DESIGN & ANALYSIS OF PROPELLER BLADES FOR A SMALL-SIZED UAV

CHANG HAN BING

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN & ANALYSIS OF PROPELLER BLADES FOR A SMALL-SIZED UAV

CHANG HAN BING

This report is submitted
in fulfilment for the degree of
Bachelor of Mechanical Engineering

FACULTY OF MECHANICAL ENGINEERING

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2021

DECLARATION

I declare that this project report entitled "DESIGN & ANALYSIS OF PROPELLER BLADES FOR A SMALL-SIZED UAV" is the result of my own work except as cited in references

Signature : ……………………………………………………….

Name : ……………………………………………………….

Date : ……………………………………………………….

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of degree of Bachelor of Mechanical Engineering.

Signature : ....

Name : ....

Date : ....

DEDICATION

To my beloved mother and father

ABSTRACT

An Unmanned Aerial Vehicle (UAV) nowadays has become an important part of people's lives. UAVs for transporting people or goods are considered to develop into reality. In this project, the main focus is to investigate the thrust performance from various parameters of propeller blades for small-sized UAVs. Using the propeller blade parameter for small-sized UAVs, the thrust performance was calculated based on the number of blades, blade pitch angle, and propeller diameter. The methodology to design the Variant 1 propeller blade for small-sized UAVs uses the reverse engineering method in SOLIDWORK 2018 software. After that, the SOLIDWORKS Flow Simulation analysis program is used to determine the thrust performance with the various propeller blade parameters for small-sized UAVs. The experimental setup testing will be designed to determine the thrust performance to validate the CFD simulation. The result shows that increase in the number of blades, blade pitch angle, and propeller diameter have better thrust performance for the small-sized UAV.

ABSTRAK

Kini, kenderaan udara tanpa pemandu (UAV) telah menjadi bahagian penting dalam kehidupan masyarakat. UAV yang digunakan untuk mengangkut orang atau barang dianggap sebagai kenyataan. Dalam projek ini, prestasi teras pelbagai parameter bilah baling-baling UAV kecil dikaji. Dengan menggunakan parameter baling-baling baling-baling UAV kecil, prestasi tujahan dikira berdasarkan bilangan bilah, sudut nada dan diameter baling-baling. Kaedah merancang bilah baling-baling Variant 1 untuk drone kecil menggunakan kaedah teknik terbalik dalam perisian SOLIDWORK 2018. Selepas itu, program analisis Simulasi Aliran SOLIDWORKS digunakan untuk menentukan prestasi tuju pelbagai parameter bilah baling-baling UAV kecil. Pengujian peranti eksperimental bertujuan untuk menentukan prestasi tujahan untuk mengesahkan simulasi CFD. Hasilnya menunjukkan bahawa peningkatan bilangan bilah, sudut nada dan diameter baling-baling mempunyai prestasi tujahan yang lebih baik untuk UAV kecil.

ACKNOWLEDGEMENTS

The finished of this thesis is thanks to all guidance and assistance given to me by many individuals and groups. I significantly appreciate the help from them all along to finish this thesis writing.

First and foremost, I would like to express my sincere and acknowledgment from my supervisor, En. WAN MOHD ZAILIMI BIN WAN ABDULLAH @ ZAKARIA from Universiti Technical Malaysia Melaka (UTeM) from the Faculty of Mechanical Engineering helped and supported me during this period and appreciated his guidance and teaching to complete this thesis. Without his guidance and knowledge that was given to me, I would be facing many problems during the process of finishing the thesis. I would also like to express my gratitude to my second panel, Pn. NURUL HANIM BINTI RAZAK for giving comments and guide for my project report.

Lastly, I would like to thank my parents for their moral support and support throughout my life. I would also like to thank all people who supported and guided me throughout this process.

