

MEASUREMENT OF DYNAMIC THRUST PRODUCED BY DIFFERENT SELECTION
OF PROPELLER

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requirements for the award of the degree of Bachelor of Engineering (Mechanical)

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DECLARATION

I declare that this thesis entitled “MEASUREMENT OF DYNAMIC THRUST PRODUCED BY DIFFERENT SELECTION OF PROPELLER” 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 :

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Date : 26 December 2018

DEDICATION

*“Dedicated, in thankful appreciation for
support, encouragement and understandings
to my beloved family, lecturers, and supportive friends.”*

ACKNOWLEDGEMENT

I would like to take this opportunity to express my gratitude to those who have contributed to the success of this project. My sincere appreciation to my supervisor, Dr.-Ing. Mohd Nazri Bin Mohd Nasir for his endless guidance and advice. Would like to extend my gratitude to my fellow friends for their support and assistance. Finally, I am most thankful to my beloved family for their encouragement and understanding over the years.

ABSTRACT

The Unmanned Aerial Vehicles (UAVs) is ground base controller aircraft. The rate of use of the UAVs has increased recently that not only in military, but also in commercial application use such as civil surveillance, search and rescue, agriculture, oil & gas exploration for natural gas exploration and also in film making. Due to that various requirement of application, it is necessary to define their performance in order to obtain their propulsive performance and efficiency. The main component of electric propulsion system UAVs is a propeller, brushless electric motor, electronic speed controller and a battery. The rotating propeller, being one of the components of the UAVs is constantly subjected to various dynamics loads. This study focuses on measuring the dynamic thrust produced by different selection of propeller. The experimental study on dynamic thrust produced by propeller conducted with different of flows speeds inside the Subsonic Low Speed Wind Tunnel located at FKM Aerolab. The thrust generated by the propeller and the efficiency were measured. The results obtained through the wind tunnel testing were tabulated and corresponding graphs were plotted to show the result of the experiment.

ABSTRAK

Pesawat udara tanpa pemandu, atau lebih dikenali sebagai 'Unmanned Aerial Vehicle, UAVs' adalah sebuah pesawat yang dikendalikan tanpa pemandu. Kadar penggunaan UAV telah meningkat baru-baru ini yang mana penggunaan UAV ini tidak hanya digunakan didalam aktiviti ketenteraan, malah turut digunakan dalam bidang komersil seperti pengawasan sivil, misi encari dan menyelamatkan, pertanian, penerokaan minyak dan gas dan juga dalam pembuatan filem. Oleh kerana penggunaan UAV didalam pelbagai keperluan aplikasi yang berbeza, adalah satu keperluan untuk memastikan prestasi dan kecekapan sistem penggerak. Komponen utama sistem penggerak UAV adala terdiri daripada kipas, motor electric, pengawal kelajuan elektrik dan juga bateri. Kipas yang berputar, adalah salah satu komponen dorongan UAV yang sentiasa tertakluk kepada pelbagai beban dinamik. Projek ini menumpukan pada pengukuran tujahan dinamik yang dihasilkan dari pemilihan kipas yang berbeza. Kajian pada tujahan dinamik yang dihasilkan oleh kipas ini dijalankan dengan menggunakan kelajuan angin yang berbeza didalam terowong angin yang terletak di makmal Aero. Tujahan yang dihasilkan oleh kipas dan juga kecekapan sistem dorongan akan diukur. Keputusan yang diperoleh dari ujikaji didalam terowong angin akan dibandingkan antara satu sama lain dengan menggunakan graf yang bersesuaian.

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LIST OF ABBREVIATIONS

UAVs	-	Unmanned Aerial Vehicles
C_P	-	Coefficient of Power
C_T	-	Coefficient of Thrust
D	-	Propeller Diameter, m
ρ	-	Density of air, kg/m ³
n	-	Propeller rotational speed, rev/sec
T	-	Thrust, N
P	-	Power, W
V	-	Air Velocity, m/s
RPM	-	Rotation per Minute
J	-	Advance Ratio
η	-	Propulsive Efficiency
R	-	Radius of Propeller

CHAPTER 1

INTRODUCTION

1.1 Project Overview

The Unmanned Aerial Vehicles (UAVs) is an aircraft that without a human pilot to operate it. Unlike the common aircraft, the UAVs is a ground-based remote control by controlling it nearby. Some of the UAVs also can be programmed to fly autonomously according to the programmed flight path.

Propellers have been the keystone of aviation since the Wright Brothers completed the first sustained and powered flight on December 17, 1903; the flight, which was made possible by the propeller the Wright brothers designed and built (Gamble and Arena 2010). Wilbur Wright was then the first person to recognize the propeller is nothing more than a rotating twisted wing whose primary function is to convert shaft power into propulsive thrust at the highest possible efficiency.

Nowadays, the use of propeller for Unmanned Aerial Vehicles (UAVs) propulsion is also quite frequent these days (Deters, Ananda Krishnan et al. 2014). These types of UAVs are made possible by batteries. To convert energy into thrust, a propulsions sting must be designed which includes a motor and a propeller.

1.2 Problem Statement

Theoretically, more blades will affect propeller performance because every additional blade will cause disturbances which interfere with the flow of the other blades. The lower the number of blades, the better as the preceding blade disturbs the airflow for the following blade.

Propeller design considerations include the number and shape of the blades but compromises are required. As an example, increasing the ratio between the length and width of the surface of the blade (known as aspect ratio) will reduce drag. However, as the amount of thrust that is produced by a propeller is proportional to the blade area, increasing the aspect ratio means that either longer blades or more blades are required to maintain the equivalent thrust.

1.3 Objectives

The objectives of this study are:

- i. To design measurement techniques in order to remotely quantify dynamic thrust.
- ii. To measure the performance of propulsion system at different settings.

1.4 Scope of Work

The scopes of this study are:

- i. Literature studies on the propulsion system used in UTM UAV known as CAMAR v3.
- ii. The experiment will be executed at wind speed ranging from 0 to 24m/s.
- iii. Other settings and nature of the experiment shall be relevant to CAMAR v3.

CHAPTER 2

LITERATURE REVIEW

2.1 Development of Propeller

The creation of the propeller can be traced back to Leonardo da Vinci's helical screw helicopter which believed is the ancestor of the aircraft propeller. The first idea of a propulsive aircrew propeller were belongs to J.P. Paucton, a French mathematician found during the late 1700 to early 1800. In year 1875, Thomas Moy finally created a large model that had twin 12-foot propellers which 6 blades each. These massive propellers produce 1100 pounds of thrust each during full power while rotating at 425rpm.

In early stages of development of propellers, the most influential aviation pioneers were the Wright brother's propeller. They had concluded that a propeller was simply a whirling wing. They have also gained thrust efficiency by reducing the blades rotational speed using a chain and sprocket transmission.

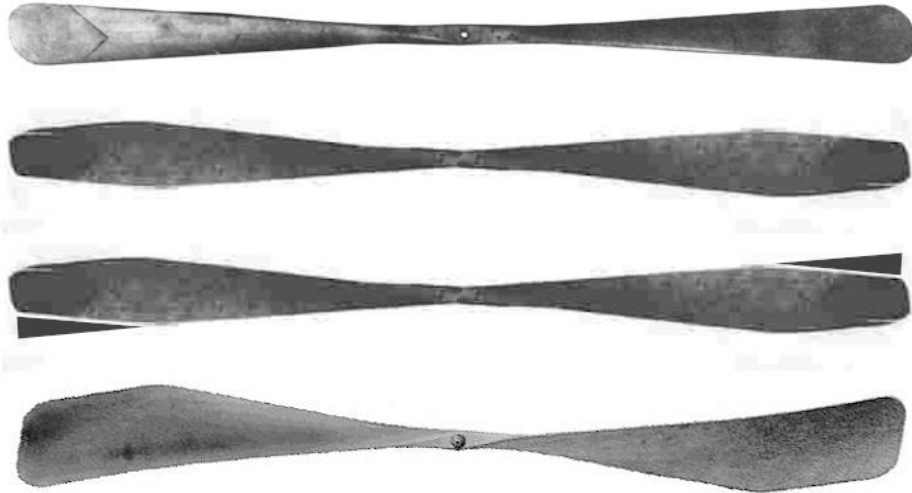


Figure 1: Wright Brother's propeller between 1904 and 1905

(Source: Wright Brothers Aeroplane Company from <http://www.wright-brothers.org>)

2.2 Propeller - Terms and Definitions

Aircraft propellers are simple devices that have no moving and adjustable parts. Most of the propellers are similar in design and the shape. Propellers behave as a rotating wing producing lift in the direction of the axis of rotation. The simple purpose of the propeller is to convert the power produced by the engine to axial thrust thru torque transfer (rotational force) to the propeller.

