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Analysis on Propeller Design for Medium-Sized Drone (DJI Phantom 3)

Mohammad Iqmal Mohd Ali, Azri Nazarain Afandi, Ahmad Maulan Bardai

Abstract: ***Unmanned aerial vehicles, UAV, has increases in the drastically in these past several years because of their reliability, cost effectiveness and multi-functionality. Stage, research has been made on quadcopter by worldwide researchers. The 3D model of propeller blade of the drone was created using CATIA with dimension. Computational Fluid Dynamics (CFD) software is used in this project to analyze the effect of different shape of propeller. There are 3 type of propeller that used in this project which is normal propeller, bullhorn propeller and hybrid bullhorn propeller. The focus of this project is to study and identify the best propeller design for specific drone which is DJI Phantom 3. There is certain parameter is kept constant which are the velocity of the wind, the propeller shape and the RPM of the propeller. The data will be collected to make comparison between the type of design. The best design will be chosen based on good in lift and drag coefficient. These data will be compared among of three propellers to know which one has the best performance.***

Keywords: UAV, propeller design, computational fluid dynamics, DJI Phantom 3

I. INTRODUCTION

General introduction

Nowadays, drones have been phenomenal in being a trendy gadget owned by millions od people around the globe. Originally developed for military and research purposes, they have been further developed to be readily available and user-friendly not only for professional tasks, but also for entertainment and recreational purposes. Just like how researchers have been rapidly focusing more on improving aviation-related technology [1-9], procedures [10-13], and intellectual concepts [14-19] quite recently, drone developmental studies are no exception. Hence, this research will focus one specific part of a drone – the propellers.

Research Objectives

Propeller size and design play important roles in getting thrust. Thus, the purpose of this study is to identify the best propeller design for specific size of drone which is DJI Phantom 3 drone. Furthermore, with the best design of propeller makes the drone fly smoothly. To get the best propeller design, Computational Fluid Dynamics (CFD) software being used. The result gain from CFD software will be compared in term of thrust and drag coefficient and the best propeller will be chosen.

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Mohammad Iqmal Mohd Ali, Universiti Kuala Lumpur, Malaysian Institute of Aviation Technology, Dengkil, Selangor, Malaysia

Azri Nazarain Afandi, Universiti Kuala Lumpur, Malaysian Institute of Aviation Technology, Dengkil, Selangor, Malaysia

Ahmad Maulan Bardai, Universiti Kuala Lumpur, Malaysian Institute of Aviation Technology, Dengkil, Selangor, Malaysia

II. LITERATURE REVIEW

Airfoil

Airfoil that is placed in a stream of air will produce two forces that is perpendicular to the direction of air. The force that goes upward is called lift, the lift force must overcome or greater than the weight for it to generate lift. This lift depends on the relative velocity of air and the angle of attack [20].

To calculate the lift, if the lift coefficient (Equation 1) of an airfoil (wing) at a specified angle of attack is given, it can be determined by using the equation:

$$L = \frac{1}{2}\rho v^2 A C_L$$

Equation 1: lift coefficient

Where,
L = lift force,
ρ = air density,
v = true airspeed,
A = planform area, and
CL = lift coefficient at the desired angle of attack

Quadcopter

Quadcopters can be described as a small vehicle with four propellers attached to rotor located at the cross frame. This aim for fixed pitch rotors is used to control the vehicle motion. The speeds of these four rotors are independent. By independent, pitch, roll and yaw attitude of the vehicle can be control easily. Pitch, roll and yaw attitude off Quadcopter are shown in Figure 1 [21].

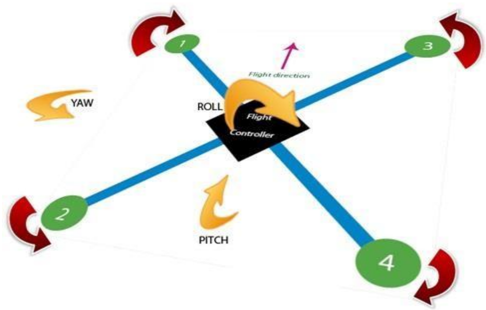

Fig. 1 Movement of a quadcopter

Early propellers, or those designed before the end of the Second World War, were designed using an empirical approach.

