UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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COMPUTATIONAL FLUID DYNAMICS STUDY OF BIO-MIMETIC WIND TURBINE FOR ENERGY HARVESTING USING OPENFOAM

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COMPUTATIONAL FLUID DYNAMICS STUDY OF BIO-MIMETIC WIND TURBINE FOR ENERGY HARVESTING USING OPENFOAM

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A dissertation submitted
in fulfillment of the requirements for the degree of Master of Engineering
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DECLARATION

I declare that this thesis entitled "COMPUTATIONAL FLUID DYNAMIC STUDY OF BIO-MIMETIC WIND TURBINE FOR ENERGY HARVESTING USING OPENFOAM" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : AHMAD SHAFAWI BIN ABDULLAH

Date : 15-03-2019

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APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfilment of Master of Mechanical Engineering (Energy Engineering).

Signature : ....

Supervisor Name :DR. MOHAMAD SHUKRI BIN ZAKARIA

Date : 15-03-2019

DEDICATION

To my beloved family

ABSTRACTS

The biomimetic design is a new approach introduced as an innovative in design branches. Through human observation of the surrounding, the proliferation of ideas is nurtured and translate into technology development in solving human problems. Implementation of biomimetic approaches can be such as natural process replication and mechanism imitation. In this study, an artificial design approach mimicking Green turtle's (*Chelonia mydas*) flipper is adapted to the design of the wind turbine blade. Airflow simulation is performed between two design, the base design and bio mimicry design. The simulation using the OpenFOAM software utilizing the approach of RANS turbulent model with Spalart-Allmaras one equation solver. The aim of the study is to examine the aerodynamic characteristic of the lift and drag coefficient. The results of the simulation found out that significant differences between the two designs. It was observed that bio mimetic design generated 50% more lift at 10° angle of attack compare to same profile in base design. Drag coefficient characteristic shows contradiction between both where based design shows fluctuation while bio mimetic exhibits sudden stagnation at stall angle. The result of the biomimetic design reveals its ability to produce better lift forces at higher angle of attack. In case of wind turbine blade, this roughly contribute to more energy can be extracted due to higher stall angle. Although only one of the aerodynamic performance indicator had been investigated, it gives forethought that potential bio mimicry design has. In achieving the proper accuracy, the scope of the simulation can be expanding to evaluate the real competency of this innovation.

ABSTRAK

Rekabentuk biomimetik adalah satu pendekatan baharu yang diperkenalkan sebahagian dari cabang-cabang inovasi dalam rekabentuk. Melalui pengamatan manusia terhadap alam persekitaran, percambahan idea-idea dipupuk dan diterjemahkan ke dalam pembangunan teknologi dalam menyelesaikan permasalahan manusia. Pendekatan biomimetik boleh melalui beberapa kaedah seperti replikasi proses semulajadi dan peniruan kaedah atau mekanisma. Di dalam kajian ini, pendekatan rekabentuk tiruan yang diambil dari rupabentuk bahagian belakang kaki pendayung hadapan seekor penyu agar (Chelonia mydas) diadaptasikan kepada rekabentuk bilah turbin angin. Simulasi aliran udara dilakukan bagi mengenalpasti kesan-kesan penting di antara dua jenis bilah, bilas asas dan bilah biomimetik. Simulasi menggunakan perisian OpenFOAM menggunakan pendekatan model gelora RANS dan solver Spalart-Allmaras satu persamaan. Matlamat kajian adalah untuk menelitikan sifat aerodinamik bagi pekali angkat dan pekali seretan. Keputusan dari simulasi mendapati perbezaan yang ketara bagi dua rekabentuk tersebut. Pemerhatian keputusan mendapati rekabentuk biomimetik menghasilkan 50% daya angkat lebih tinggi pada sudut perang 10^o dibandingkan dengan rekabentuk asas. Namun ciri daya seretan berbeza di antara keduanya di mana rekabentuk asas menunjukkan nilai turun-naik manakala rekabentuk bio mimetik mempamerkan bentuk genangan pada sudut tegun. Keputusan bagi rekabentuk biomimetik menampakkan keupayaannya untuk menghasilkan daya angkat lebih baik pada sudut serang yang lebih tinggi dibandingkan dengan rekabentuk asas. Dalam kes melibatkan turbin angin, ini sekaligus dapat meningkatkan keupayaan untuk meningkatkan penghasilan tenaga lanjutan dari sudut tegun yang lebih tinggi. Walaupun hanya satu sifat aerodinamik yang dilihat dalam kajian ini, sedikit sebanyak memberikan gambaran kasar bahawa inovasi pada rekabentuk pinggir mengekor suatu bilah turbin boleh memberikan kesan kepada kecekapan bilah. Skop kajian ini boleh diperluaskan untuk menilai kecekapan sebenar inovasi ini.