Propellers are airfoils, shaped are designed similar to wings. Instead of producing lift in a vertical direction, propellers are designed to produce lift in a forward direction that called thrust. Just like wings, propellers accelerate airflow over their cambered surfaces. The high velocity of the air results in a lower static pressure in front of the propeller, pulling the airfoil forward. All propellers have the same basic parts such as blade, trailing edge, leading edge and tip.

The blades of a propeller like those of the helicopter rotor can be thought of as being rotating wings. Since the axis of the rotation of the propeller is horizontal, the aerodynamic force produced is directed forwards to provide thrust rather than upwards to generate lift.

The thrust force is therefore related to the differences in pressure between the forward and the rearward-facing surfaces of the blades. Blade angle is the angle between the propeller plane rotation and the chord line of a propeller airfoil section. In other terms, blade station is reference position on a blade that is a specified distance from the center of the hub (Pauliny 2012)

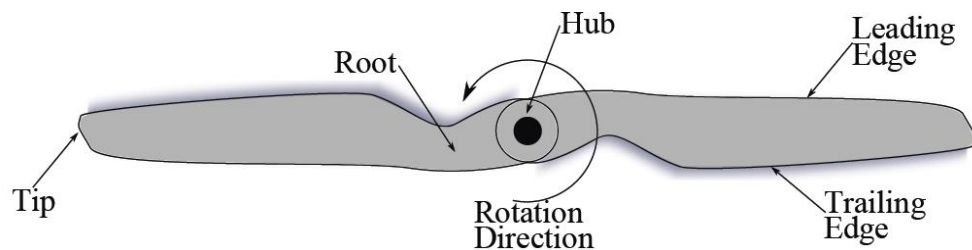


Figure 2: Propeller basic parts

2.3 Specification of propeller

Selection of propeller is one of the most critical because different propeller manufacturers use carrying geometry styles for their propeller. Some commonly used materials for propellers include plastic, wood, and fiber glass. The most important characteristic of the propeller material is its rigidity. The rigidity gives more efficiency to the propeller performance because deflection of the propeller affects the efficiency. Rigidity also helps to reduce the vibrations of the propellers.

2.4 Propeller – Geometry and Pitch

A propeller with ideal efficiency is able to convert energy supplied from engine fully into forward thrust. The geometry of blade plays an important role to optimize the efficiency of propeller. It is often thought as a rotated wing due to their shape or airfoil section which is similar to the wing.

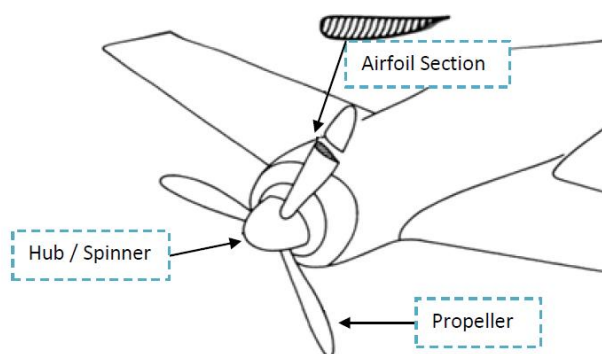


Figure 3: The airfoil cross section of propeller (Phillips 2004)

According to Dustin Eli Gamble, a propeller is generally defined by its diameter and pitch (Gamble and Arena 2010). The diameter of the propeller is defined by the measurement of the distance between blade tips. The definition of pitch is the same as woodscrew; it is the distance that the propeller will advance forward with one revolution (Wall 2012).

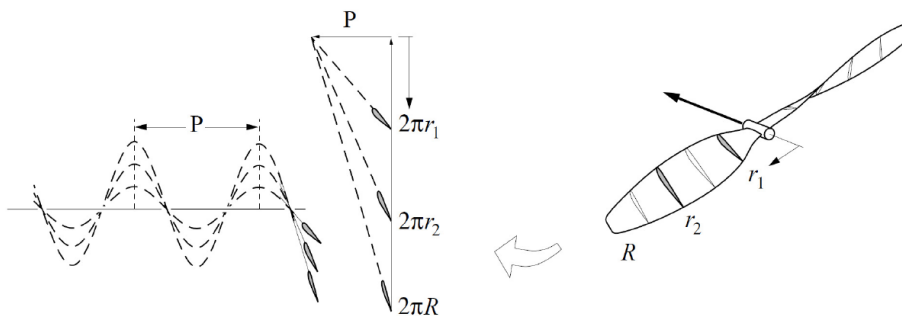


Figure 4: Propeller Pitch

When the aircraft is in flight, the relative velocity between the air and a section of a propeller blade has two components, as illustrated in Figure 2. The flight direction was coming from the forward flight velocity. The other (tangential) component comes from the blade velocity due to rotation.

If the propeller blade is set at a positive angle of attack relative to the resultant relative velocity, it will generate a force; in the same way as a wing generate lift. However, instead of resolving this force into lift and drag components, it can be resolved with more conveniently into forward thrust, and tangential resistance. The resistance force will produce a turning moment about the propeller shaft axis, and it called the resistance torque which the engine has to overcome.

The production of thrust by a propeller blade is similar to the generation of lift by a wing. It therefore follows that the blades will produce trailing vortices. Since the blade is rotating, however, the trailing vortices take the form of helical trails.

2.5 Number of blades

A propeller can have any number of blades. The additional number of blades to increase the solidity of blades has a lesser adverse effect compare that increase the blade's width/chord (Rajeevalochanam, Nanjundaiah et al. 2016). A propeller with more blades will increase the uniform distribution of thrust and power but with a small improvement of efficiency (Ghoddoussi and Miller 2016). The most common propeller has two blades because of two-bladed propellers generally more efficient than a larger propeller that produces the same thrust and airspeed. Since three or more blades have more lifting area than two blades of the same size, the blade length can be reduced somewhat while maintaining the same forward speed, rpm and engine shaft power (Garner 2009). The reason propeller blades number varies

is most often related to the power produced by the engine; more powerful engines require more propeller blades. Adding more propeller blades decreases the overall efficiency of the propeller because each blade has to cut through more turbulent air from the preceding blade (Edwin P. H., & David B., 1938).



Figure 5: Different number of UAV propeller

As aircraft wings, increasing the aspect ratio of the propeller blades reduces the drag and resistance. However, the amount of thrust that can be produced is depends on the total blade area. The use of high aspect ratio blades may result in an unacceptably large propeller diameter. Large high-powered propeller driven aircraft often have low-aspect-ratio ‘paddle’ blades.