One such example of this approach is documented in National Advisory Committee on Aeronautics (NACA) Technical Note (TN) 212 (Weick, 1925), which allows for a propeller to be designed for a light aircraft by calculating it.

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The coefficient (Equation 2), J, is the advance ratio of a propeller and is defined as:

$$J = \frac{V}{nD}$$

Equation 2: advance ratio of propeller

Where,
V= aircraft speed,
n= revolutions per second
D= propeller diameter

Summary

Based on the two equations above added with other considerations regarding the design such as propeller types, possible designs, possible types of forces that would interact with the propellers (e.g. thrust bending, centrifugal, aerodynamic twisting, centrifugal twisting, etc.), researchers would proceed with computational fluid dynamics (CFD) software, CATIA, to start designing the propellers.

III. METHODOLOGY

Design Planning

Designing propeller blade is created using CATIA mechanical design software with standard 3D product design by addressing advance process and productivity tools as a requirement mechanical industry. CATIA is choose due to the ability of their tools to promote best practice design that follow industry and company standard. CATIA has highly productive for mechanical assemblies and drawing generation which allows to design faster than other software.

In this project, the propeller with diameter of 9.4 inch were used. This propeller size was chosen because it works perfectly with the DJI Phantom 3 motor. Three designs of propeller were proposed by taking the propeller dimension to draw the propeller model and analyze the thrust and drag coefficient using CFD software.

In this study, simple propeller design was used. The measurement does not follow any actual drone propeller. The simple propeller is use because the purpose of this project only to study the characteristic of various propeller design. By using simple propeller, the result can be seen clearly. NACA airfoil 16-913 is used to make the propeller blade. NACA airfoil 16-913 have the max thickness 13% at 50% chord and the max chamber 9% at 0% chord.

Creating 3D model of propeller

Three (3) shapes of propellers were chosen to be made: normal propeller, hybrid bullnose propeller and bullnose propeller.

