Experimental study of UAV propeller Thrust generation for various Propeller Blade-Span and the relation with mouth-ring

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Abstract. In this study, the main focus is to investigate the thrust generation of various propeller blade width-spans with the relation of mouth-ring application. By using the parameter, the thrust was calculated based on the value of velocity, voltage and rpm. The testing was performed in two condition that is with mouth-ring and without mouth-ring and 2 size of propeller been tested in this experiment. The application of mouth-ring is based on the gap between the wall of mouth-ring and the blade tip. There are 3 size of gap; 10mm, 8mm and 5mm. The result shows that 10mm mouth-ring have better thrust generation other than two gap. In addition, if compare to with and without mouth-ring, the application of mouth-ring also has proved it has a better thrust. Furthermore, the application of mouth-ring is evaluating to be good base on this study.

1. INTRODUCTION
Electric UAVs continue to be popular applications in roles ranging from traffic monitoring to filming and others. Propeller is use to generate thrust for a comfortably lift and to generate thrust under most flight conditions is well understood due to this long history of use and development.

The study requires evaluating the thrust generation of the propeller as the various width-span of the propeller blade being tested. If the thrust increase, it can help to lift the UAV comfortably. We can withstand the problem by reducing the power usage. In these applications, UAV needed large amount of required thrust force to perform a good lifting and maintain a good stability. It is important that enough force need to be produced in order to stabilized the UAV.

With various width-span of the propeller, we can get a suitable blade based on the result. Thrust can be changed by either changed the width-span or changing the rotational rate of the motor drive. As for the relation with mouth-ring, the study included the materials of the mouth-ring made of. Heavy material will likely affect the power usage and the thrust required in order to lift up the UAV. In this case plastic and carbon fibre been used to study the relation between materials and various width-span of the propeller blade.

2. METHODOLOGY

2.1. Project development Flow
At the first stage of the testing, the experimental have been setup. The apparatus has been connected to each device. Two size of propeller use in this experiment; 10 inch and 9 inch. The exact voltage is used to run the propeller: 4V, 7V, 9V and 11V.
Anemometer and tachometer will be used to take the velocity and rpm value on the rotating propeller. The reading was taken to make the calculation to know the value of the thrust generate. Next, the experiment repeated using 10-inch propeller with the application of 3 mouth-rings. Each of the mouth-ring have the gap between 5mm, 8mm and 10mm. Same step of taking the data used in this mouth-ring application test.

Since all the tested have been done, the thrust value is being calculated and compares the data based on the thrust value. A few graphical explanations needed to show the data comparison between the application of using mouth-ring and without using mouth-ring.

2.2. Design Modelling
In this study, the mouth-ring is made of using a tube that is made to ring. Each of the mouth-ring inner diameters is 27.4cm, 27cm and 26.4 cm. The size of the mouth-ring is based on the gap size between mouth-ring and blade tip.

![Figure 1. The gap of the mouth-ring and the blade tip](image)

3. SELECTION OF PART
For the part, several devices were used in order to make the testing. The device is brushless motor 1000kV, electric speed controller (ESC), remote control, receiver, anemometer, and tachometer and dc power generator.

There are two size of propeller used that is made of plastic used in this test.

| Table 1. Propeller diameter. |
|-----------------------------|
| Material | Diameter |
| Plastic | 9 inches (22.86 cm) |
| Plastic | 10 inches (25.4 cm) |
3.1. Equations
The equation used is based on the static thrust equation

\[ T = \dot{m}V \]

Where \( \dot{m} = \rho AV \)
\[ \therefore T = \rho AV^2 \]

Where:
\[ A = \frac{\pi d^2}{4} \]
\( \rho \), density of air = 1.225 kg/m³
\( V = \) velocity of air accelerated by the propeller (m/s)
\( d = \) propeller diameter

Here, the thrust produced by the propeller depends on the air density, RPM, diameter, shape and area of the blade and lastly the propeller pitch that also related to the angle of attack.

![Figure 2. Point of velocity reading](image)

4. Result
Based on the testing, data below will explain about all the findings

4.1. Case Scenario 1: Free propellers

| Volt (V) | 10 inch (25.4cm) | 9 inch (22.86 cm) |
|----------|-----------------|------------------|
| 4        | 0.1701          | 0.1008           |
| 7        | 0.394           | 0.305            |
| 9        | 0.5211          | 0.3882           |
| 11       | 0.7066          | 0.5022           |
Figure 3. Thrust value of free propeller without mouth-ring

4.2. Case Scenario 2: With mouth-ring application; 10mm, 8mm and 5mm gap.

Table 3. Thrust value with mouth-ring application.

| Volt | Thrust (N) |
|------|------------|
|      | 10mm | 8mm | 5mm |
| 4    | 0.1824 | 0.1636 | 0.1999 |
| 7    | 0.3889 | 0.3619 | 0.3649 |
| 9    | 0.6936 | 0.5600 | 0.5135 |
| 11   | 0.9193 | 0.6986 | 0.5833 |
4.3. Case Scenario 3: Comparison between without mouth-ring and with-mouthring.