2.7 Introduction to thrust

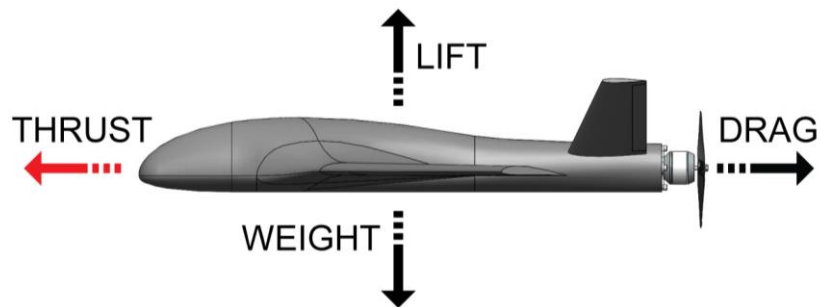


Figure 6: Forces acting on aircraft

Basically, there are four physical forces acting on the aircraft; thrust, lift, weight and drag. Thrust is the force which moves aircraft through the air that is generated by the propulsion system of the aircraft. Thrust has to be greater than drag to accelerate the aircraft by increasing the engine power and propeller rotations (RPM). In order to pull the airplane forward, air will accelerate across the propeller blades and create a strong pressure differential (Anderson Jr 2010). When accelerating, the drag load will increase as well. Due to that, more power is required at higher airspeed for the acceleration process. Due to the fact that the engine is already specified, choosing a propeller that will offer the maximum thrust is very important. The more thrust which can be harnessed from the engine, the more the airplane will be able to lift (John Tester, 2009).

Besides static thrust, propellers also produce dynamic thrust. Dynamic thrust is the difference between the speed of the air the propeller moves (slipstream velocity) and the aircraft's forward velocity with respect to the air's movement around the aircraft. The dynamic thrust is important; combined with drag information, it can give the maximum attainable speed, flight speed for minimum energy consumption, and many other performance characteristics.

2.8 Propeller Parameter

The performance characteristic of the propeller can be express using non-dimensional parameter equations such as advance ratio, J , Coefficient of Thrust, C_T , Coefficient of Power, C_P , and the Propeller Efficiency, η . The non-dimensional coefficient of thrust, power can be respectively defined as:

$$C_T = \frac{T}{\rho n^2 D^4} \quad (2.1)$$

$$C_P = \frac{P}{\rho n^3 D^5} \quad (2.2)$$

$$J = \frac{V}{nD} \quad (2.3)$$

Where,

T = Thrust (N)

P = Power (W)

ρ = Air Density (kg/m³)

n = Motor Speed (rev/sec)

D = Diameter of propeller (m)

V = Velocity of air (m/s)

2.10 Propulsive efficiency

High efficiency does not depend on just getting a good ratio of thrust to resistance, since that would imply using very small pitch and helix angles. A small helix angle means that the blade would be whirling around at high speed doing a great deal of work against the resistance, without doing much useful work in moving the aircraft forwards.

Propulsive efficiency can be described as the ration between an output power and input power. The input power is the power generated by the motor, also called as shaft power. The shaft power is expressed in watts and it is the product of the torque (Nm) and the angular velocity (rad/s) (McCoy 1939).

According to Miguel Marques Borges (2015), the propulsive efficiency is an important characteristic parameter of the propeller arising due to its rotation in the air. It answers the question, how efficiently is the engine power (power input) converted to thrust power (power output) (Borges 2015). The efficiency of the propeller can be express as:

$$\eta_p = \frac{C_T}{C_P} J \quad (2.4)$$

2.11 Power Supply

Nowadays, many UAVs are using electric propulsion system. Furthermore, for these electrically powered vehicles, the power storage system, in most cases a battery, represents the largest component by weight in the vehicle (Borges 2015).

As shown in Figure 6, the battery used for UAV shall be lighter and deliver a good amount of power to the system. Because of the prevailing advantages, a Lithium Polymer battery is commonly used for UAVs.

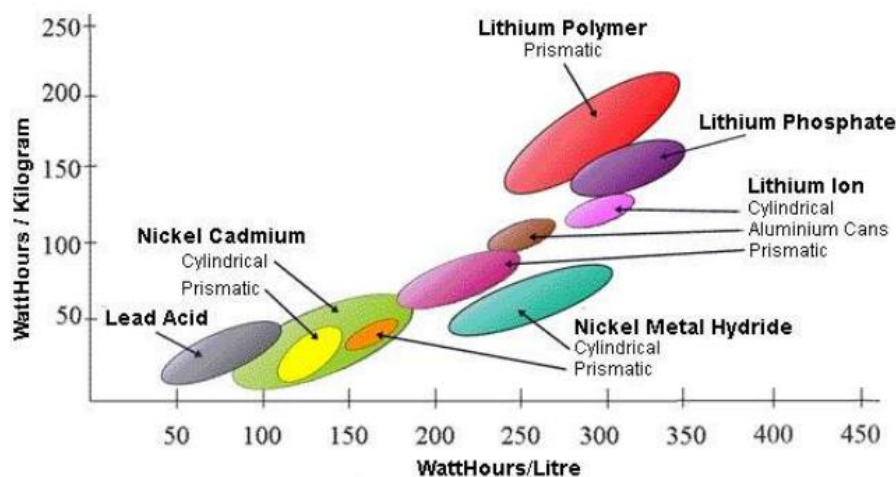


Figure 7: Comparison of energy densities for various chemistries (Reid, Manzo et al. 2004)

2.12 Propulsion system of UAVs

The main components in an UAV electric propulsion system are a battery, a motor, the speed controller and the propeller. The propeller is mounted to the motor, which is connected to the battery, speed controller and receiver. The receiver receives the control signal from the transmitter in the ground, and sends the signal to speed controller, which varies the speed of the motor.

2.13 Lithium Polymer Batteries

Lithium polymer (LiPo) batteries are rechargeable battery of lithium-ion technology in a pouch format. Unlike the cylindrical and prismatic cells, LiPo come in soft package or

pouch, which make them lighter but also less rigid. Each type of battery chemistry, whether it be Lithium-polymer, Lithium ion, nickel metal hydride, or other has specific characteristics that define its electrical operation, size, weight and other properties.

LiPo batteries differ from other battery systems in the type of electrolyte used. The original polymer design was on 1970s using a solid (dry) polymer electrolyte that resembles a plastic-like film. This insulator allows the exchange of ions (electrically charged atoms) and replaces the traditional porous separator that is soaked with electrolyte.

The main advantages of using LiPo batteries for this study is that they have about four times the energy of density of nickel cadmium or nickel metal hydride batteries. There is no memory effect, i.e. the reduction of capacity due to incomplete discharge. The self-discharge rate can be neglected with around 2-3% per month (RETZBACH, 2008). LiPo batteries are very lightweight and pliable and have variety of sizes or shape. Other than that, LiPo batteries is durable than most batteries.

The disadvantages of the LiPo batteries are commonly related to safety and it can be controlled by proper handling. Excess charge or exceeding of the maximum operational temperatures can cause the decomposition of the electrodes or the electrolyte. This may result in the release of gases which may overstretch the casing and inflame when escaping.

2.14 Electric Motor

Basically, electric motors are electromechanical machines that convert electrical input power into mechanical output power. There are two type of electric motor that commonly used to drive the propeller. They are Brushed and Brushless DC motor.

2.14.1 Brushless Direct Current Motor

Nowadays, Brushless Direct Current motors are one of the motor types rapidly gaining popularity (Yedamale 2003). As the name implies, BLDC do not use brushes for commutation; instead, they are electronically commutated. The brushless DC (BLDC) motor is a permanent magnet synchronous machine where the magnetic fields are uniformly in the air gap such that when the motor is turning at constant speed. The BLDC motor with its permanent magnet field excitation, replaces electromagnets which have windings and require external electric energy source.

The major difference between the BDC and BLDC is the use of brushes. BLDC motors do not have brushes and must be electronically commutated. Commutation is the act of changing the motor phase currents at the appropriate times to produce rotational torque. With a BLDC motor, electrical current powers a permanent magnet that causes the motor to move, so no physical commutator is necessary. A BLDC motor is highly reliable since it does not have any brushes to wear out and replace.