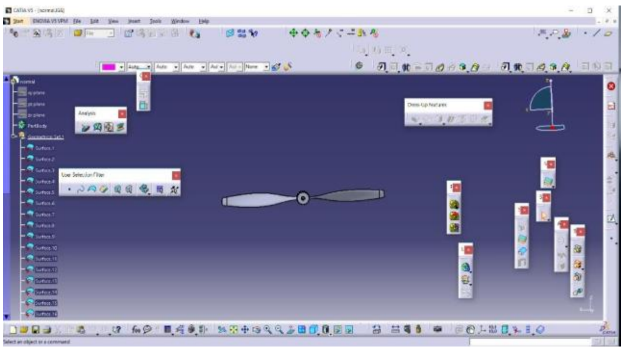

Fig. 2 Normal propeller

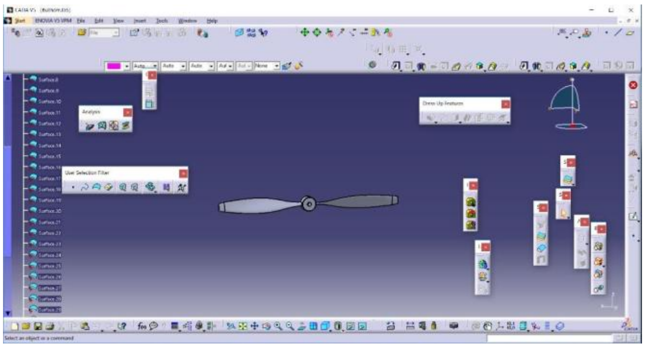

Fig. 3 Bullnose propeller

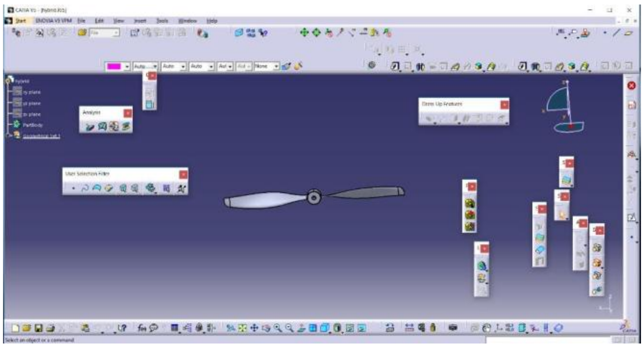

Fig. 4 Hybrid bullnose propeller

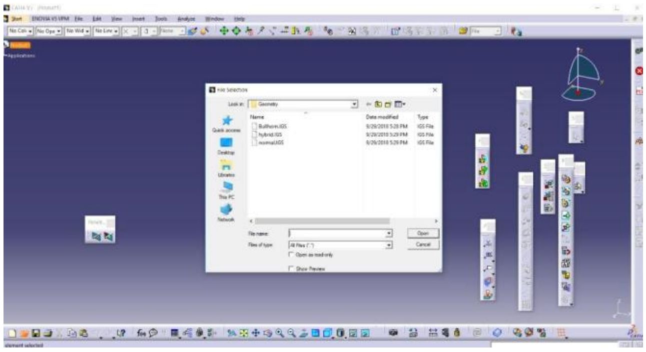

Fig. 5 *igs file format

Computational Fluid Dynamics software

Different methods are available to determine propeller performance, including experimental and numerical analysis. In the experimental method, the propeller blade is tested in a wind tunnel for both static and advancing flow conditions. Meanwhile, numerical analysis adopts three-dimensional computational fluid dynamics (CFD) simulation, utilizing the Reynolds-average Navier–Stokes (RANS) equation. CFD methods have become significant and highly useful tools for propeller design and analysis. Furthermore, Ansys software being use for this project because it is one of the most powerful tools to determine flow properties. In this experiment, the lift and drag coefficient can be determined through this software. The rotational speed of the propeller in this research were fixed to KV 800 rpm/v which means equal to the DJI phantom 3 drone motor. This test runs on different airspeed parameters which are 5/m/s, 10m/s, 15m/s, 20m/s, 25m/s, 30m/s, 35m/s, 40m/s, 45m/s and 50m/s.

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Ansys software

Step 1: Import the propeller *igs file into ansys workbench.
Step 2 : Create the boolean and enclosure for the propeller.

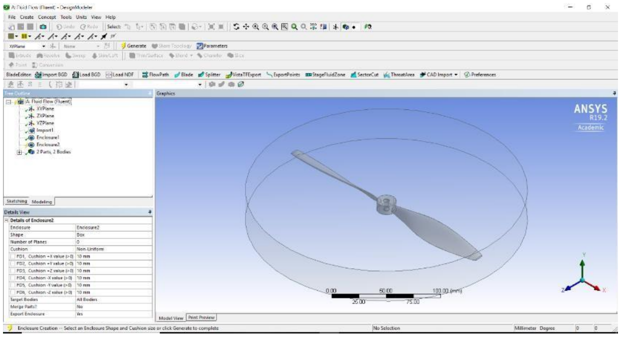

Fig. 6 Creates enclosure 1

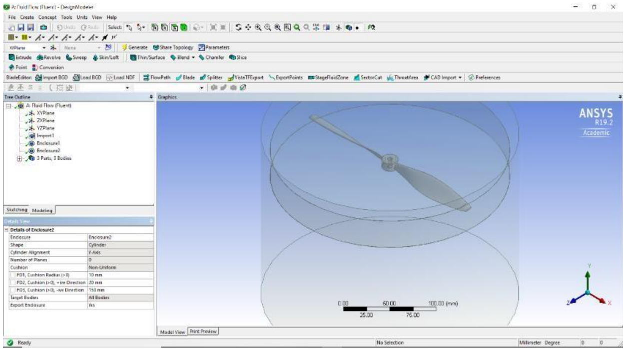

Fig. 7 Creates enclosure 2

Step 3: Meshing the propeller. The meshing can be set with variable size of interval count. The smaller the size of particle/division, the more accurate result will be obtained.

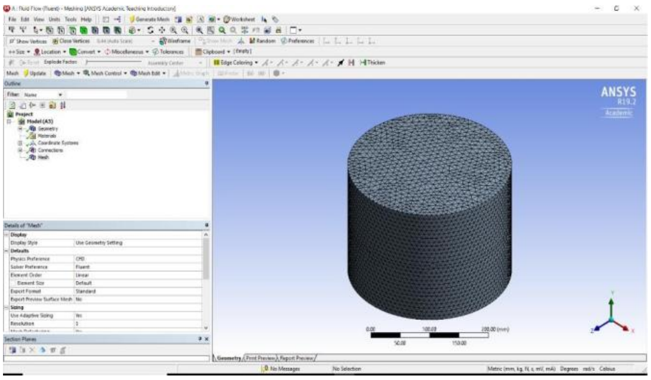

Fig. 8 Meshing

Step 4: Run the fluent program.