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLE

PAGE

LIST OF ABBREVIATION

UAV	Unmanned Aerial Vehicle
BEM	Blade Element Momentum
CFD	Computational Fluid Dynamics
RPM	Revolutions per minute
FBD	Free Body Diagram

LIST OF SYMBOL

C_L	Lift coefficient
C_D	Drag coefficient
L	Propeller length
D	Propeller diameter
T	Thrust
v	Velocity of incoming flow
Δv	Additional velocity, acceleration by the propeller
ρ	Density of the air
P_a	Available power
P_{engine}	Engine power
η	Efficiency
C_T	Thrust coefficient
C_Q	Torque coefficient
C_P	Power coefficient
Q	Torque
P	Mechanical power supplied to turn the propeller
n	Rotational speed
J	Advance ratio
$\rho V_d A$	Mass per unit time through the disk

$(V_s - V_0)$	Velocity increase from far upstream to far downstream
A	Disk area

Chapter 1

INTRODUCTION

1.1 Background

An abbreviation for Unmanned Aerial Vehicle is the term UAV, commonly called a drone, is an aircraft system that flies from a distance. The advantages of unmanned vehicles include the absence of humans from the way of damage and a degree of maneuverability and stability in the deployment that was previously unachievable while a human pilot needed accommodation. UAVs can be remotely operated aircraft that are flown at a ground control station by a pilot or can fly manually based on pre-programmed flight plans or more advanced dynamic automation systems.

One of the fundamental elements of propulsion and aircraft design is the propeller, which generates the thrust in the same direction as a spinning wing. There are at least two blades connected to a central hub in the standard propeller design. The central hub helps to connect the blades to the shaft of the motor. The blades are generally long and narrow, and a cut can create an airfoil shape through the blade perpendicular to the long axis. The optimum design of the blade is based on the wing's aerodynamic properties, i.e. the coefficients of lift and drag and the annual average wind speed. These blade designs are also chosen based on the principle of blade element momentum (BEM).

1.2 Problem Statement

In this technology era, small-sized UAVs in this century have become the most popular day by day. Thus, operating on the performances of thrust for small-sized UAV will affect by the blade design parameters. The idea aims to investigate the parameters of the blade design able to generate the thrust through the CFD flow simulation and experiment just for validation, this is because to identify which blade design parameters is most efficient to generate the thrust for the small-sized UAV.

1.3 Objective

For this project, there are two objectives to be achieved as listed below:

1. To study the effects of the blade design parameters to generated thrust.
2. To estimate the amount of thrust required in small-sized UAV design.

1.4 Scope of work

The scope of this project are listed as follows:

1. This report will focus on the study and review the small-sized UAV blade design parameters.
2. Only carry out the result of CFD flow simulation and analysis of the small-sized UAV blade are presented in this project.
3. This project will be to design an experimental setup for thrust measurement to validate with the CFD flow simulation.
4. This project will present the reference data of the blade design parameters.

CHAPTER 2

LITERATURE REVIEW

2.1 Small-sized UAV

2.1.1 Introduction of UAV

There are generally two main UAV types: fixed-wing systems and multirotor systems, as shown in figure 2.1. The fixed-wing system is commonly used to describe the use of fixed static wings in the aviation industry, combined with forwarding airspeed to generate the lift. Besides that, the aviation multirotor systems represent an aircraft that uses rotating wings to create the lift. The advantages of fixed-wing systems can fly faster than multirotor systems, more suitable for long-distance travel. However, the multirotor systems do not need a landing path and create less noise than fixed-wing systems (Vergouw et al., 2016).

Figure 2.1: Types of UAV

(https://www.gao.gov/key_issues/unmanned_aerial_systems/issue_summary)

Nevertheless, this project's suitable UAV type would be the multirotor systems because of its rotating wings to generate the thrust and more flexible maneuvers than fixed-wing systems. In most commonly, the quadcopter is the most popular multirotor frame, which consists of four motors. The hexacopter and octocopter are other standard configurations in the multirotor frame, six and eight motors, respectively (Polak, 2012).

These UAVs have more power for thrust than the quadcopter. Figure 2.2 shown the + and X orientation of the quadcopter. They need to be as light as possible without sacrificing the UAV platform's manufacturing components' strength. The UAV manufactures these composite materials such as carbon fiber or fiberglass and other lightweight materials such as aluminium or plastic (Khan, 2011).