A BLDC motor is constructed with a permanent magnet rotor and wire wound stator poles. Electrical energy is converted to mechanical energy by the magnetic attractive forces between the permanent magnet rotor and a rotating magnetic field induced in the wound stator poles.

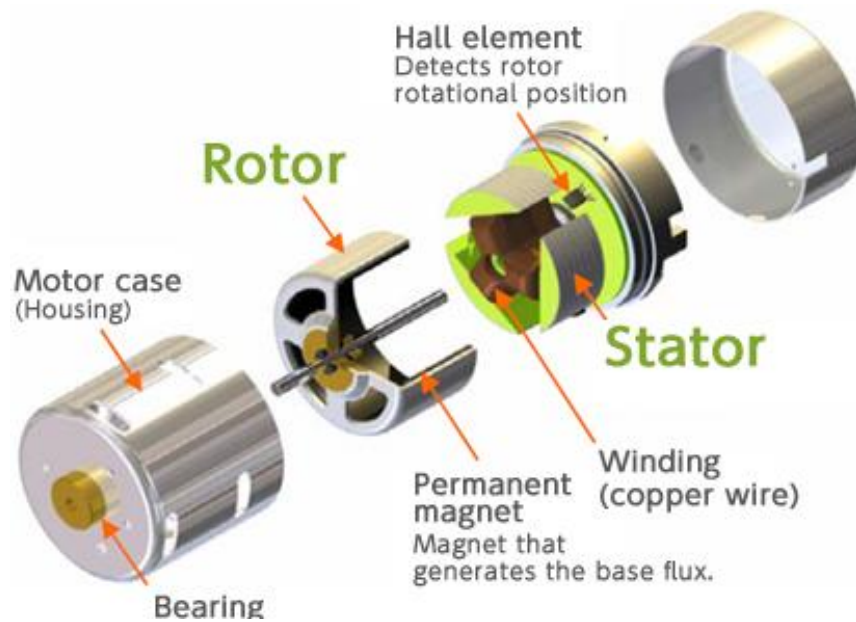


Figure 8: Basic components in BLDC motor

2.15 Electronic Speed Controller

An Electronic Speed Controller (ESC) for BLDC motor controls the voltage passed to motor. ESCs are also known as motor drivers or pulse width modulation (PWM) drivers. The ESC receives a throttle signal and changes the duty cycle and frequency of the output voltage waveform to adjust the motor's speed and torque. When the current is driven through the stator windings the moving electric charge interacts with the rotor magnetic field and generates force on the rotor which can cause it to rotate. ESCs come in different max amperage sizes, and are usually accompanied by their specifications of switching frequency and internal resistance.

2.16 Introduction of Low-Speed Wind Tunnel

Majority of the experimental data needed in aerodynamics is generated using wind tunnels. The wind tunnel is an important equipment or device for experimental work in aerodynamics. Wind tunnel also is the main tool for aerodynamics design of aircrafts. The main function of the wind tunnel is to provide a uniform and controllable air flow through the testing section.

A wind tunnel is a specially designed and protected space into which air is drawn, or blown, by mechanical means in order to achieve a specified speed and predetermined flow pattern at a given instant. The flow achieved can be observed from outside the wind tunnel through transparent windows that enclose the test section and flow characteristics are measurable using specialized instruments.

There is an extensive literature on design of experiments that can provide valuable information for design and conduct of wind tunnel experiments just as for other areas of study and development. Basically, there are two types of wind tunnels and two basic test-section configurations. Hence, there are almost endless variations on the specific features of various tunnels. The two basic types are open circuit and closed circuit.

2.16.1 Open circuit wind tunnel

In an open circuit wind tunnel, there is intake and an exhaust. There is no use for corners and long diffusers but the power needed to drive the wind tunnel is high because of the loss of energy in the out-flowing air. The open circuit wind tunnels the simplest and most affordable to build. In these tunnels air expelled directly in to the laboratory and typically reingested after circulating through the lab, though some tunnels utilize instead a compressed

gas source. In addition to their low costs, open circuit tunnels are also advantageous because they are relatively immune to temperature fluctuations and large disturbances in return flow, provided that the volume of the laboratory is much greater than that of the tunnel.

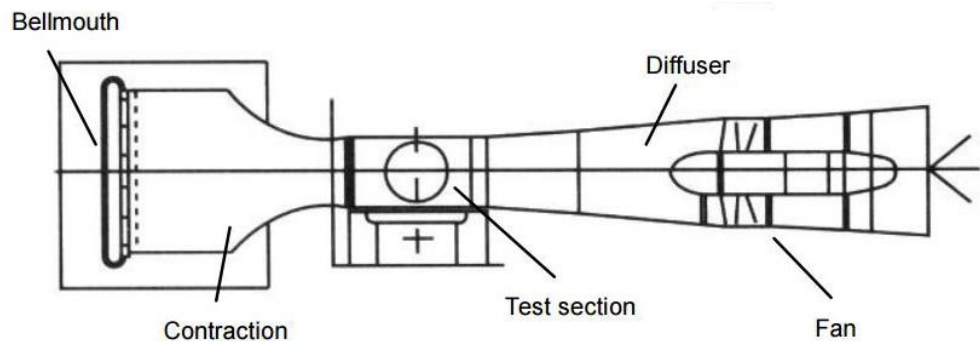


Figure 9: Plan view of an open circuit wind tunnel (Diamler-Benz Aerospace Airbus, Bremen, Germany)

The advantages of using open circuit wind tunnel are the construction of the wind tunnel is typically less expensive. Open circuit wind tunnel also doesn't have a purging problem if running an internal combustion engine or do extensive flow visualization via smoke. It is due to the both inlet and exhaust is open to the atmosphere.

The disadvantages of the open circuit wind tunnel may require extensive screening at the inlet to get high-quality flow. The same may be true if the inlet and exhaust is open to the atmosphere, when wind and cold weather can affect the experiment.

2.16.2 Closed circuit wind tunnel

Closed circuit wind tunnels (also known as closed return) form an enclosed loop in which exhaust flow is directly returned to the tunnel inlet. In a closed circuit wind tunnel, the air is recirculated to improve efficiency for high speed testing. These tunnels are usually larger and more difficult to build. The closed circuit wind tunnels must be carefully designed in order to maximize uniformity in the return flow.

The advantages of closed circuit wind tunnel are through the use of the corner turning vanes and screens, the quality flow can be well controlled and most important it will be independent of other activities in the building and any weather conditions. The disadvantages of closed circuit wind tunnel are the higher construction cost due to return ducts and corner vanes. If being used extensively for smoke flow visualization experiments or running of internal combustion engines, the wind tunnel must be a way to purge tunnel.

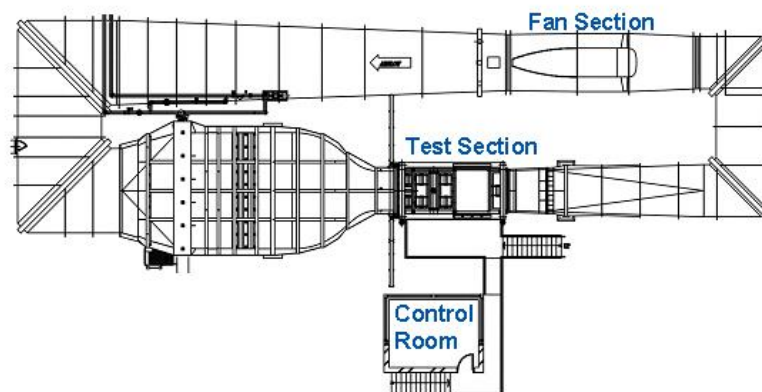


Figure 10: Plan View of Closed Circuit Wind Tunnel at UTM Aerolab

CHAPTER 3

METHODOLOGY

3.1 Introduction

The overall objective of this project was to measure the dynamic thrust produced by different number of selection. Research methodology characterized how the study will be carried out to achieve the objective of the study. An efficient arrangement and thorough comprehension of the methodology of the research is essential to accomplish the study accordingly. Method and approach of the study will be described in this chapter. Data collected from the experiment shall be used for further analysis. The coefficients and the efficiency obtained will be plotted against the advance ration.