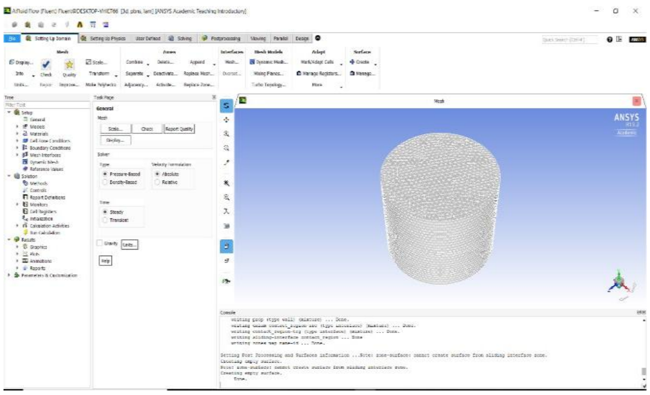

Fig. 9 Fluent program

Step 5: Enter and select the parameters in order to run the analysis to get the result. The rotational speed of the propeller in this research were fixed to 800 rpm. The test is run on different airspeed parameters which are 5m/s, 10m/s, 15m/s, 20m/s, 25m/s, 30m/s, 35m/s, 40m/s, 45m/s and 50m/s.

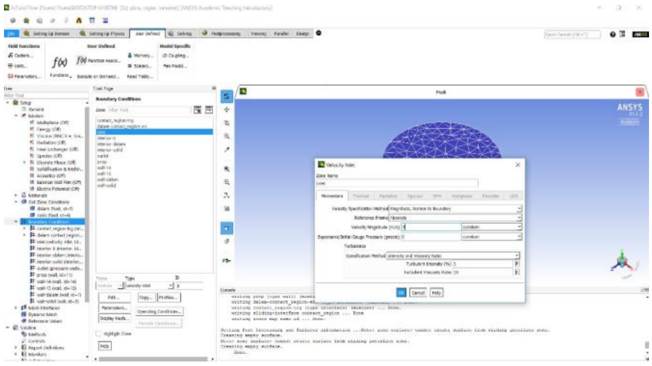

Fig. 10 Insert airspeed

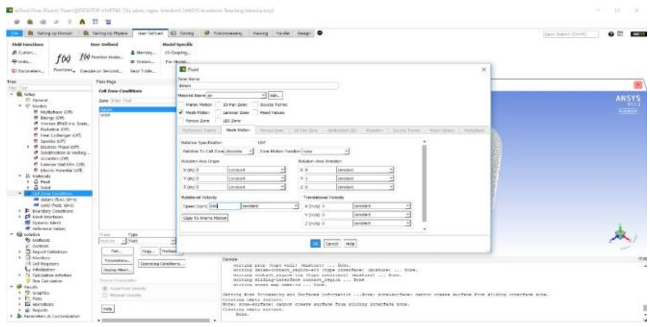

Fig. 11 Rotating value of propeller (800 rpm)

Step 6: Run the analysis. Take the value of the coefficient of lift and drag at the post result forces.