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Alhamdulillah, praise to Allah, with his inayah', Finally, I have successfully completed my master project report entitled "Computational Fluid Dynamics study of bio-mimetic wind turbine for energy harvesting using OpenFOAM" successfully.

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LIST OF SYMBOLS

A	Area
AoA	Angle of attack
c	Chord length
C_d	Drag coefficient
C_l	Lift coefficient
C_m	Moment coefficient
C_P	Power coefficient
D	Drag
η	Efficiency
F	Force
F_d	Drag force
F_l	Lift Force
λ	Tip speed ratio
$\dot{m}$	Mass flow
μ	Dynamic viscosity
v	Kinematic viscosity
Re	Reynolds number
ρ	Fluid density
V_a	Far field wind speed
V_∞	Velocity at infinity

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CHAPTER 1

INTRODUCTION

1.1 Background

Recent decade climate changes scenario has increase people's awareness to evaluate their action towards energy consumption and production. As being the main source of global green gas emission, the energy sector is burdened with the responsibility in planning and developing strategies to achieve the climate goal. One of the measure is to decrease dependency on fossil and explore the alternative, the clean and inexhaustible sources of energy, renewable energy. Today, 14% of global energy demand are fulfilled by renewable energy sources which is reported in UNDP World Energy Assessment 2000. The increase of wind power industry inspired many researchers to investigates further on potential performance and adaptation while engineers explore potential design to achieve better efficiency and full utilization. Countries such as Spain, Denmark and Germany has demonstrated the potential of wind as new power supply. However, China is crowned as new world leader, being achieved the largest wind power farm installed (Lewis, 2016). With this development, more than 30 wind turbine manufacturer emerged according to CWEA. Therefore, inducing healthy competition among player to manufacture and produce more robust design to meet China's diverse climate condition. Figure 1.1 shows the overall capacity of all wind turbine installed worldwide by the end of 2017 according to preliminary statistic published by World Wind Energy Association on February, 2018.

Country/ Region	Total capacity end 2017	Added capacity 2017	Total capacity end 2016	Total capacity end 2015	Total capacity end 2014	Total capacity end 2013
China*	187730	19000	168730	148000	114763	91413
United States	88927	6894	82033	73867	65754	61108
Germany	56164	6145	50019	45192	40468	34658
Rest of the World*	48500	5600	42822	37522	32219	26493
India**	32879	4600	28279	24759	22465	20150
Spain	23026	6	23020	22987	22987	22959
United Kingdom	17852	3340	14512	13614	12440	10531
France	13760	1695	12065	10293	9296	8254
Brazil	12763	1963	10800	8715	5962	3399
Canada	12239	341	11898	11205	9694	7698
Italy*	9700	443	9257	8958	8663	8551
Turkey*	6981	900	6081	4718	3763	2958
Sweden*	6721	228	6493	6029	5425	4470
Poland*	6534	752	5782	5100	3834	3390
Denmark	5320	93	5227	5064	4883	4772
Portugal*	5316	0	5316	5050	4953	4724
Australia*	4879	553	4326	4186	3806	3049
Grand Total	539291	52552	486661	435259	371374	318577

Figure 1.1 Worldwide Capacity of Wind Turbine (WWEA, 2018)

