MEASUREMENT OF AERODYNAMIC FORCES PRODUCED BY PROPELLERS AT DIFFERENT FLIGHT ORIENTATION.

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MEASUREMENT OF AERODYNAMIC FORCES PRODUCED BY PROPELLERS AT DIFFERENT FLIGHT ORIENTATION.

SHARIKA A/P KALIANI

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requirements for the award of the degree of
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DEDICATION

This thesis is dedicated to all those who never give up on their ambition, goal and dream despite of age factor and life direction.

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ABSTRACT

The overwhelming attraction of Unmanned Aerial Vehicle (UAV) among government bodies, corporate company and society has intrigued my attention in analyzing the performance and efficiency of propeller at different flight orientation.

ABSTRAK

Sambutan luar biasa dan tarikan terhadap penggunaan '*Unmanned Aerial Vehicle'* (UAV) oleh sesetengah badan kerajaan, syarikat korporat dan masyarakat sejagat telah mencetuskan perhatian saya dalam menganalisis prestasi dan kecekapan bebaling pada orientasi penerbangan yang berbeza.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

1.1.1 Aerodynamics

Aerodynamics is the study of how air interacts with moving solid objects, and it is an important field of study for the design and optimization of aircraft, automobiles, and other modes of transportation (Anderson, 2007). Aerodynamics seeks to comprehend and predict the behaviour of fluid flow over surfaces in order to reduce drag, increase lift, and enhance performance (Hoerner, 1965).

One of the most important applications of aerodynamics is in aircraft design. The ability to control and manipulate airflow over an aircraft's wings and body is critical for efficient flight (Katz & Plotkin, 1991). For example, the shape and size of an aircraft's wing can have a significant impact on its performance. A wing that is too thick or has too much camber can cause excessive drag, whereas a wing that is too thin or has too little camber can cause insufficient lift (McCormick, 1979). Engineers can design wings that are optimized for both lift and drag by understanding aerodynamic principles.

Aerodynamics is also important in the design of automobiles, in addition to aircraft. Aerodynamics in automobiles is concerned with reducing drag, increasing fuel efficiency, and improving performance (Drela, 1989). The shape of a car's body can greatly affect its aerodynamic performance. Cars with a more aerodynamic shape, such as those with a low drag coefficient, experience less drag and are more fuel efficient (Hoerner, 1958). Aerodynamic features such as spoilers, air dams, and diffuser can also aid in lowering drag and improving performance (Hoerner, 1965).

Aerodynamics is also important in high-speed train design, including maglev trains (Lissaman, 2005). These trains levitate above the track thanks to superconducting magnets, allowing them to reach extremely high speeds. However, the high speeds attained by these trains pose significant aerodynamic challenges. The airflow around the train can cause drag and turbulence, slowing it down and making it less stable (Li, et. al., 2017). Engineers can design high-speed trains that are optimised for both speed and stability by understanding aerodynamic principles.

Wind turbines are another example of how aerodynamics is important (Shen & Shen, 2009). Wind turbine blades should be designed to capture as much wind energy as possible while minimizing drag and turbulence (Srensen et al., 2011). The aerodynamic shape of the blades, the angle of attack, and the tip speed ratio are all important factors in wind turbine design (Barthelmie, et. al., 2010).

Aerodynamics is also important in athletics. Aerodynamics is used by athletes and coaches to improve performance in sports such as cycling, swimming, and running (Coe, et. al., 2018). In cycling, for example, the rider's position on the bike, helmet design, and clothing can all have an impact on aerodynamics (Barras, et. al., 2015). Athletes and coaches can improve performance by understanding the principles of aerodynamics.

1.1.2 Propellers

Propellers are devices that convert rotational energy into thrust and are commonly used as a means of propulsion in aircraft, ships, and boats (Gibson, 2018). The propeller concept can be traced back to Archimedes' invention of the screw in the third century BCE, which was later refined and used for propulsion by the Greek inventor Hero of Alexandria in the first century CE (Crouch, 2003).

Jean-Marie Le Bris, a Frenchman, invented the modern propeller in the early nineteenth century (Le Bris, 1868). Le Bris designed a glider with a screw-shaped propeller attached to the front that he used for short distance flights. The Wright brothers, however, are credited with developing the first successful powered aircraft, the Wright Flyer, in 1903. (Wright, 1903). The Wright brothers used a wooden propeller designed using wind tunnel testing and mathematical calculations (Wright, 1901).

Propellers were made of wood in the early days of aviation and were designed using simple geometric shapes such as airfoils (Crouch, 2003). However, as aircraft technology advanced, propellers were made of more durable materials such as aluminium (Gibson, 2018). and composite materials (Wernick, et. al., 2011). Propeller design became more complex as computer-aided design (CAD) software was used to optimise the shape and size of the blades (Gibson, 2018).

Propellers are divided into three types: fixed-pitch, variable-pitch, and feathering (Gibson, 2018). Fixed-pitch propellers have fixed blades that can be adjusted to different angles, whereas variable-pitch propellers have adjustable blades (Lissaman, 2005). Feather propellers can be adjusted to completely stop rotation. In aircraft, variable-pitch and feathering propellers are used to optimise performance under various flight conditions (Lissaman, 2005).

Propellers are also used for propulsion in ships and boats (Liu, et. al., 2019). Propellers are typically located at the stern of a ship and are powered by a diesel or steam engine (Liu, et. al., 2019). Ship propellers are designed differently than aircraft propellers because they are intended to operate in a marine environment (Liu, et. al., 2019). Ship propellers must be able to withstand the corrosive effects of saltwater and move large volumes of water efficiently in order to propel a ship (Liu, et. al., 2019).

There has been a surge of interest in the use of electric and hybrid propulsion systems in ships in recent years (Kirby, et. al., 2017). Electric propellers, also known as azimuth thrusters, are gaining popularity in the marine industry because they are more efficient and emit less noise and pollution than traditional propellers (Kirby, et. al., 2017).

1.1.3 Flight orientation

Flight orientation in aviation refers to an aircraft's position and attitude while in flight (Barras, et al., 2015). An aircraft's flight orientation can affect its performance and efficiency (Gibson, 2018), as it changes the fluid flow conditions around the propellers, wings, and other components (Srensen et al., 2011). Level flight, climbing, descending, turning, and manoeuvring are the most common flight orientations (Li, et al., 2017).

Level flight occurs when an aircraft maintains a constant altitude while flying at a relatively constant speed with minimal pitch and roll (Shen & Shen, 2009). This is the most common flight orientation and serves as the standard against which other flight orientations are measured (Barthelmie, et al., 2010).