3.2 Details of Apparatus

The main components used for this experiment is a:

1. Propeller
2. Brushless outrunner motor
3. Electronic Speed Controller (ESC)
4. Lithium Polymer (LiPo) battery
5. RCBenchmark 1520 thrust stand
6. Subsonic Low Speed Open Loop Wind tunnel.

3.2.1 Selection of Propeller

The tested propeller will be using Master Airscrew ‘Scimitar’ propeller. Two blades and three blades propeller was selected with the same configurations. Scimitar is the shape like Scimitar sword, increasing sweep along the leading edge. Details of the propeller as table below:

Diameter (inch)	Pitch (inch)	Material	Number of Blades	Weight (g)
13	8	Glass fiber reinforced composite	2	47.1
13	8		3	54.4

Table 1: Propeller specification



Figure 11: Master Airscrew ‘Scimitar’ 2 Blades and 3 Blades Propeller

3.2.2 Brushless Outrunner DC Motor

As described in the chapter two, the motor selection shall be capable to test the propeller selected. The brushless motor for the thrust testing will be using brushless outrunner motor by Turnigy SK3.



Figure 12: Turnigy Aerodrive SK3 5045-500KV

Brand	: Turnigy SK3
Model	: Aerodrive SK3 5045-500KV
LiPo Battery Cell	: 5S – 7S LiPo
RPM/V	: 500KV
Max Current (A)	: 60A
Max Voltage (V)	: 26V
Max Power	: 1350W
Resistance (mh)	: 22
Shaft Diameter (mm)	: 6

Table 2: Turnigy Aerodrive SK3 5945-500KV motor specification

3.2.3 Lithium-Polymer Battery

Lithium Polymer (LiPo) batteries have become the most preferable electric power source available for UAV research recently. The main reason for this is that the LiPo battery packs are significantly lighter and have higher electrical capacity. Besides of the battery's capacity, the selection of the batteries also need to be compatible with the size of the propeller. This is because if the size of the propeller is bigger, it will required higher value voltage and current. For these experiments, a 6 Cell 5200mAH LiPo battery is used to power the system.



Figure 13: KPAMax 6S LiPo Battery

Manufacturer/Brand	: KPAMax
Number of Cells	: 6S
Capacity	: 5200mAh
Voltage	: 22.2V
Continuous Discharge	: 45C
Weight	: 715g
Dimension LxWxH (mm)	: 138 x 60 x 44

Table 3: Specifications of KPAMax 30C LiPo battery

3.2.4 Electronic Speed Controller (ESC)

For the purposes of this experiment, the ESC shall be compatible with the motor size and the propeller size. The ESC maximum current shall be higher than the maximum current of the motor to avoid any damage on the motor. The Red Brick 100A ESC been used as the functions of an interface between the motor and power supply.



Figure 14: Red Brick 100A ESC

Brand/Model	: Red Brick
Continuous Current	: 100A
LiPo Battery Cell	: 2S – 7S LiPo
Dimension LxWxH (mm)	: 62x38x21
Weight (g)	: 108g
UBEC	: 5A/5V

Table 4: Red Brick 100A ESC Specification

3.2.5 RCBenchmark 1520 Thrust Stand

The RCBenchmark 1520 thrust stand was used in this experiment for data acquisition and display. The RCBenchmark thrust stand was designed to reduce the time and cost associated with building a custom test rig. The tool is able to measure all the necessary parameters while controlling the ESC signal and recording the data in a CSV file for the data analysis. The advantages of using this thrust stand is the accuracy of data measurement and continuous data logging (in spreadsheet). The ability of performing calibration is very important to ensure test result is consistent.

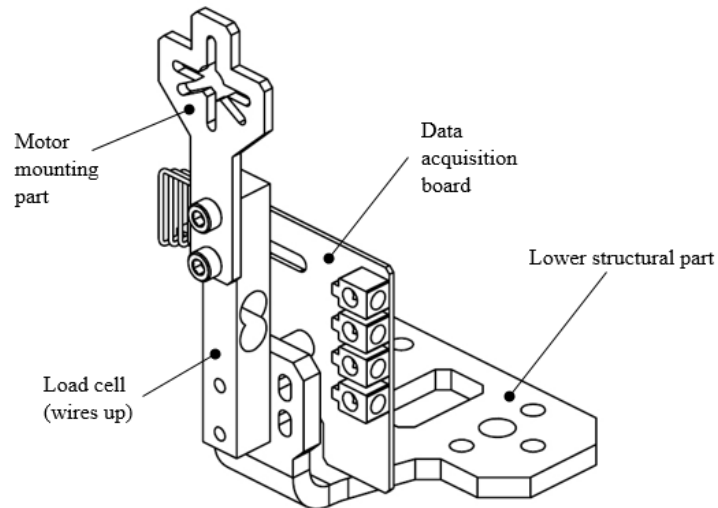


Figure 15: RCBenchmark 1520 Thrust Stand

Specification	Min.	Max.	Tolerance	Unit
Thrust	-5	5	0.5%	Kgf
Voltage	0	35	0.5%	V
Current	0	40	1%	A
Angular Speed	0	190k	-	eRPM

Table 5: Specification of the RCBenchmark Thrust Stand

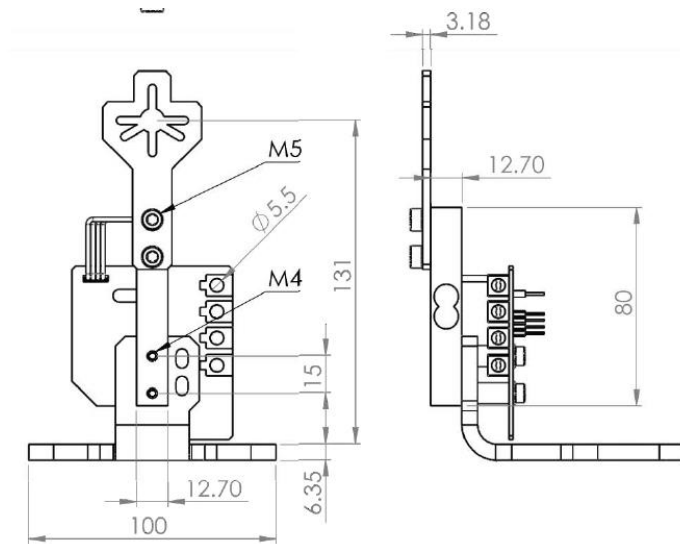


Figure 16: General dimension of the thrust stand

3.2.6 Wind Tunnel

To select the wind tunnel, the test section and the wind speed capability were considered. The test section shall be big enough for the propeller and thrust stand to be installed. To achieve the required wind speed for the experiment, open loop Subsonic Low Speed Wind Tunnel located at AeroLab was selected.