Table 4. Thrust value of with mouth-ring and without mouth-ring

| Volt (V) | Thrust (N) without mouth-ring | Thrust (N) with mouth-ring |
|----------|-------------------------------|---------------------------|
| 4        | 0.1701                        | 0.1824                    |
| 7        | 0.394                         | 0.3889                    |
| 9        | 0.5211                        | 0.6936                    |
| 11       | 0.7066                        | 0.9193                    |

Figure 4. Graph for Thrust value with mouth-ring application
6. CONCLUSION

The thrust generation of various propeller blade width-spans with the application of mouth-ring was examined through this research study. Both of tests with mouth-ring or without mouth-ring were tested also with the applied of gap between mouth-ring and the propeller. The conclusions which can be drawn from this research are:

a) The thrust can be large by using a bigger diameter of propeller. The bigger the area of the propeller, the higher the velocity which lead to thrust increase. Bigger diameter propeller also gave better air flow across the surface of the blade.

b) Application of mouth-ring can increase the thrust produced with the right design and size. It also can act as a protection in surroundings. Use of mouth-ring (duct) help in velocity increase with the good streamline of along the air flow through the duct.

c) Size of the blade tip clearance would also effect the thrust generation. If the gap is too large, it rejects all the advantages of using the duct.

7. RECOMMENDATION

There is recommendation that can be improved in this project in order to get better results:

Figure 5. Graph Thrust value of with 10 mm mouth-ring and without mouth-ring
a) Use various diameter of mouth-ring for testing. This study only focus on 1inch diameter of mouth-ring, maybe for the next study will be test on various diameters.

b) Increasing the range of blade tip clearance (gap size). Result show that using 10mm has higher thrust than using 8mm and 5mm. The gap can be test using more than 10mm to see if there any increasing of thrust id the gap become bigger.

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References

[1] M. Cutler and J. P. How, “Analysis and Control of a Variable-Pitch Quadrotor for Agile Flight,” vol. 137, no. October, pp. 1–14, 2015.
[2] J. P. How, T. Supervisor, and E. H. Modiano, “Design and Control of an Autonomous Variable-Pitch Quadrotor Helicopter,” 2012.
[3] A. Smidresman, D. Yeo, and W. Shyy, “Design, Fabrication, Analysis, and Testing of a Micro Air Vehicle Propeller,” no. June, 2011.
[4] B. Michini, J. Redding, N. K. Ure, M. Cutler, and J. P. How, “Design and Flight Testing of an Autonomous Variable-Pitch Quadrotor.”
[5] M. Cutler, B. Michini, and J. P. How, “Comparison of Fixed and Variable Pitch Actuators for Agile Quadrotors,” pp. 1–17.
[6] D. Witt, P. Y. L. J. Young, N. Architecture, and M. Engineering, “Comparative Study of FPP vs CPP for an All-Electric Naval Combatant.”
[7] A. Balachandran, A. Shah, and J. Challa, “Propulsion Selection and Analysis for Unmanned Aerial Vehicles for SAE Aero Design Series,” pp. 29–35, 2014.
[8] M. Cutler and J. P. How, “Actuator Constrained Trajectory Generation and Control for Variable-Pitch Quadrotors,” pp. 1–15.
[9] Y. Naidoo and G. Bright, “Rotord Aerodynamic Analysis of a Quadrotor for Thrust Critical Applications,” no. November, pp. 23–25, 2011.
[10] B. D. Rutkay, “A Process for the Design and Manufacture of Propellers for Small Unmanned Aerial Vehicles by Affairs in partial fulfillment of the requirements for the degree of Master of Applied Science,” 2014.
[11] S. Yilmaz, D. Erdem, and M. S. Kavsaoglu, “Performance of a ducted propeller designed for UAV applications at zero angle of attack flight: An experimental study,” Aerosp. Sci. Technol., vol. 45, pp. 376–386, 2015.
[12] D. Yongle, S. Baowei, and W. Peng, “Numerical investigation of tip clearance effects on the performance of ducted propeller,” Int. J. Nav. Archit. Ocean Eng., vol. 7, no. 5, pp. 795–804, 2015.
[13] G. M. Hoffmann and C. J. Tomlin, “Quadrotor Helicopter Flight Dynamics and Control: Theory and Experiment *,” no. August, pp. 1–20, 2007.
[14] A. I. Abrego, A. Engineer, M. Field, R. W. Bulaga, and C. Engineer, Performance Study of a Ducted Fan System,” pp. 1–6, 2002.
[15] R. J. Weir, “Ducted Propeller Design and Analysis,” vol. 29000, no. October, 1987.
[16] K. Regmi, “Investigation of Perforated Ducted Propellers to use with a UAV ,” 2013.
[17] S. Yilmaz and D. Erdem, “Effects of Duct Shape on a Ducted Propeller Performance ,” pp. 1–9.
[18] Y. Tamura, Y. Nanke, and M. Matsuura, “Development of a High Performance Ducted Propeller,” no. 7, pp. 1–8.
[19] “Unmanned Air Vehicle (UAV) Ducted Fan Propulsion System Design and Manufacture Submitted by Wah Keng Tian Department of Mechanical Engineering,” 2010.
[20] M. Rutkowski and W. Krusz, “Design and analysis of ducted fan for ,” no. Icas 2002.
[21] J. M. Stubblefield and R. W. Kimball, “Numerically-based Ducted Propeller Design Using Vortex LatticeLifting Line Theory,” no. 1993, 2008.