Climbing is the process by which an aircraft gains altitude while maintaining a positive pitch attitude (Li, et al., 2017). This causes the propellers' angle of attack to increase, which can result in a decrease in thrust and an increase in drag (Li, et al., 2017).

Descending is the inverse of climbing in that an aircraft's altitude decreases with a negative pitch attitude (Li, et al., 2017). This causes the propellers' angle of attack to decrease, which can lead to an increase in thrust and a decrease in drag (Li, et al., 2017).

Turning flight is when an aircraft changes its flight direction, usually by rolling and yawing (Shen & Shen, 2009). This flight orientation can alter the fluid flow around the propellers, resulting in increased drag and decreased efficiency (Shen & Shen, 2009).

Any flight orientation that is not level, climbing, descending, or turning is considered manoeuvring flight (Li, et al., 2017). This can include various pitch, roll, and yaw combinations, such as looping, rolling, and spinning (Li, et al., 2017). This flight orientation can cause complex changes in the fluid flow around the aircraft, resulting in significant changes in propeller performance (Barthelmie, et al., 2010).

1.2 Problem Statement

Propellers, which are used to convert rotational energy into thrust, are critical components in the design and operation of aircraft, ships, and boats (Gibson, 2018). The shape and size of the blades, the rotation speed, and the fluid flow conditions all have an impact on propeller performance (Srensen et al., 2011). The flight orientation, or the position and attitude of the aircraft, ship, or boat during operation, is an important factor that influences propeller performance (Barras, et al., 2015). The measurement and comprehension of aerodynamic forces produced by propellers at various flight orientations is critical for propeller design and optimization for improved performance and efficiency (Coe, et al., 2018).

Previous research on the measurement of aerodynamic forces produced by propellers has primarily concentrated on propeller performance in a single flight orientation, typically level flight (Shen & Shen, 2009). In real-world operations, however, aircraft, ships, and boats may encounter a variety of flight orientations such as climbing, descending, turning, and manoeuvring (Li, et al., 2017). These different flight orientations can cause changes in the fluid flow conditions around the propellers, which can affect propeller performance (Barthelmie, et al., 2010). During a climb, for example, the angle of attack of the propellers increases, resulting in less thrust and more drag (Li, et al., 2017). Similarly, during a turn, the fluid flow around the propellers can become turbulent, reducing propeller efficiency (Shen & Shen, 2009).

Despite the importance of flight orientation on propeller performance, the aerodynamic forces produced by propellers at various flight orientations have received little attention (Barthelmie, et al., 2010). The inability of designers and engineers to optimise propeller performance and efficiency is hampered by a lack of understanding of the aerodynamic forces produced by propellers at various flight orientations (Coe, et al., 2018). As a result, research on the measurement of aerodynamic forces produced by propellers at different flight orientations is required to provide a better understanding of propeller performance in real-world operations (Li, et al., 2017).

1.3 Objective

In order to perform study on the measurement of aerodynamics forces produced by propellers at different flight orientation, the following objectives must be achieved:

i. To measure the aerodynamic forces produced by propellers at different flight orientations.

1.4 Scope of Study

i. The propulsion system uses a lithium polymer battery (3 – 4 cells).
ii. A carbon nylon propeller will be used for this experiment.
iii. This experiment uses a thrust stand series 1580 produced by RcBenchmark.

CHAPTER 2

LITERATURE REVIEW

2.1 Propeller Principle

A propeller is a mechanical device that converts rotational motion into thrust and is commonly found in various modes of transportation such as ships, aeroplane, and automobiles. A propeller's operation is based on converting the energy of a spinning shaft into the kinetic energy of a fluid, such as air or water. A propeller's basic design consists of a central shaft connected to an engine or motor, and a number of blades attached to the shaft. The blades move through the fluid as the shaft rotates, creating a force that propels the vehicle forward. The amount of thrust generated by the propeller is affected by the angle of attack of the blades, the shape of the blades, and the speed of rotation.

The angle of attack of the blades is one of the most important factors influencing a propeller's efficiency. The angle of attack is the angle at which the blade meets the fluid, and it influences how much lift and drag the blade generates. A positive angle of attack produces lift, whereas a negative angle of attack produces drag (Barlow, Rae, & Pope, 1996). A propeller's optimal angle of attack is typically around 15 degrees, and most propellers are designed to operate at this angle (Cumpsty, 2002). The angle of attack, on the other hand, does not remain constant throughout the rotation; it varies due to relative velocity and rotational velocity; this is known as the dynamic angle of attack, and it is a critical factor for high-speed propellers (Babinsky, 2014).

Another important factor influencing propeller efficiency is the shape of the blades. The shape of the blades is typically aerofoil in shape to minimise drag and maximise lift (Barlow et al., 1996). The amount of lift generated is also affected by the curvature of the blade, with a more curved blade producing more lift than a flatter blade (Abbott & von Doenhoff, 1959). Furthermore, the length of the blade influences the amount of lift produced, with a longer blade producing more lift than a shorter blade (Larrabee, 2013). However, the shape of the blades influences the noise level produced by the propeller (Keinar, 2018).

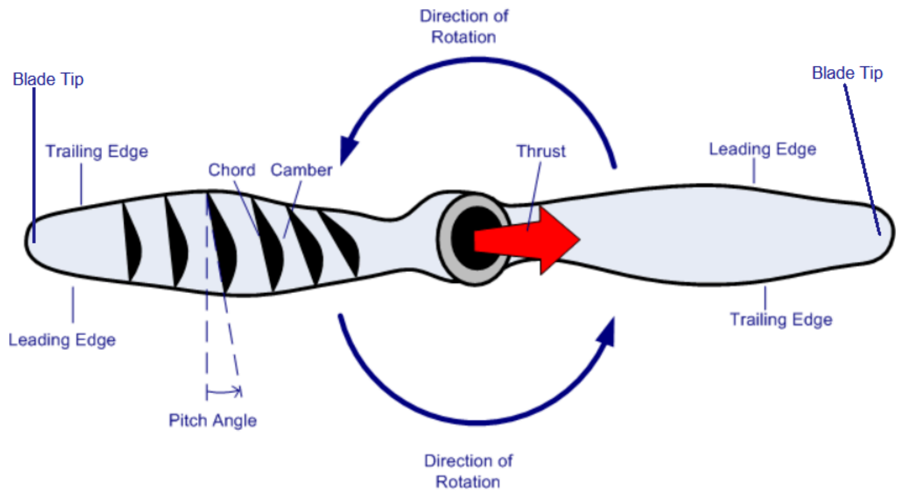
The rotational speed of a propeller is another important factor that influences its efficiency. The amount of thrust generated by the propeller increases as the rotational speed increases (Barlow et al., 1996). However, there is a limit to the amount of thrust that a propeller can generate, and at very high rotational speeds, the propeller may become less efficient (Larrabee, 2013). Furthermore, the speed of rotation affects the noise level produced by the propeller, with a faster rotation speed producing more noise (Keinar, 2018).