Typical wind turbine system consists of a hub and blade that makeup the rotor, drive shaft and gear box spinning the generator shaft converting mechanical energy to electricity. There are two types of wind turbine system available. That are horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). Both have advantages and disadvantages over respective field. However, HAWT is more dominance in wind industry due to more efficient in capturing the wind and extracting to energy. VAWT rotor works based upon drag while in HAWT rotor depends on maximizing the lift on aerofoil blade. In other words, blade design is more crucial in HAWT system as the blade is the major component directly interacting with the wind converting to power needed. Thus, it is the utmost important factor influencing efficiency of wind turbine that grab intention of designer or engineer in wind power industry. Commonly, design method that being mostly applied based on Blade Element Momentum (BEM) theory. This theory explain how the wind turbine operates. It's a combination of momentum balance and examining forces on blade element induced by lift and drag. BEM theory rely on two important assumptions which are no aerodynamics interactions between different blade elements and lift and drag coefficient are the solely determinants for the forces on the blade. Another important factor is tip turbine blade losses. It is accounted in BEM as a correction factor. This leads to optimizing design of the blade for maximum power production.

In this paper, the performance of biomimetic horizontal axis wind turbine inspired by green turtle flippers will be study with open source computational fluid dynamic software, OpenFOAM®. The proposed bio mimetic design was mimicking the span-wise shape of wavy trailing edge that can be found on front flippers of a green turtle. A three-dimensional single blade model will be design and simulate using the software. The lift coefficient and drag coefficient will be predicted and compared to a tapered and twisted wind turbine from Krogstad and Lund (2012). Further investigation of parametric study of the design also be considered. The geometrical shape of the proposed bio mimetic design of green turtle and scope area of interest are shown in Figure 1.2 and Figure 1.3.

Fig 1.2 Green Turtle front flippers

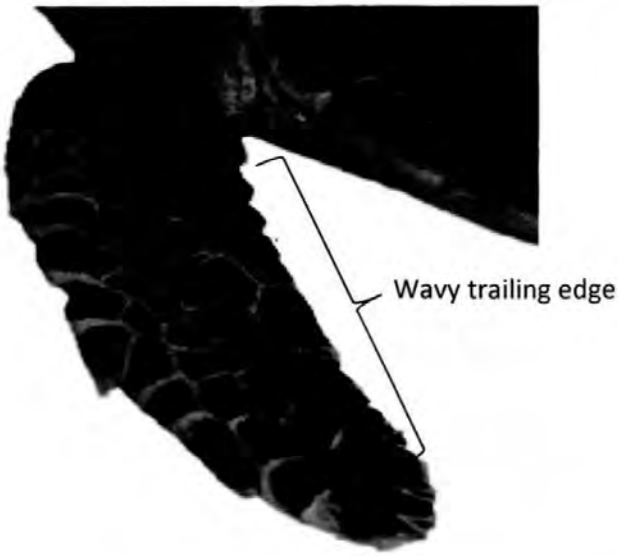

Fig 1.3 The wavy shaped at trailing edge of a green turtle flipper

1.2 Problem Statement

Innovation inspired by nature catch attention of designers and innovators towards radically new approach in solving our problems. Known as biomimicry revolution, despite extracting knowledge from nature but moreover things can be learned from living creation. Doing the nature's way could possible change the way we manage resources. In bio-mimetic turbine blade design, recent research (Chu and Ikeda et al) focusing their investigation on optimization of full body while Shi et al (2015) and Micallef (2014) resolving on leading edge design imitated from whale's tubercles. The biomimetic design based on trailing edge has the potential to be investigate. These can be observed on span wise wavy shape on whale fins and also on sea turtle flippers. Trailing edge investigations mostly associated with increasing aerodynamic drag and consequently increased drag diminishes turbine power generation. Previous investigation of effect of trailing edge design on lift and drag showed potential adaptation (Xu,2014), (Yang, 2016). The effect of trailing edge shows lift loss and lift recovery at outboard and inboard region and drag is reduced all over region. However, the modification showed positive effect on overall power generation performance. Hence, in this study, the proposed trailing edge modification was based on bio mimetic design. The aerodynamic analysis in term of lift and drag coefficient of base design (Krogstad and Lund, 2012) and bio-mimetic design will be studied further.

1.3 Objectives

The aim of this project is to study the aerodynamic performance of the design in term of lift coefficient (C_l), drag coefficient (C_d) and lift to drag ratio (C_l/C_d).