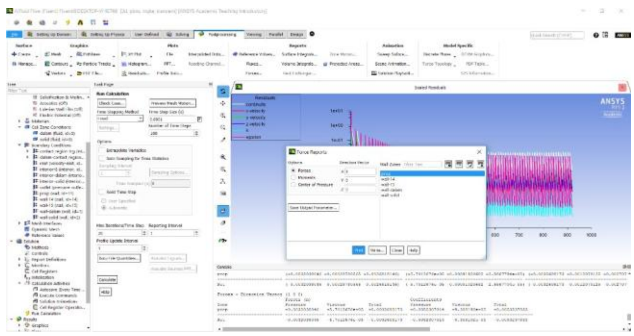

Fig. 12 Value of drag coefficient

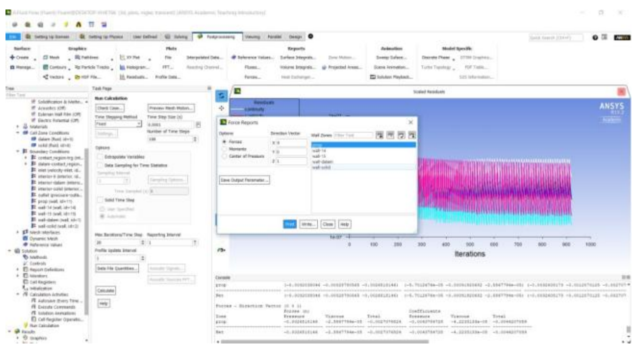

Fig. 13 Value of lift coefficient

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Lift and drag coefficients

Lift coefficient is a dimensionless coefficient that relates the lift generated by a lifting body to the fluid density. The lift coefficient is defined by:

$$C_L = \frac{L}{\frac{1}{2}\,\rho\, V^2\, S_{ref}}$$

Equation 3: lift coefficient

Where,
L = lift force,
P = the density,
V = the airspeed, and
S = the area

Drag coefficient (C_D) is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment. The drag coefficient (C_D) is defined by:

$$C_D = \frac{D}{\frac{1}{2}\rho v^2 S}$$

Equation 4: drag coefficient

Where,
D = the drag force,
P = the density,
V = the airspeed, and
S = the area

Lift over drag ratio is important in this research to determine which propeller have best characteristics. This ratio is calculated from coefficient of lift/coefficient of drag as the result in fluent.

IV. ANALYSIS

Coefficient of lift and drag of the propeller

Coefficient of lift

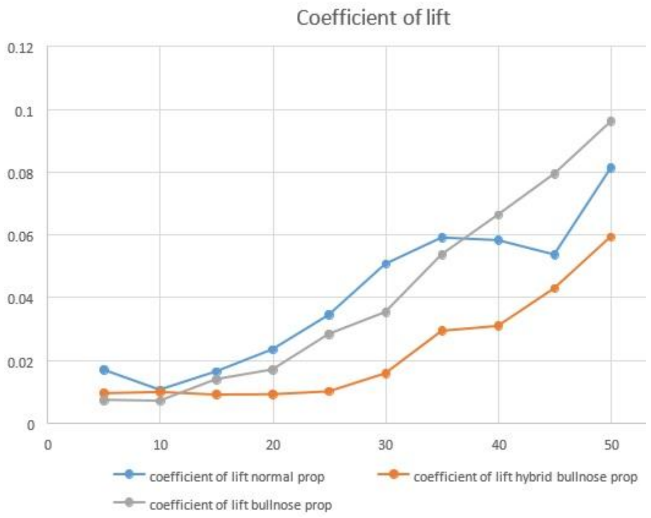

Fig. 14 Coefficient of lift VS air speed

Figure 14 shows the graph of coefficient of lift vs airspeed. From the graph above, bullnose propeller has the lowest lift coefficient followed by the hybrid bullnose and normal propeller at 5m/s. At airspeed of 10 m/s, normal and hybrid bullnose propeller gain almost the same value of lift coefficient.

The normal propeller produces highest lift coefficient from airspeed of 5m/s to 35m/s while bullnose propeller gains the highest lift coefficient at high airspeed which begin from 40 m/s to 50m/s. Meanwhile the pattern on the graph shows that hybrid bullnose propeller has the lowest value of lift coefficient starting from 15m/s and above. In addition, there are drop amount of lift coefficient for normal propeller at 40 m/s and 45 m/s.