Propellers can also be classified according to the number of blades they have. Propellers with two or three blades are the most common, but propellers with four or more blades are also used. The number of blades affects propeller thrust and efficiency, with more blades generally providing more thrust but at the expense of decreased efficiency (Larrabee, 2013). Furthermore, the number of blades affects the noise level produced by the propeller, with more blades generally producing more noise (Keinar, 2018).

For many years, propeller design has been a research topic, and various design methods have been proposed to optimise propeller performance. The blade element theory, which is based on an analysis of the forces acting on each element of the blade, is one of the most commonly used methods (Larrabee, 2013). This method calculates the lift and drag coefficients for each element of the blade and allows for the angle of attack and shape of the blade to be optimised for maximum efficiency. Another method that has been proposed is the use of computational fluid dynamics (CFD) to simulate and predict the flow around the propeller (Zhong, Lu, & Chen, 2010). CFD enables detailed analysis of the fluid flow around the propeller and can be used to optimise propeller design for maximum efficiency and minimum noise.

In recent years, there has been a surge in interest in the use of advanced propeller materials, such as composite materials. Composites have several advantages over traditional materials, including increased strength and stiffness, reduced weight, and improved corrosion resistance (Larrabee, 2013). Furthermore, composites can be engineered to have specific properties, such as increased stiffness in specific areas to reduce blade vibrations. According to research, using composite materials in propeller construction can result in significant improvements in performance and efficiency (Khambadkone, Suresh, & Sivakumar, 2009).

Finally, active controls, such as variable pitch blades, can improve propeller performance. Variable pitch propellers allow you to change the angle of attack of the blades while the propeller is running. This enables the angle of attack to be optimised for different operating conditions, such as different speeds or altitudes (Larrabee, 2013). Furthermore, active controls can be used to reduce propeller noise by adjusting blade pitch to reduce the amplitude of the blade passing frequency (Keinar, 2018).



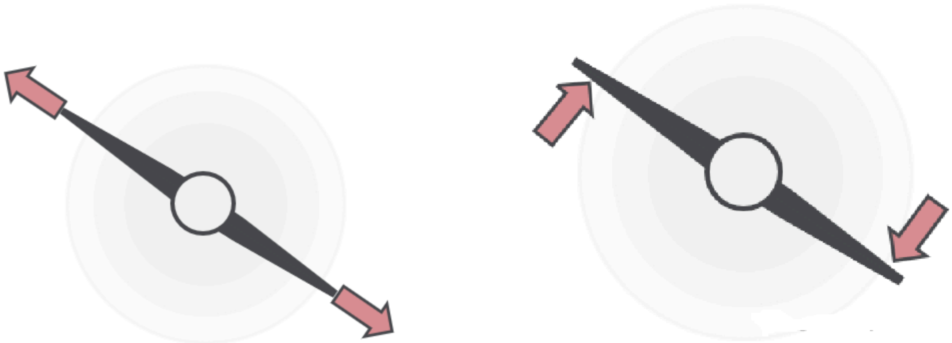
2.2 Forces Acting on a Propeller

In order to ensure that the design of the propeller is optimized to ensure maximum performance and efficiency, the forces acting on a propeller must be study in detail. Lift is one of the primary forces acting on a propeller. Lift is responsible for propelling the vehicle forward and is generated by the angle of attack of the blades and the shape of the blades. The angle of attack is the angle at which the blade meets the fluid, and it influences how much lift the blade generates. A positive angle of attack produces lift, whereas a negative angle of attack produces drag (Barlow, Rae, & Pope, 1996). A propeller's optimal angle of attack is typically around 15 degrees, and most propellers are designed to operate at this angle (Cumpsty, 2002). The shape of the blades is also important for producing lift, and it is typically aerofoil in shape (Barlow et al., 1996).

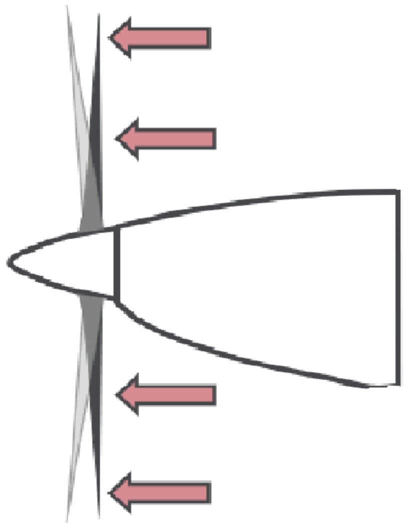
Drag is another important force acting on a propeller. The friction between the air or fluid and the blades causes drag, which acts in the opposite direction of the thrust. Drag is affected by the angle of attack of the blades, the shape of the blades, and the rotational speed. A positive angle of attack produces lift, whereas a negative angle of attack produces drag (Barlow et al., 1996). The shape of the blades, which is typically aerofoil in shape, is also important for drag generation (Barlow et al., 1996). The propeller's drag is also affected by its rotation speed, with faster rotation speeds producing more drag (Barlow et al., 1996).

The air or fluid in which a propeller operates also has an effect on the forces acting on it. The fluid in the case of marine propellers is water, and the forces acting on the propeller are influenced by its density, viscosity, and velocity (Larrabee, 2013). The fluid in the case of aircraft propellers is air, and the forces acting on the propeller are influenced by its density, viscosity, and velocity (Cumpsty, 2002).

Torque, bending moments, and centrifugal forces are all forces that act on a propeller in addition to lift and drag. Torque is the rotational force produced by the engine or motor and is responsible for propeller rotation. Bending moments are caused by weight and aerodynamic loads acting on the blades, and they can cause the blades to deform or fail if not properly designed to withstand these loads. The rotation of the propeller generates centrifugal forces, which can cause the blades to expand radially. These forces must be considered in the design and optimization of the propeller to ensure proper operation and longevity.

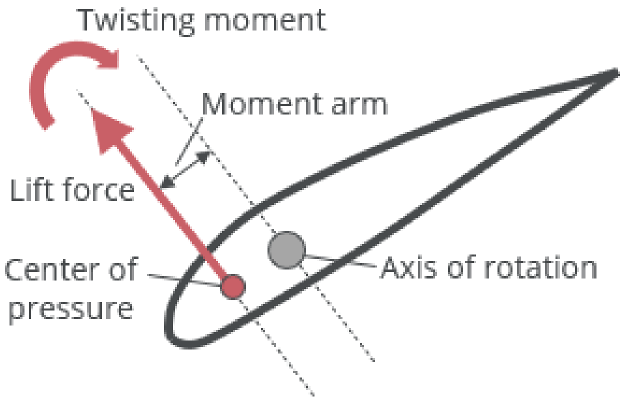


Thrust bending is a phenomenon that occurs in propellers when the thrust force acts on the blades, causing them to bend. This bending moment can cause the blades to deform, resulting in decreased propeller performance and efficiency. Understanding thrust bending dynamics is critical for propeller design and optimization for maximum efficiency and performance.