The specific objective are as follows:

1. To determine the lift coefficient (C_l) and drag coefficient (C_d) of base design.
2. To determine the lift coefficient (C_l) and drag coefficient (C_d) of proposed bio mimetic design.
3. Analyse on aerodynamic performance based on lift to drag ratio (C_l/C_d).

1.5 Scopes and Limitation

In this research, the study focusing on studying the potential of bio mimetic design. This project aim is to evaluate the relationship between the biomimetic design and the aerodynamics lift and drag properties thru simulation and comparison with the established design.

The scope and limitation in this research are as follows:

i. Research involve numerical study using OpenFOAM software.
ii. Simulation on 3D single blade of each base and bio mimetic design.
iii. Turbulence model of RANS and simpleFoam solver will be employed in the simulation.

1.6 Overview of this report

This dissertation is divided into five chapters. Chapter 1 briefly describe about wind power and wind turbine aerodynamics. The aim and problem statement are also introduced. A brief statement of objective and scope are also presented here. In chapter 2, literature review about bio mimetic design and variation of turbulence model. Types of solver accompany with the model are also summarized here. Simulation methodology are explained in chapter 3. Steps involved prior sketching to simulation elaborated here. Result are analysed in chapter 4. Aerodynamics comparison of based design and bio mimetic design is addressed here. Lastly, conclusion and future works are included in chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Bio-mimicry is the artificial system design that adopted from natural behaviour. It's can be said as smart invention from nature-biomimicry. This approach can be considered as reverse engineering process as the behaviour of the biological agent is analysed in order to mimic this behaviour in artificial system. Mimicking from the nature is not a new thing. Early example that can be said as mimicking the nature can be seen in human effort in flight inspired by studying how the birds fly. In any chances, human strives for idea to solve and ease their problem. Diversity and complexity of this God creation, opportunity to imitate is limitless. Recent development in technologies adapting biomimicry towards innovation. Diverse application can be seen in almost discipline such as termite mounds inspired building design in construction and architectural. Gecko inspired adhesive tech, biomedical, materials improvement, energy harness, improving aerodynamics in engineering design and more.

In improving the performance of the blade design in wind turbine, one of the invention idea was looking back at natures. Animals such as birds, whales and plant seeds have inspired researchers to investigate further the hidden potential from these creations.

Compare to vertical axis wind turbine (VAWT), horizontal axis wind turbine (HAWT) are more dominant in wind turbine industry. HAWT are very sensitive to blade profiles and design (Schubel et al). Major parameters such as tip speed ratio, blade plan shape and quantity and aerodynamics performance influence the performance of the wind turbine. A biomimicry innovation on such parameter could possibly indicate significant changes in wind turbine performance.

2.2 Bio-mimicry

Quoted from the Bio-mimicry Institute, biomimicry can be considered alternative approach to innovation inspired human to seek sustainable solution. The challenge to human to create new ways of living that ensure survival on earth. Recent main references on bio-mimicry on wind turbine blade design are discussed here. A rotor blade based on *drayobalanops aromatica* seed were studied by Chu et al and they predicted the power coefficient, thrust coefficient and blade root bending stresses. Previous study regarding seed merely on how the seed dispersed during wind pollination. Later on new focus on aerodynamics characteristic study of the seed itself especially on winged seed either theoretically and experimentally. In the early beginning, the relationship between aerodynamics performance and geometrical configuration of the seed is the main focus. Recently detailed flow field measurement is possible with the rapid development of new measurement technique and tools. Aerodynamics of seed dispersal includes the autorotation of seed during descent to slow down the falling speed and thus increasing the long dispersal distance. In a study of maple seed fall, researchers found out that unusual high lift mechanism which in known as leading edge vortex, unexpectedly being utilized during this slow descent. This leading edge vortex can also be found on most flapping wings of insect or other flying creatures. Besides maples seed, other class of winged seeds are also being investigated such as tulip seed and ash seed which their rotation about vertical axis and simultaneously spinning around wind span. Unfortunately, detail study of their aerodynamics and kinematics are not clearly documented and poorly understood.