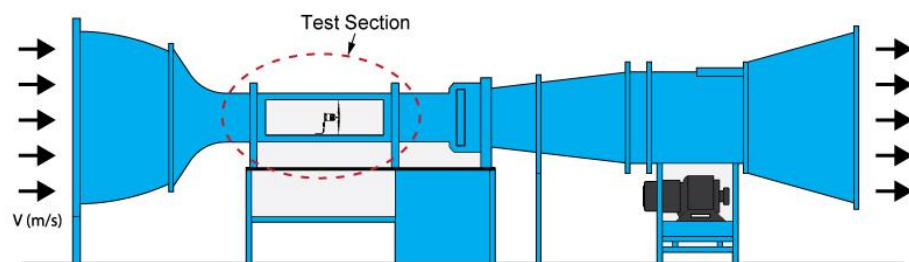


Figure 17: Subsonic Low Speed Wind Tunnel

Wind Tunnel	: Open Loop
Test section dimension LxWxH (m)	: 1.2 x 0.45 x 0.45
Maximum wind speed	: 33m/s
Driven system	: Axial fan driven by 15kW DC motor
Instrument/measurement systems	: multi-tube manometer, anemometer

Table 6: Technical Specifications of the Low Speed Wind Tunnel

3.2.7 Schematic Diagram

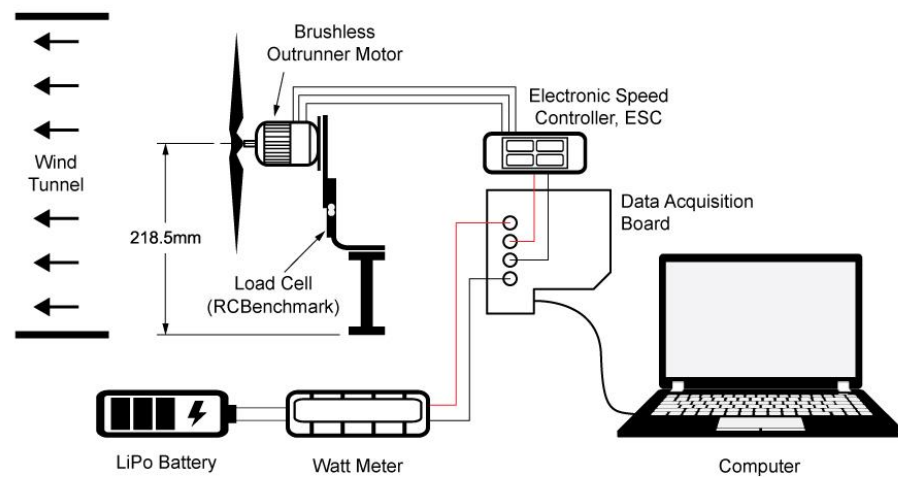


Figure 18: Schematic diagram of the experiment

3.3 Actual Testing Setup

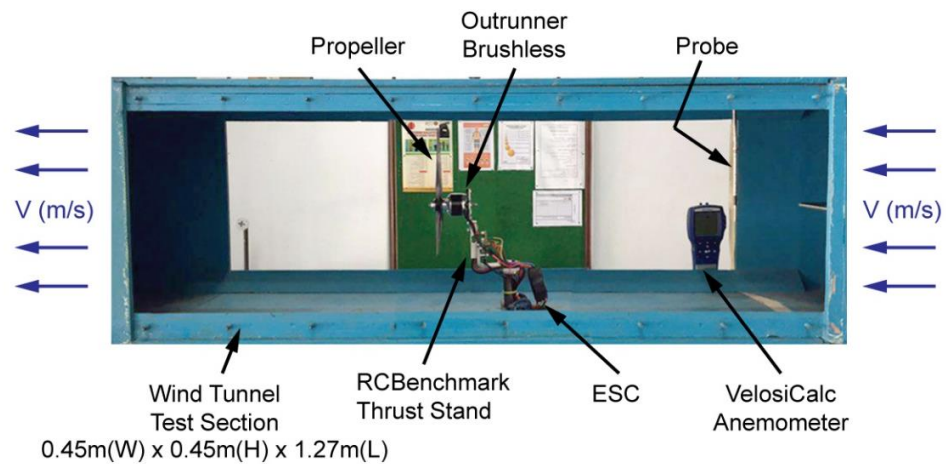


Figure 19: Actual testing setup

3.4 Wind Tunnel Experiment Procedure

The dynamic thrust experiment were conducted by using the Subsonic Low Speed Wind Tunnel. The test were performed at each different setting of air speed start from 0m/s, 4m/s, 8m/s, 12m/s, 16m/s, 20m/s and 24m/s. The details of the experiment procedure as below:

1. Mount the RCBenchmark thrust stand inside the wind tunnel test section.
2. Mount the motor to the mounting parts of the thrust stand in pusher configuration.
3. Secure propeller to the motor shaft and ensure the bolts are properly tighten.
4. Check the alignment of the propeller inside the test section to ensure the position of the propeller is center.
5. Connect all cable as per schematic diagram.
6. Check the inside of the test section and ensure there are no tools or foreign item loose in the tunnel.
7. Close all access ports or any gap using cloth tape.

8. Connect the USB cable to computer, open the RCBenchmark software, choose the automatic control and select the script Sweep-Continuous. The scrip will perform a ramp-up, followed by a plateau, and finished with a ramp-down.
9. Set the output signal to the ESC with $1000\mu\text{s}$ (minimum value) and $1700\mu\text{s}$ (maximum value) as shown in Figure 19.
10. Press 'Start' to start the script and the software will automatically controlled the throttle as per required in the script.
11. Repeat step 10 with different setting of velocities which are 0m/s , 4m/s , 8m/s , 12m/s , 16m/s , 20m/s and 24m/s .
12. Repeat step 3 until step 11 for different number of propeller. All the experiment data will be recorded in CSV file.
13. After all the experiment completed, dismantle the propeller and motor only. Repeat step 10 to step 11 to measure tare value of thrust.
14. The data obtained from the experiment were plotted and the results discussed.

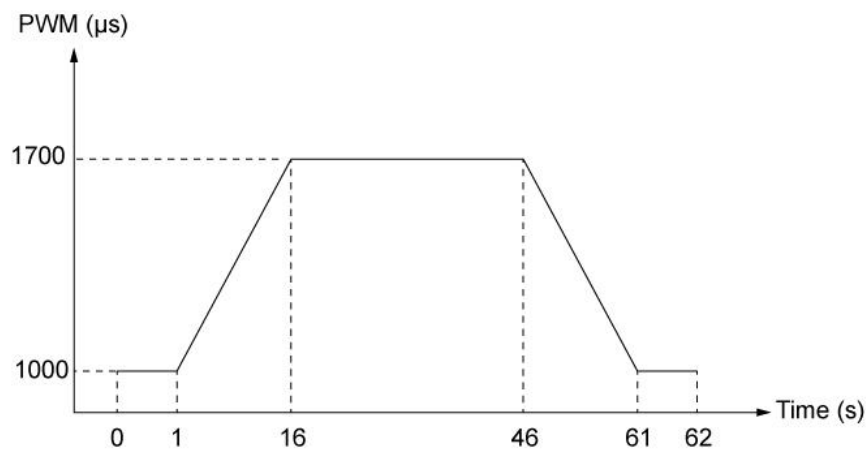


Figure 20: Sweep-Continuous script diagram

3.5 Flow Chart of Methodology

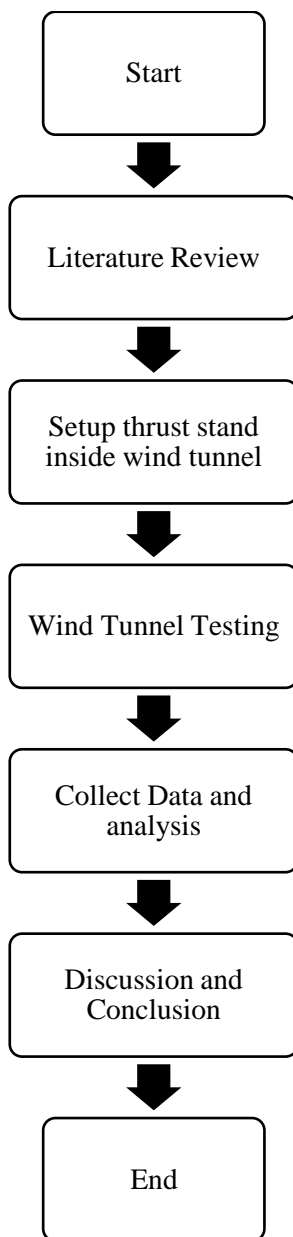


Figure 21: Flow chart for project methodology

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the results for the experiment was presented and discussed. The main focus of the analysis is to determine the efficiency of the propeller. The coefficient of thrust, coefficient of power, advance ratio were calculated using the non-dimensional parameter equations with references from the output data from RCBenchmark.