The difference in thrust force acting on the blades is one of the primary causes of thrust bending. The thrust force acting on the blades is not uniform, and this difference causes the blades to bend. This difference in thrust force is caused by factors such as blade angle of attack and blade shape (Barlow, Rae, & Pope, 1996). A propeller's optimal angle of attack is typically around 15 degrees, and most propellers are designed to operate at this angle (Cumpsty, 2002). However, the angle of attack is not constant throughout the rotation, it varies due to the relative velocity and the rotational velocity, this is known as the dynamic angle of attack which is a crucial factor for high-speed propellers (Babinsky, 2014). Another important factor that affects thrust bending is the speed of rotation of the propeller. As the speed of rotation increases, the thrust force acting on the blades also increases, which leads to an increase in thrust bending (Barlow et al., 1996)

Aerodynamic twisting is a propeller phenomenon in which the angle of attack of the blade’s changes along the length of the blade. This change in angle of attack is caused by the variation of the blade's relative velocity and rotational velocity as it moves through the fluid, resulting in a twisting motion of the blade. Aerodynamic twisting can reduce propeller performance and efficiency while also increasing noise and vibrations. Understanding the dynamics of aerodynamic twisting is critical for the efficient and effective design and optimization of propellers.



The difference in relative velocity and rotational velocity of the blade as it moves through the fluid is one of the primary causes of aerodynamic twisting. The relative velocity is the velocity of the fluid in relation to the blade, and it varies along its length. The rotational velocity is the velocity of the blade as it rotates, and it varies along its length. The difference in these velocities causes a change in the blade's angle of attack, which is known as the dynamic angle of attack (Babinsky, 2014). This dynamic angle of attack is critical for high-speed propellers because it affects propeller performance by changing lift and drag forces acting on the blade (Babinsky, 2014). Another important factor that affects aerodynamic twisting is the speed of rotation of the propeller. As the speed of rotation increases, the relative velocity and rotational velocity of the blade also increase, leading to an increase in aerodynamic twisting (Barlow et al., 1996).

2.3 Multicopter

A multicopter, also known as a quadcopter or a drone, is a type of aircraft with multiple rotors. These rotors provide lift and propel the multicopter, allowing it to fly in a stable and controlled manner (Barlow, Rae, & Pope, 1996). A multicopter's anatomy includes several key components such as the frame, motors, propellers, electronic speed controllers (ESCs), flight controller, and battery.

A multicopter's frame is the structure that holds all of the other components in place. The frame is typically constructed of lightweight materials such as aluminium or carbon fibre, and it must be strong enough to withstand the forces generated by the rotors while in flight (Larrabee, 2013). The battery and flight controller are also housed in the frame, which are key components that control the flight of the multicopter.

A multicopter's motors provide the rotational energy that spins the propellers, creating lift and propulsion. Brushless DC motors are commonly used because of their high efficiency and dependability (Larrabee, 2013). The motors are attached to the frame via a series of brackets and are controlled by electronic speed controllers (ESCs), which regulate motor speed.

Propellers are the multicopter's main lifting surfaces; they convert the rotational motion of the motors into thrust and are responsible for lifting the multicopter into the air (Barlow et al., 1996). The number of propellers, their size, and shape are all important factors that influence the multicopter's performance and efficiency.

The electronic speed controllers (ESCs) are in charge of controlling the motor speed. They receive commands from the flight controller and adjust the motor speed accordingly (Larrabee, 2013). They also allow the multicopter to rotate, move forward and backward, and move laterally by controlling the direction of the propellers.

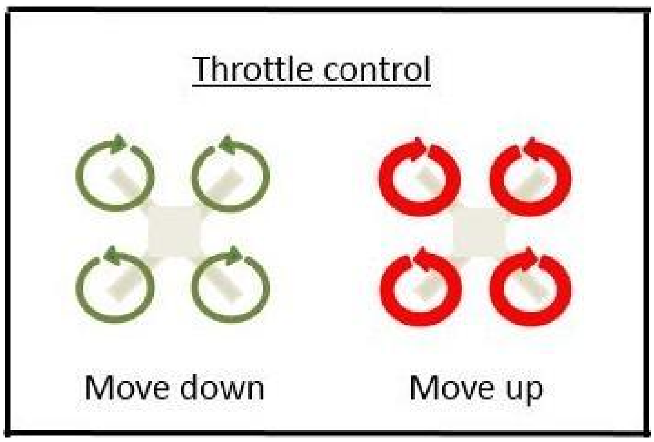
The flight controller is the multicopter's brain; it is in charge of controlling the multicopter's flight by receiving input from various sensors such as accelerometers, gyroscopes, and GPS (Larrabee, 2013). The flight controller also receives commands from the pilot and sends commands to the multicopter's motors and ESCs to control its flight.

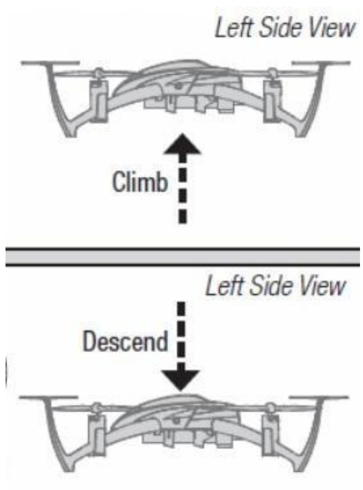
Finally, the battery is the power source for the multicopter. It provides the energy to the motors and other electronic components, and it must be able to supply enough power for the duration of the flight (Larrabee, 2013). The battery is typically a lithium polymer (LiPo) battery, which is known for its high energy density and low weight.

2.4 Flight Orientation of Propeller

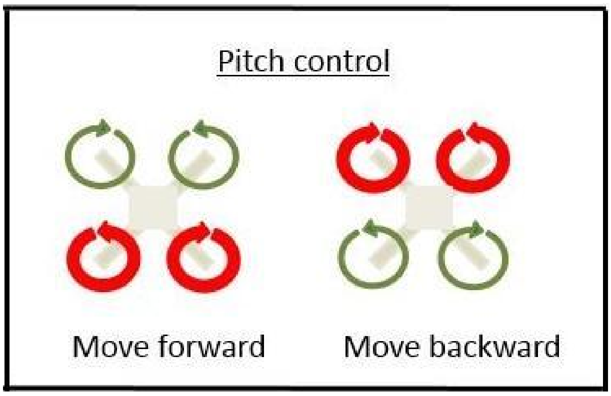
Flight orientation, also known as aircraft attitude, refers to an aircraft's position and orientation in relation to the earth. The flight orientation of a propeller-driven aircraft is determined by four primary control inputs: throttle, pitch, roll, and yaw. Each of these controls is critical to the aircraft's operation and stability.