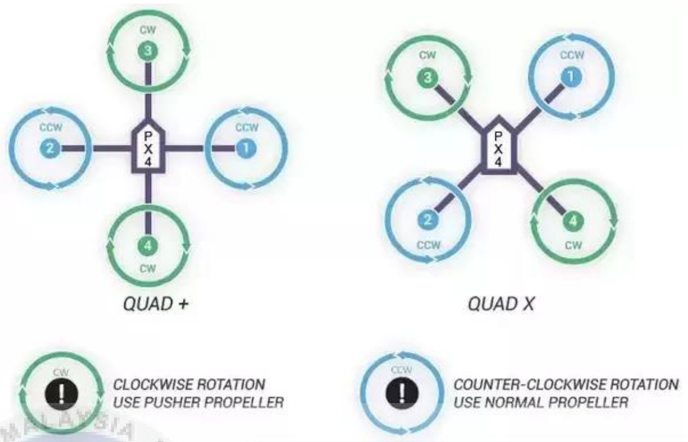

Figure 2.2: + and X orientation of the quadcopter

(https://www.quora.com/Why-is-x-configuration-preferred-over-+-config-of-quadcopter)

2.1.2 Propeller Rotation for UAV Movement

Two pairs of the counter-rotating rotors and propellers, positioned at the top of the square assembly, make up the small-sized UAV. The UAV setup consists of a couple of motors that will rotate clockwise, while the other pair of motors will rotate counter-clockwise, as shown in figure 2.3 (Alejandro, n.d.). Even out the two opposing rotations to keep the UAV stable. Therefore, if all the rotors were to rotate in the same direction, it will result in net torque, resulting in the complete UAV rotation. As the rotors rotate all together, they push the air down and the airlifts the rotor back. When the rotors spin rapidly, the UAV rises into the atmosphere, and the UAV descends to the ground when the rotors slow down.

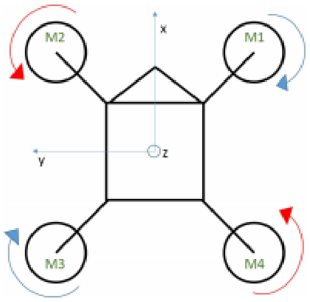

Figure 2.3: UAV Setup

(https://link.springer.com/article/10.1007/s42452-019-0698-7)

2.1.3 3D Orientation for UAV Control

The research was done by Parihar et al., 2016 shows a small vehicle with four rotor propellers on the cross frame can be identified by UAV. The goal is to control movement by using fixed pitch rotors. The UAV's motion depends on the three components: roll, pitch, and yaw moments, as shown in figure 2.4. Besides that, to control these motions, the thrust, aileron, elevator, and rudder are used with four actuators. Thrust is a necessary input for each movement, whereas the other three can be used at once or combining the desired action to change direction and angular motion. The rotation rudder is used as the control input for the yaw angles. The elevator can also be controlled by aileron deflective for the pitch angle control and roll angle control (Warsi et al., 2014).

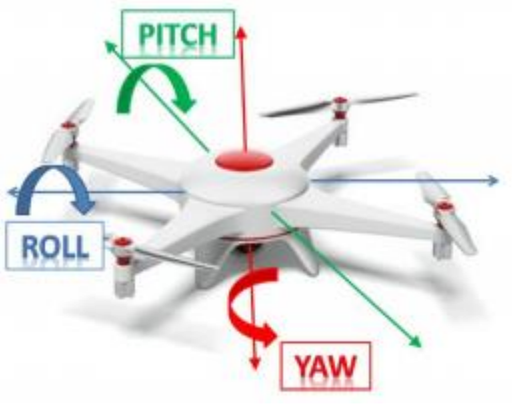

Figure 2.4: Roll, Pitch, and Yaw moment

(https://cacm.acm.org/magazines/2018/10/231377-fundamental-concepts-of-reactive-control-for-autonomous-drones/fulltext)

2.2 Basic of Propeller Blades

The research was done by Whitmore & Merrill, 2012 shows a propeller blade is a mechanical instrument that, through torque transfer, transforms motor power to axial thrust. Thrust is created when the rotating airfoil mount catches the fluid, accelerates the fluid, and drives it down the fluid stream tube. The more air the propeller discharges per unit time, the more power is transferred to thrust. Propeller blades are inclined to incoming flow to increase air accumulation and mechanical performance. Figure 2.5 below shown the velocity diagram for a cross-section of the propeller blade.

