will give negative impact because based on Soltani et al. (2011), lift coefficient for NACA 6 series drop by 35% when the airfoil receives as erosion effect. This drawback needs to be eliminated to help wind turbine blade operated in top condition.

So, to analyses the effect of erosion on aerodynamic performance, identification on lift and drag coefficient need to be known to identify the different before and after the emerging of erosion. In a wind turbine system, the value of lift and drag coefficient depends on an airfoil shape. Any slight changes on the shape of airfoil could decrease lift coefficients while increasing the drag coefficients (Wang et al., 2016). Because of the harmful effect from erosion, some researchers had conducted several analyses on this area study. As an example, Sareen et al. (2014), identify that a leading-edge erosion on a wind turbine airfoil can decline aerodynamic performance of the blade.

Another problem that needs to be highlighted in aerodynamic airfoil study is the application of Computational Fluid Dynamic (CFD) method. Although CFD has a more advanced speciality, CFD-based aerodynamic shape optimization is not often be used in wind energy research compare both aerospace and automotive communities which had been using it massively (He et al., 2018). So, CFD method in aerodynamic study should be explored increasingly as it has many advantages. Some researches already started applied CFD method in their study such as Gharali, Kobra & Johnson, David, (2012) and Gaudern, Nicholas, (2014). Results from a previous study also show that CFD studies efficiently generate data for aerodynamic of a wind turbine blade. So, applying CFD method in this study is a significant effort to achieve this study's objective.

1.3 Objective

The objectives of this study are:

1. To investigate erosion effect on lift coefficient C_L, drag coefficient, C_D, and boundary layer pattern for S809 airfoil profile and S826 airfoil profile using Computational Fluid Dynamic (CFD).
2. To compare affected aerodynamic performance between S809 airfoil profile and S826 airfoil profile.

1.4 Scope of Project

In this study, two types of airfoil be used, which is S809 airfoil and S826 airfoil. These airfoils are analyzed to know the effect of erosion on wind turbine blade. The aerodynamic behaviour of the airfoil is simulated using Computational Fluid Dynamics method using ANSYS Fluent. A 2D shape of the airfoils is generated to model the airfoil shape. All the boundary condition be set by referring to the actual condition of the wind turbine blade. In the end, lift coefficient C_L, drag coefficient, C_D and boundary layer thickness of the airfoils were determined.

1.5 General Methodology

To achieve the objective of this study, eight procedures needed to be executed. In the beginning, any reading source such as journals, articles, and books relevant to this study be examined to complete the Literature Review in Chapter 2. Then, two types of airfoil be chosen to represent a wind turbine blade shape. Airfoil that is selected in this paper was referred from airfoiltools.com. After that, erosion condition is defined to identify effect that be generated by erosion phenomenon on the wind turbine blade. Three erosion conditions were applied in this study. The erosion condition will represent the actual condition faced by wind turbine blade when used after several years. After all the design be generated, the simulation begins. In analyzing the erosion effect, boundary condition be applied in the simulation to represent the real condition that be face by the airfoil blade. The simulation process used Computational Fluid Dynamic (CFD) method to get aerodynamic of the airfoil. Identification of aerodynamic characteristic be done by ANSYS Fluent solver. In this software, the lift coefficient, drag coefficient and boundary layer thickness be generated. In the end, the different of affected aerodynamic for these two airfoils be explained further in this paper as each profile might face different effects from the erosion. There is a flow chart, as shown in Figure 1.4 to show the primary sequence of the methodology.