4.2 Thrust and Motor Speed

From the experiment, the values of thrust and motor speed were directly obtained from the RCBenchmark software. The thrust obtain from the different setting of air speed were plotted against the motor speed. It should be noted that when the propeller speed is increased, the performance also improves (Brandt and Selig 2011). Figure 20 and Figure 21 shows the value of thrust against the motor speed for two blades and three blades propeller respectively. It is shown that the thrust generates by the propeller increases whilst the increments of the motor speed. By contrast to thrust values, three blades propeller generates higher thrust at zero air speed (static thrust) with 21.53N compared to two blades propeller with only 17.5N of thrust. The data also shows that three blades propeller generate higher thrust at maximum RPM for all airspeeds setting.

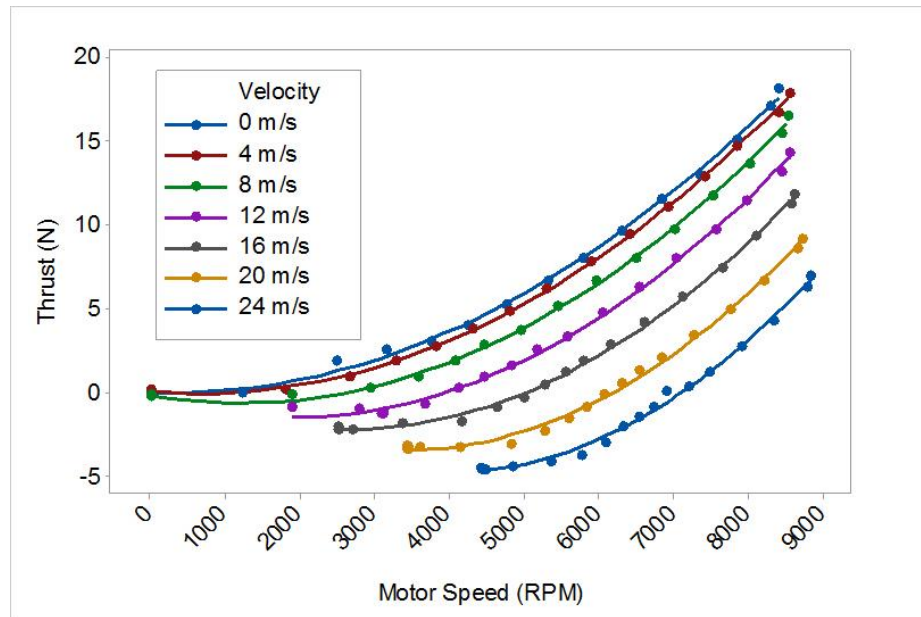


Figure 22: Two Blades Propeller - Thrust vs Motor Speed

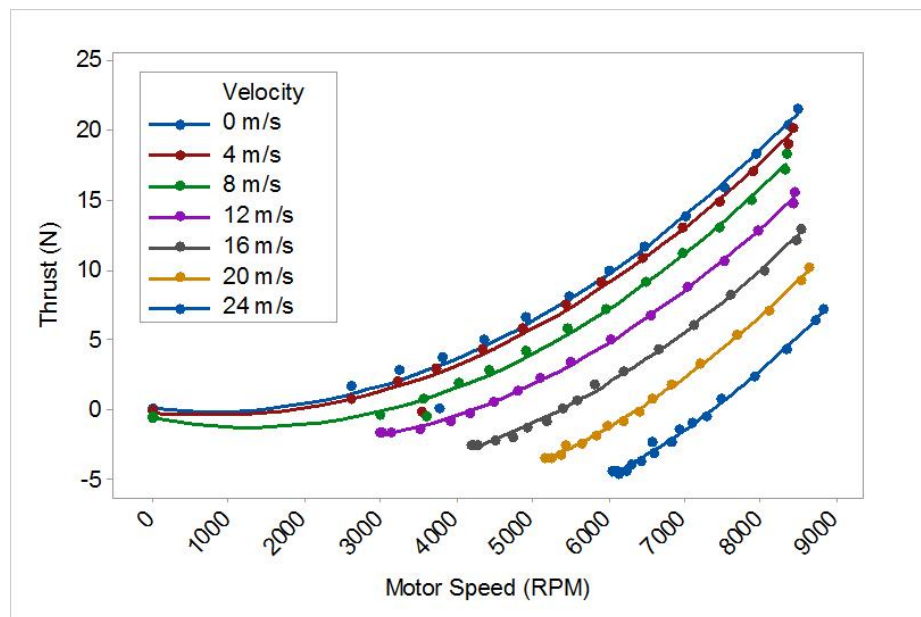


Figure 23: Three Blades Propeller - Thrust vs Motor Speed

4.3 Current vs Air Velocity

The data of current withdraws by the system were directly measured by RCBenchmark software.

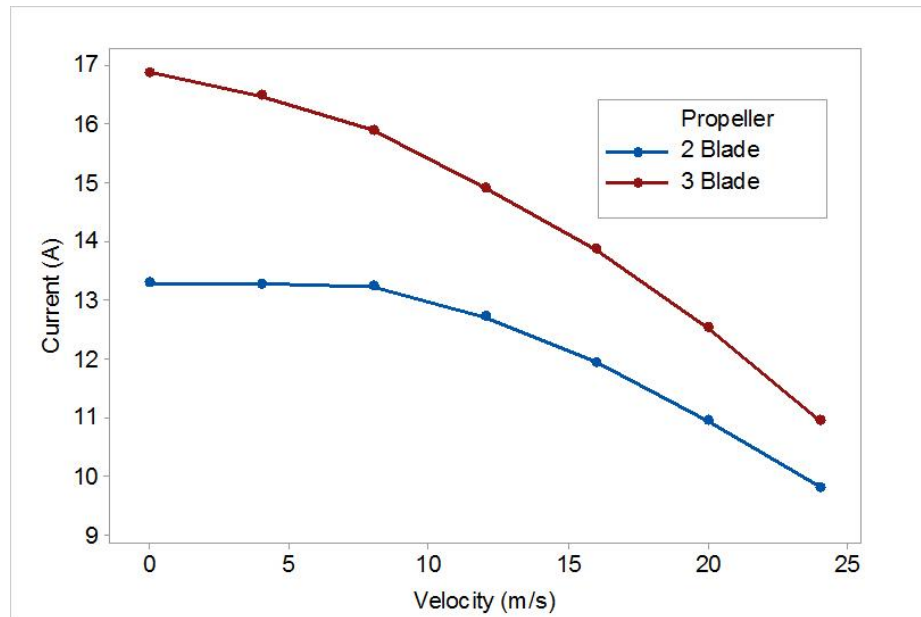


Figure 24: Current versus Air Velocity

Figure 22 shows the comparison of current consumption against the air velocity. From the graph, it appears that two blades propeller withdraw more current compare to two blades propeller. At zero air velocity, three blades had to draw more amps with 16.87 amp while two blades only 13.2 amp. The difference in current consumption at zero velocity are higher, but as the air velocity increased the difference become reduced. Motors always run at a fixed speed for a given voltage. Additional blades will increase the weight and motors has to work harder to get its preferred speed and will pulled as much current from the power source as it needed. As the airspeed increase, the load on the propeller is reduce.

4.5 Coefficient of Thrust, C_T

The comparison of coefficient of thrust between two blades and three blades propeller shown in the figure 23. The results of the coefficient of thrust were plotted against advance ratio for airspeeds from 0 m/s to 24m/s.