Throttle controls the engine's power output, which affects the aircraft's speed and altitude. The pilot can adjust the engine's power output and thus control the aircraft's speed and altitude by increasing or decreasing the throttle (Abbott & von Doenhoff, 1959).

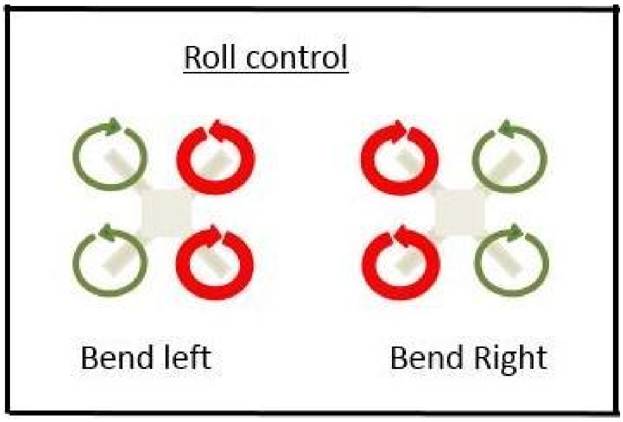




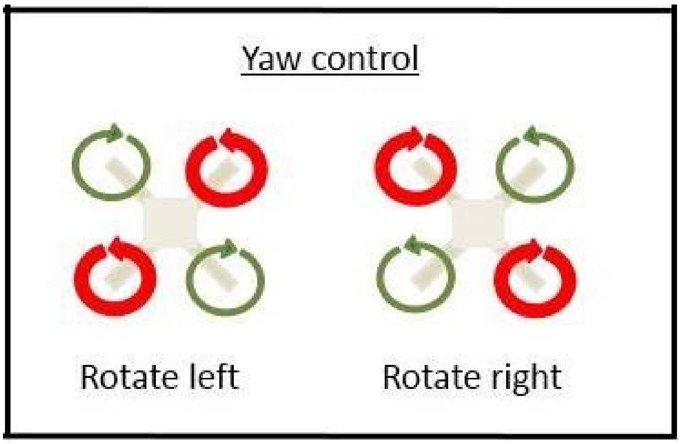
The angle of attack of the propellers is controlled by pitch, which affects the lift force generated by the propellers. The pilot can change the pitch of the propellers to increase or decrease lift force, allowing the plane to climb or descend (Barlow et al., 1996).The rotation of the aircraft around its longitudinal axis is controlled by roll.

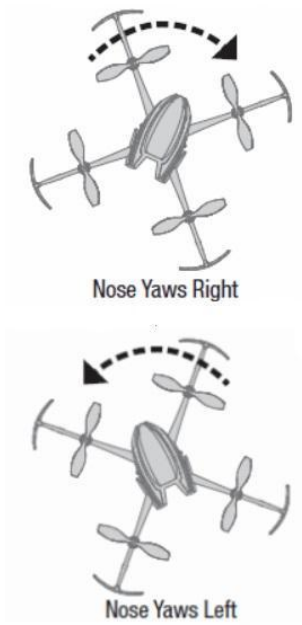


The pilot can roll the aircraft to the left or right, causing the aircraft to bank and change course (Cumpsty, 2002).



The rotation of the aircraft around its vertical axis is controlled by yaw. The pilot can yaw the aircraft to the left or right, causing it to turn and change course (Larrabee, 2013).





Controlling these flight orientations correctly is critical for the safe and efficient operation of propeller-driven aircraft. If the pilot does not maintain proper pitch control, for example, the aircraft may stall and lose altitude. Similarly, if the pilot fails to maintain proper yaw control, the aircraft may deviate from its intended path and become disoriented (Zhong, Lu, & Chen, 2010).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the methodology used to achieve the objective that is to measure the aerodynamic forces produced by propellers at different flight orientations. Information and results gathered during the preliminary experiment will be used for further analysis.

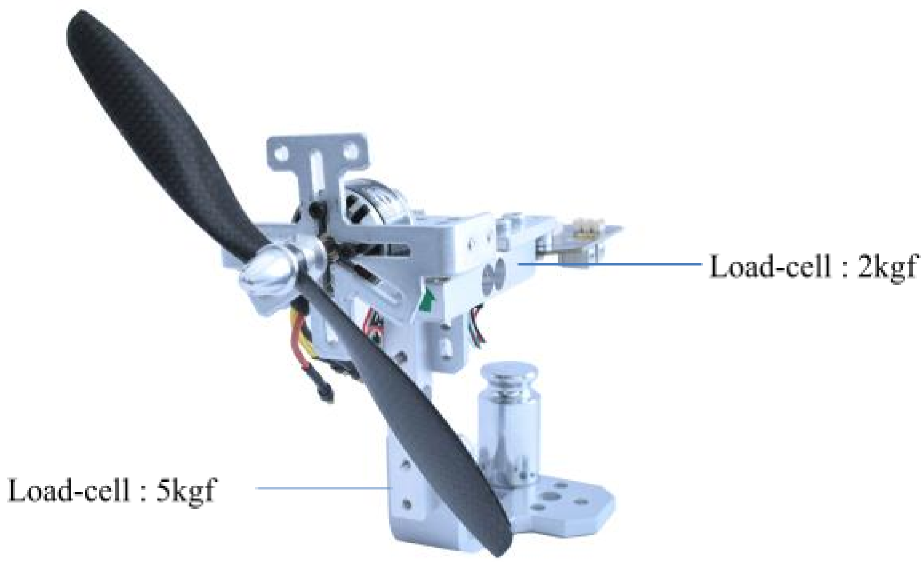
3.2 Installation and Assembly of Experimental Set-up

The main components used for this preliminary experiment are:

i. RcBenchmark Series 1580 Thrust Stand
ii. Nylon Propeller (6 x 4 inches)
iii. Brushless DC Motor (KS2400)
iv. Lithium-Polymer Battery (3-4S)
v. Electronic Speed Controller (ESC)

3.2.1 RcBenchmark Series 1580 Thrust Stand

RcBenchmark Series 1580 Thrust Stand is used in this experiment to collect data on the force produced by propeller. It consist of hardware and software. The main part which measures the forces such as thrust and torque in this device is the load-cell. There are 3 load-cell in this particular series of thrust stand. One is installed vertically which has maximum capacity of 5kgf. Another 2 load-cell is installed horizontally, where each unit holds maximum capacity of 2kgf.