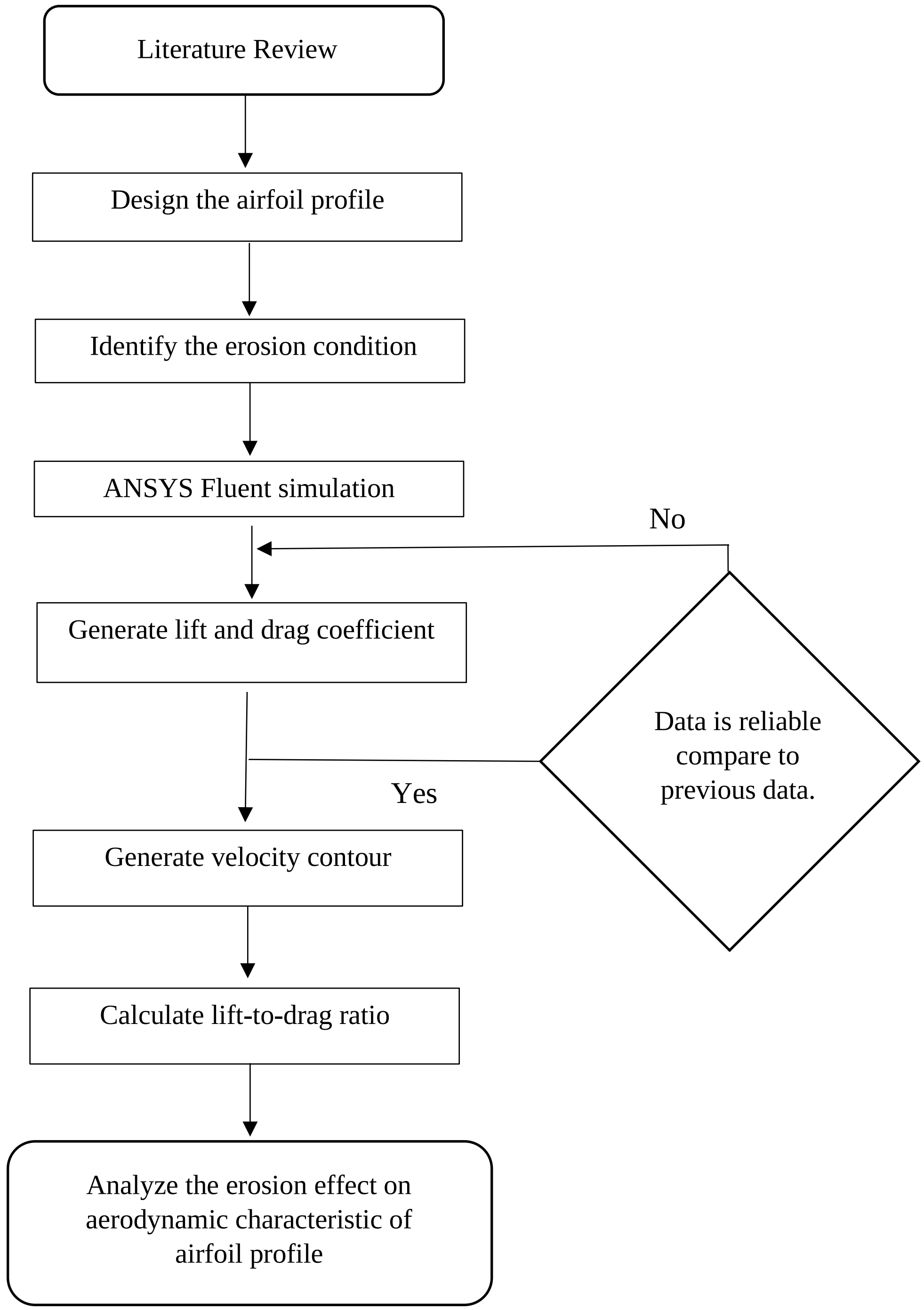

Figure 1.4: Flowchart of general methodology.

CHAPTER 2

LITERATURE REVIEW

2.1 Wind Energy

Wind energy, a type of renewable energy, was predicted as nearly matured renewable energy because this technology has already been developed rapidly since the last ten years (Dai Kaoshan et al., 2015). This technology has been applied extraordinary for the last several years as shown in Figure 2.1, and this trend will be continuing in the future (Danao et al., 2014). That is why wind energy plays a crucial role in power generation out of other renewable energy sources.

Wind energy is a renewable energy that been used to produce electricity using mechanism of a generator connected to the axis of rotor blades. The rotor blades rotate due to the resultant aerodynamic force's rotational action generated by the change of wind momentum (Mohammad et al., 2018). There are many benefits in implementing wind energy in power generation such as reducing air pollution, energy generation that less harm to the environment and a type of energy with high reliability (Jianhua et al., 2019; Majid et al., 2014). Furthermore, the low cost of this system had made this type of renewable energy generation be implemented in many areas. (Thé, Jesse & Yu, Hesheng., 2017).