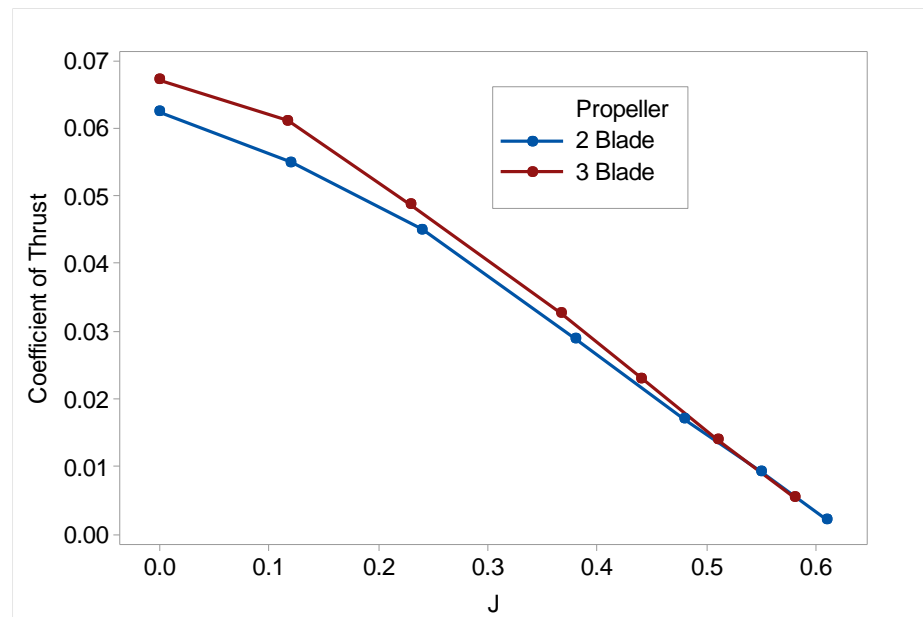


Figure 25: Coefficient of thrust versus Advance ratio

This experiment confirmed that three blades propeller provide more thrust compare to two blades propeller. Figure 25 shows that the different in air velocity affects the thrust generation. The highest value of thrust generates at zero airspeed (static thrust) and the value to thrust decrease as advance ratio is increase. Even the thrust generated by three blades propeller is higher than the two blades, not much advantages at higher number of advance ratio indicate the thrust generating capacity were reduced.

4.7 Coefficient of Power, C_p

Figure 24 shows the comparison of coefficient of power plotted against advance ratio two blades and three blades propeller. It would appear that the power decrease as the advance ratio number increase.

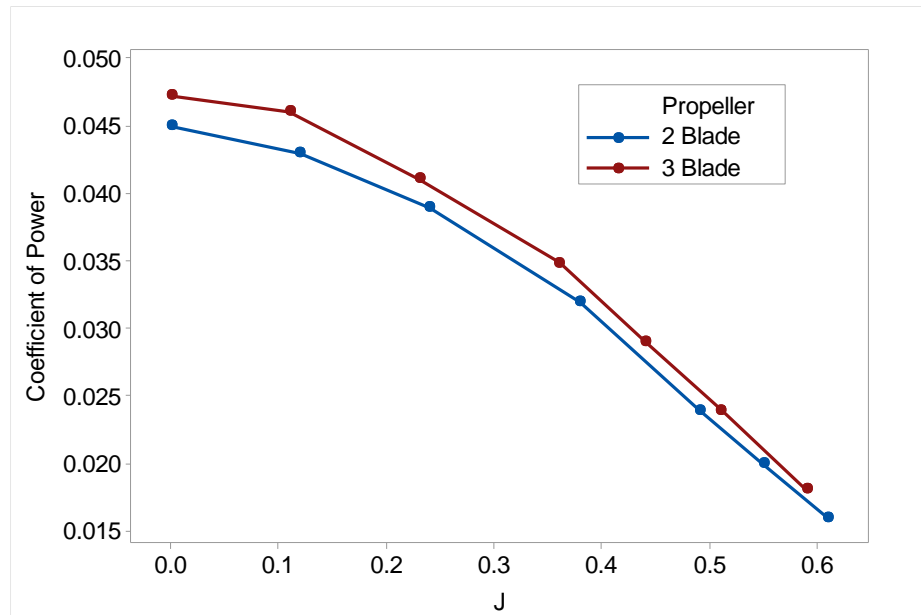


Figure 26: Coefficient of Power versus Advance ratio

Three blades propeller consume more power compare with two blades propeller. As shown on Figure 26, the highest value of power consume by three blades propeller is at zero air speed with $C_p = 0.047$ and two blades propeller is 0.045. At zero airspeed, propeller required more power in order to accelerate in the air. Beside the weight of the propeller, at the same time the resistance of the air also increase too. Thus, the motor will required more power. When the airspeed increase, the pressure different will decrease and power required by propeller also will drop.

4.8 Propulsive Efficiency, η

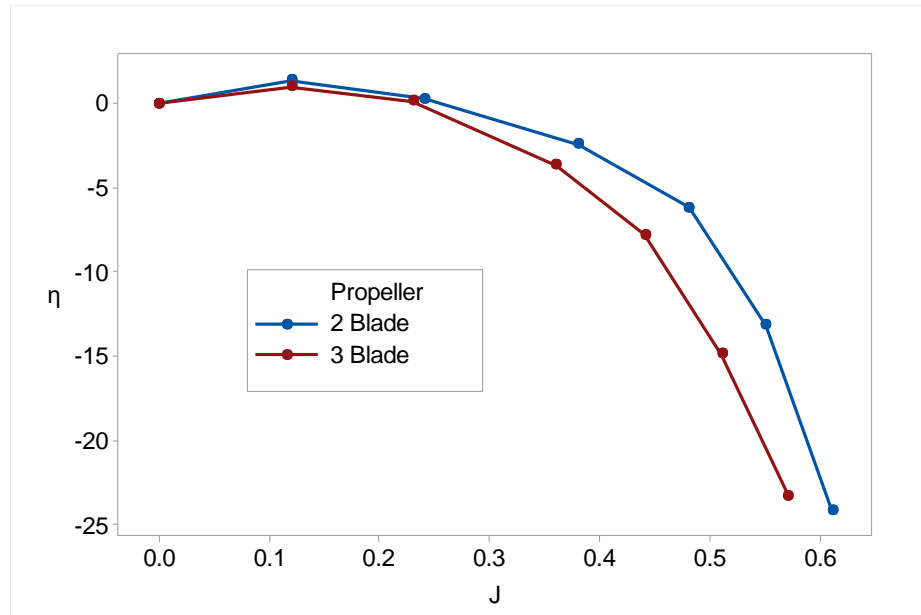


Figure 27: Propulsive efficiency versus Advance ratio

The figure 25 above show the propulsive efficiency versus advance ratio. The graph shows two blades propeller have a higher efficiency with 24% efficiency at lower advance ratio at 0.24. Propulsive efficiency is the function of airspeed, RPM and diameter of the propeller. Due to increment of coefficient of power leads to efficiency decreased. When the aircraft is stationary, the efficiency is zero until the aircraft is moving and reaches its optimum forward speed where maximum thrust is produced. Increasing the RPM beyond that point will decrease the efficiency.

CHAPTER 5

CONCLUSION

The wind tunnel testing to measure dynamic thrust has been successfully carried out on two blades and three blades propeller. These experiments were conducted to measure the dynamic thrust produced by two blades and three blades propeller with the wind tunnel's airspeed at 0 m/s until 24m/s. The propeller performance characteristic is evaluated in terms of coefficient of thrust, coefficient of power, advance ratio and the propulsive efficiency.

1. This study has shown that a propeller with more blades will perform slightly better as it produced more thrust.
2. The number of propeller blades has a small effect on the efficiency for the given diameter and pitch is the same.
3. At zero airspeed, the thrust generated by propeller is higher.
4. One of the significant findings is that the number of propeller blade has greater influence on power consumption.

CHAPTER 6

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APPENDIX C

Actual Wind Tunnel Testing