Specification	Minimum	Maximum	Tolerance	Unit
Thrust	-5	5	0.5% ± 0.001	kgf
Torque	-1.5	1.5	0.5% ± 0.001	Nm
Voltage	0	50	0.5%	V
Current	0	55	1%	A
Burst Current	0	60		A
Angular Speed	0	190 000	1	eRPM
Coil Resistance	0.003	240	0.5%	Ohm
Digital Scale	0	3	0.5%	kgf

3.2.2 Nylon Propeller

Nylon propeller is used in this experiment to prioritize safety. This is because some propellers have very sharp edges especially plastic and fibre-glass propellers which are not suitable for a study based experiment. Nylon propeller is flexible. A 2-blade propeller is used for this experiment.

3.2.3 Brushless DC Motor

The brushless DC motor used in this experiment is the SunnySky X2216 which is a short shaft version. The motor is processed by CNC miling and is a light weight model.

Stator Diameter	22mm	Rotor Diameter	27.5mm
Stator Thickness	16mm	Shaft Diameter	3.175mm
No. of Stator Slots	12	Body Length (Without Shaft)	34mm
No. of Rotor Poles	10	Body Length	36.5mm
Motor Kv	2400	Max Lipo Cell	3-4S
No-load current	1.7A/10V	ESC	60A
Motor Resistance	29mΩ	Recommended Prop (inch)	APC6040
Max Continuous Current	40A/30s	Weight for tail-pushed Aerobatics	650g (4S APC6040)
Max Continuous Power	710W	Weight	67g

3.2.4 Lithium-Polymer Battery

Lithium-Polymer battery or best known as lithium-ion polymer battery is a rechargeable battery. The battery is used to power the motor while conducting the experiment. The maximum usable voltage of this battery is 11.1V and it has to be recharged before using again.

Brand	Infinity
Capacity	2200 mah
Continuous Discharge	85 C
Number of Cells	3
Weight	188g
Voltage	11.1 V
Dimension L x W x H	24 x 32 x 105mm

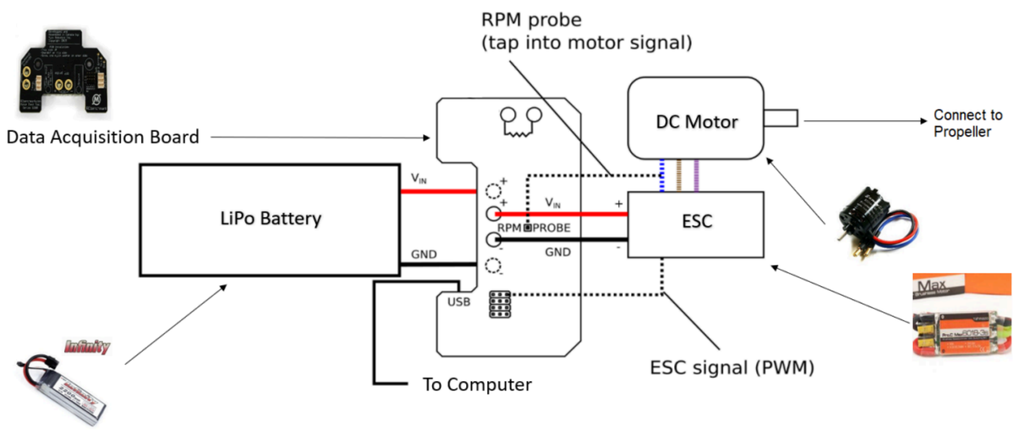
3.2.5 Electronic Speed Controller (ESC)

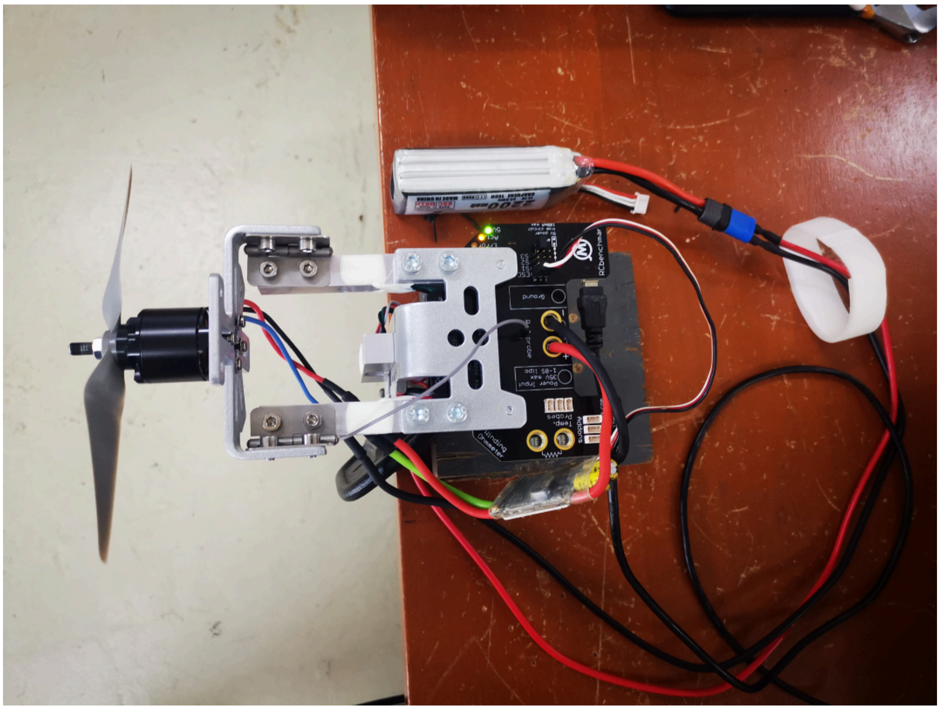
An Electronic Speed Controller (ESC) was used for this preliminary experiment. The ESC is used to control the power output and rotational speed of the motor in response to the throttle instructions.