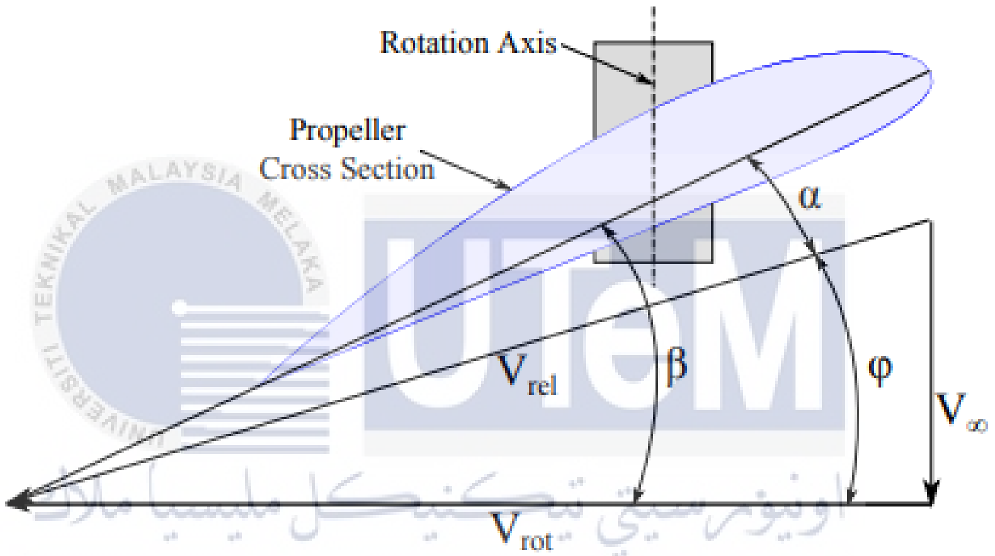

Figure 2.5: Propeller Blade Cross-section Velocity Diagram

2.2.1 Design Principle of Propeller Blades

Depending on the optimum propeller principle, only a small number of design parameters have to be defined. These variables include the number of blades, the propeller's diameter, lift and drag distributions of the propeller, axial velocity of the flow, and the medium's fluid flow density. The increased number of blades generally will affect the thrust performance; however, the more excellent thrust distribution is available with a higher number of blades, which helps maintain the propulsion system balance, and that a trade-off is required. The propeller's diameter also affects its performance significantly. Naturally, the larger propellers can generate more power and carry a larger volume of fluid. The design point's performance analysis will review the distribution of the lift coefficient, C_L and drag coefficient, C_D across the radius. The airfoils must be operating at maximum L/D for optimal performance. Nevertheless, if the propeller can generally work in bad condition, a smaller angle of attack in design is required. The incoming fluid velocity and the rotational velocity (RPM) define the propeller's pitch distribution. The axial velocity can create larger propeller designs with low efficiency. Although the fluid density will not influence the thrust's performance, it directly affects its size and shape (Publication et al., n.d.).

The approach based on the lifting/surface theories of the theoretical propeller design is well known and frequently applied. These design tools enable naval architects to quickly build an optimized propeller using a computer without the geometrical limitations seen in the propellers' sequence with relatively limited geometry choices. However, the arrangement of the propellers is still in use. They are now very frequently used in light or modestly charged propeller preliminary design. Besides, the traditional series propellers are also good options for those who cannot afford lifting surface software (Chen & Shih, 2007).

Furthermore, the propeller design requires the commonly used XFOIL research and QMIL and QPROP numerical thrust optimization programmed. XFOIL was used to achieve aerodynamical airfoil design properties such as crucial parameter values for the lift and drag. These values were then used for QMIL and QPROP, applying the mission system's characteristics at a conservative design process, to establish basic propeller geometry for reduced induced loss. These systems are essential for chosen moving motor performance parameters (Tracy, 2011).

The propeller's design for use on the small-sized UAV platforms is customarily completed to optimize the propeller's performance. The thrust limitation will be used to approximate the aircraft's conditions when the power limitation is used to simulate the motor or the motor performance to which the propeller is attached. However, it usually is much more challenging to find the best design than to improve propeller performance under such operating conditions (MacNeill et al., 2017).