Coefficient of drag

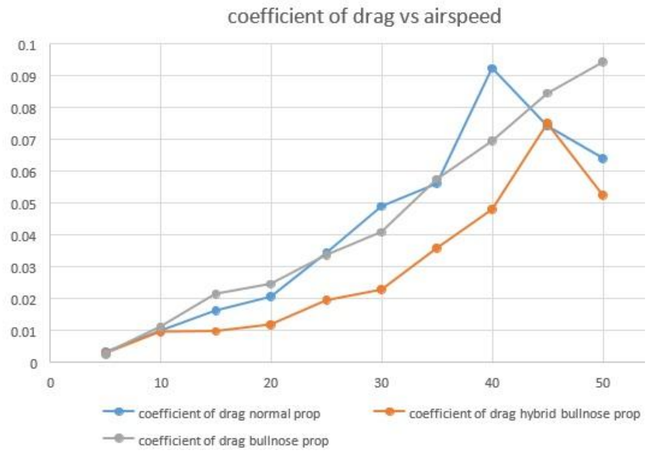

Fig. 15 Coefficient of drag VS airspeed

Figure 15 shows the graph of the drag coefficient vs airspeed. Based on the graph, normal propeller produced the highest value of drag coefficient at 25m/s, 30m/s and 40m/s. At low airspeed which is 5m/s and 10m/s, the value of the drag coefficient for all type of propeller almost at the same value. The hybrid bullnose propeller created the lowest value of drag coefficient between others. This propeller has shown that from airspeed 10m/s to 40m/s, the drag coefficient that gain is at the lowest from normal and bullnose propeller. At high airspeed, bullnose propeller gains the highest amount of drag coefficient followed by normal propeller and hybrid bullnose propeller. Figure 15 shows that the value of drag coefficient for normal and hybrid bullnose propeller tend to decrease at high airspeed.

Discussion

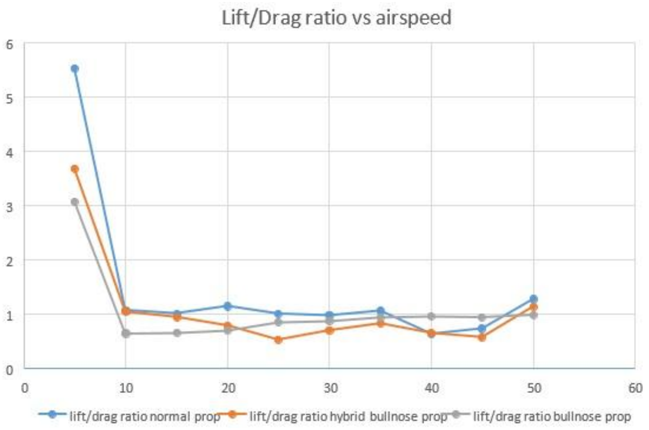

Fig. 16 Lift/Drag ratio VS airspeed

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After all type of propeller being tested, the best propeller was chosen. From the result gained, normal propeller is the best propeller design in this experiment since this propeller gain the highest value coefficient of lift from airspeed of 5m/s to 35m/s and lowest drag coefficient. In addition, this propeller also gains the highest value of drag coefficient at high airspeed. This means that normal propeller gains more lift in this study and its shown that this propeller creates higher differential pressure between back side and front side of the propeller. Higher differential pressure will create higher lift forces for the propeller.

Furthermore, hybrid bullnose has the lowest value of drag coefficient which is good, but the amount of lift coefficient is lower than another propeller. For bullnose propeller, at 5m/s value of lift coefficient that gained are low from other propeller type which means low lift created but its start to increase when going to high airspeed. From Figure 15, bull-nose propeller has higher value of drag coefficient below 25m/s.

Lift/drag ratio value vs airspeed graph has been shown in Figure 16. Figure 16 is corresponding to the efficiency of the propeller. From the graph above, normal propeller has the highest lift/drag ratio value at 5m/s compared to bullnose and hybrid bullnose. Normal propeller also gains the highest lift/drag ratio at 5m/s to 35m/s. The value of lift/drag ratio almost have the same value for these three-design propellers at 30m/s, 45m/s and 50m/s.

Normal and hybrid bullnose propeller give large effect on term of lift/drag ratio compared with bullnose propeller at 5m/s. Airspeed that being set is just for experiment purpose to study the characteristic of various propeller design. From the graph above, it shows that various propeller design does not give much differences on the lift/drag ratio of the pro-peller at higher airspeed.

V. CONCLUSION

From this experiment, the front side of propeller is the place which low pressure and high velocity occurred. Fur-thermore, the high pressure and low velocity occurred at the back side of propeller. When there is pressure difference between two sides, the lift will be created. The higher the differential pressure, the higher amount of lift created.

From the data collected, all three propellers have their own lift and drag coefficients. This shows that the shape of propeller plays important roles in gaining thrust and drag. The best propellers are the one that produce high amount of lift and low amount of drag. The best propeller for this ex-periment is normal propeller because it has higher amount of lift coefficient and lowest amount of drag coefficient. Figure 16 also shows that this propeller has the highest lift/drag ratio from compared to the other two propellers.

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