Brand	: Tahmazo
Model	: Pro.C Max 6018-3s
Continuous Current	: 60 A
Max Current (for 15s)	: 70 A
Dimension L x W x H	: 66 mm x 25 mm x 10 mm
Weight	: 49 g
BEC Voltage, Current	: 5.5 v, 3 A (peak 5 A)
Switching Frequency	: 32 kHz
No. of Nicad/NiMh Cells	: 6 – 18
No. of Li-Ion/Li-Po Cells	: 2 – 6
Internal Resistance	: 0.86 Ohm

3.2.6 Experimental Set-up

All the components listed above is assembled thru connection as shown below:





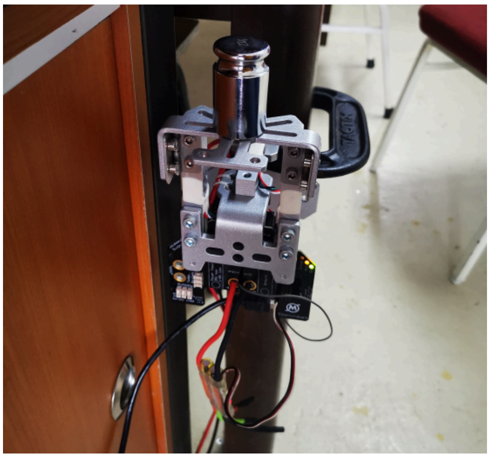
3.3 Calibration

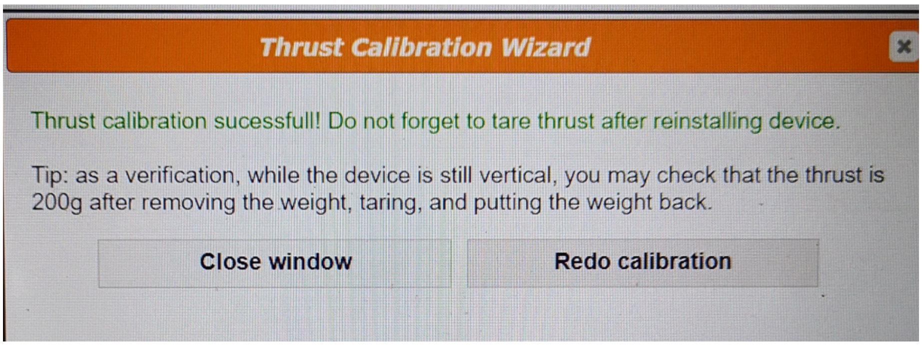
3.3.1 Thrust Calibration

i. First, the RcBenchmark software is installed in laptop and the USB is connected to the stand. Then, click the Utility tab on the software interface.

ii. The assembled thrust stand, without the motor and propeller is placed vertically using a g-clamp. All fasteners are made sure to be tight and secure.

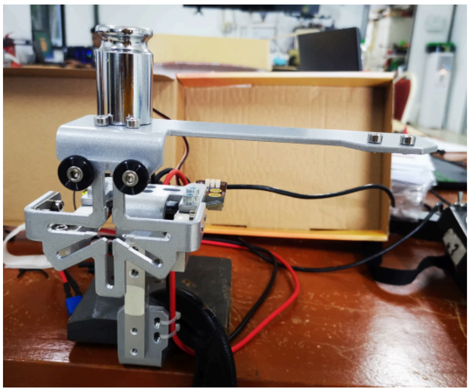
iii. 200g weight is placed on the motor mount as per instruction thru the software interface.
iv. As the next step, the weight is removed from the motor mount.
v. If the calibration is successful, move to torque calibration, if unsuccessful, steps (i) to (iv) are to be repeated.

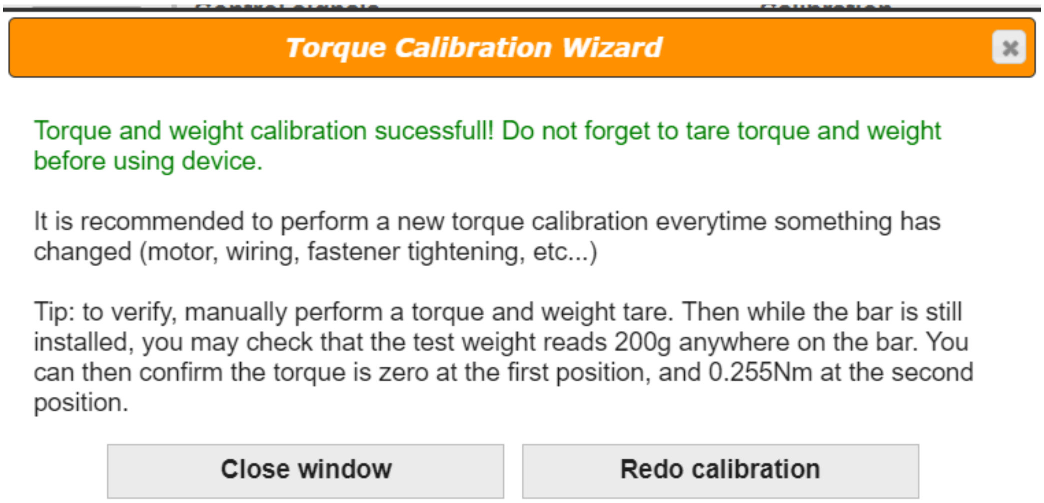




3.3.2 Torque Calibration

i. The stand is placed in a horizontal/normal position and secured with g-clamp. The horizontal bar is fastened to the motor mount and made sure is in perfectly horizontal position. A bubble level can be used to check it.
ii. Then, the 200g weight is placed tangentially to the two screw on the horizontal bar near to the motor mount.
iii. As the next step, the weight is then moved to the opposite of the horizontal bar.
iv. If the calibration is successful, move to torque calibration, if unsuccessful, steps (i) to (iii) are to be repeated.



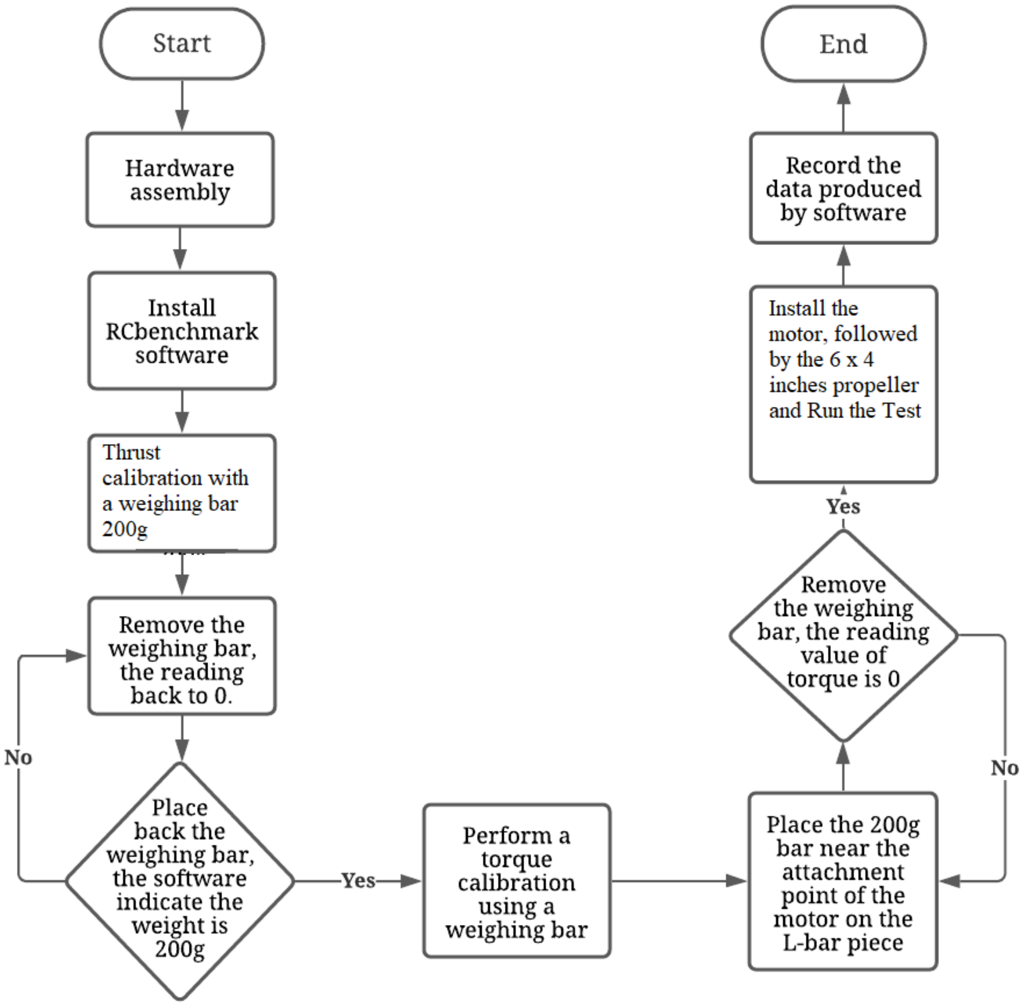


3.4 Method of Experiment

When all calibration are done, the system will show the tare value of 0 (zero). Then, the motor and propeller can be mounted but done with care as too much of pressure may affect the calibration. The preliminary experiment is done by running the test with propeller 6 x 4 inches for a start. Data is collected thru the system.

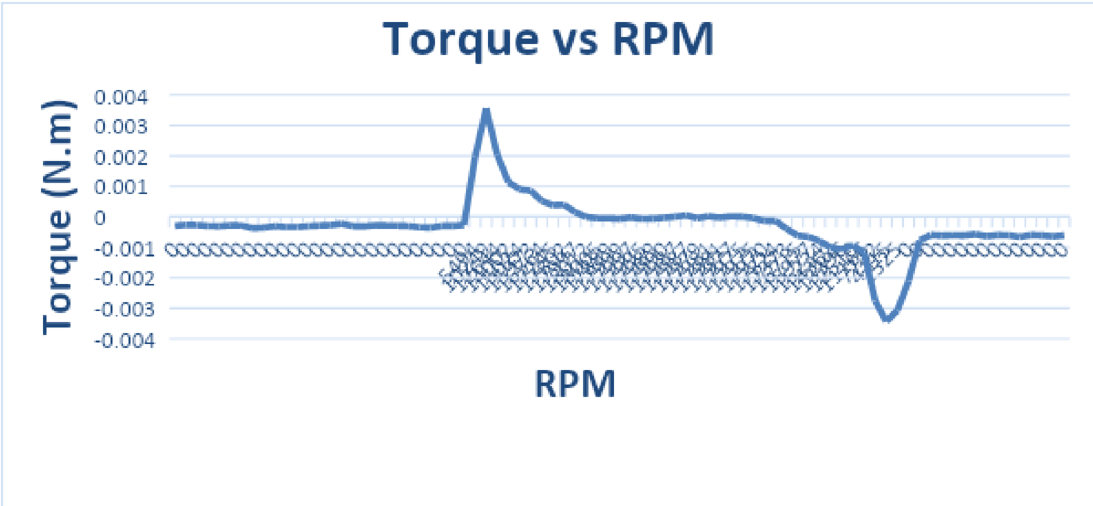
3.4.1 Flowchart

Flow chart below shows the methodology used in this preliminary experiment in order to fulfill the objective.

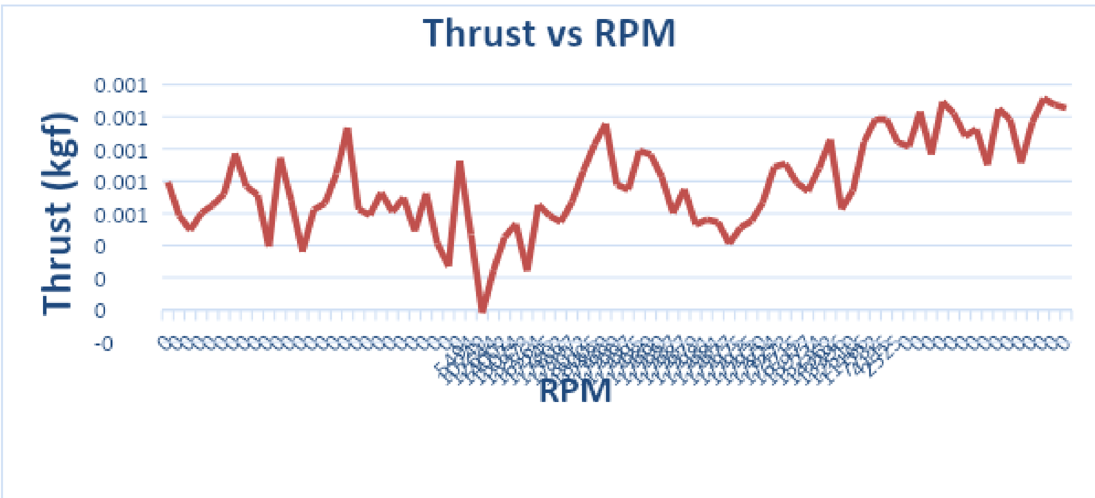


3.5 Data Extraction

3.5.1 Torque (N.m) vs RPM



3.5.2 Thrust (kgf) vs RPM



From the graphs above, both the trend shows that the result is unstable. The forces exerted on the propeller is fluctuated. However, from the torque vs RPM graph, the trend shows a steady increase at period of approximately 5000rpm until 13000 rpm.

CHAPTER 4

CONCLUSION

This study aimed to determine measurable aerodynamic forces produced by propeller at different flight orientation. However, there is no source of comparison to analyze more aspects as only procedures of experiment was focused for UPG 1. In order to achieve these objectives, several analytical calculation and experiment is planned to be done. I hope I will be able to continue to increase my knowledge in the field during UGP 2.

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Appendix A