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Aerodynamics Drone Propeller Analysis by using Computational Fluid Dynamics

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Abstract: Investigation on the airflow characteristic of the drone propeller using Ansys fluent software was performed for this study. In the past few years there has been a lot of research and study about the drone propeller due to the high demand in several industries and drone efficiency regarding the performance. The design parameters such as radius of the propeller, propeller rotational speed, and number of blades, and angle of attack should be optimized to ensure the great execution in different flight status. This paper is to compare the three type of propeller which having different parameter of angle of attack and twisting blade. The analysis and result are obtained using simulation where the value of thrust force, lift and drag coefficient can be seen. The design is tested into three different speed of rotational 4000 rpm, 6000 rpm and 8000 rpm. The result shows that, the higher angle of attack and rotational speed, it produces the higher value of thrust force.

Keywords: Propeller, Ansys Fluent, Thrust force

1. Introduction

Nowadays, transportation is becoming one of the fastest evolutions in the transportation industry, from land transportation to air transportation and the latest one is the technology that does not require a pilot to control, known as the unmanned aerial vehicle (UAV). Drone is one of the examples of UAV technology that has become popular in the past few years [1-3]. The drone is a type of UAV that has become another alternative to convert from traditional technology to modern transportation technology. Talking about the UAV technology, it cannot be denied discussing the important part in drone research which is the drone propeller.

There are two principal families of drone known as fixed wing and rotary wing. For the fixed wing, they have generally one or two propulsive system and the lift generation is performed through aerodynamic fixed surfaces. Besides normal airplane, this type of drone does not carry any human so they can be built to withstand a higher load factor and usually [4-7]. Basically, this type of drone is built for military intent like surveillance of hot spot. Another type of drone, the rotary wing has multi-rotors that usually used in civil sphere, like helicopter they are vertical take-off and landing (VTOL) aircraft [8,9]. Exploiting a complex flight control system, they can manage the rotation speed of each propeller, which it generates thrust and so regulate attitude and altitude of itself.

Focusing on the rotary-wing drone, the subject of this research, is interesting to decompose it to see how it is made of the propeller. Propeller is the most important components for drone that convert motors torque into thrust by aerodynamics forces on its rotating surfaces [10-12]. Propellers are a type of fan that converts mechanical energy in kinetic energy of the fluid. The momentum increment of the fluid generates the thrust. There is several important propeller's parameter that should be familiar before we go deeper in research on the propeller [13,14]. The parameters are listed in Table 1 below.

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Table 1 – Propeller's parameters

Parameter	Description
Velocity	Incoming fluid velocity and rotation velocity determines the pitch distribution of propeller.
Number of blades	Propeller with more blades will perform slightly better.
Diameter Propeller	Larger propeller will have a higher efficiency, as it catches more incoming fluid and so distributes its power and thrust on a larger fluid volume
Fluid Density	Density of fluid has no influence on the efficiency of a propeller but has a strong impact on size and shape.
Lift and Drag distribution	The distribution of C_L and C_D along the radius can be examined by performing an analysis for the design point.

Besides the listed parameters, there are condition parameter that should be consider for the propeller design which are twisting blade and angle of attack (AOA). For twisting blade, the propeller parameter is taken at 75% of prop length. From Fig. 1, the rim angle α is bigger at the root of the propeller compared the angle α at the tip of propeller as the velocity $V_{r\text{-}tip}$ is constant and ωr_{tip} decrease same as the α angle of attack [15].

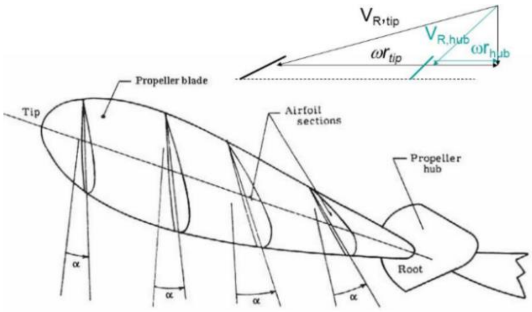


Fig. 1 – The propeller section and twist

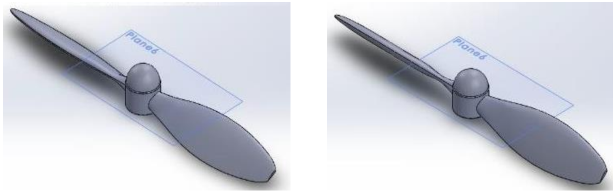
Propeller twisting known as a torsion of wing that it is parallel to the axis of the span wise that lead to the variety of the AOA, angle of attack. To reach the optimum velocities along the propeller blade, the blade is twisting and decreasing at the angle of attack at the tip of the blade. Propellers can operate at less or more constant effective angle of attack due to the twisting blade. Hence, focus on this study is to study the aerodynamic characteristic of the design of different propellers for drone application. The study of the aerodynamic characteristic of propellers will be perform using Ansys Fluent software.

2. Design and Methodology

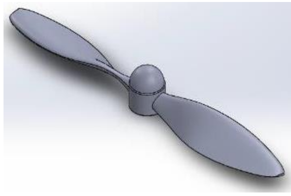
Three type of propeller are created by using Solidwork software which is one of three propellers having a twisting blade while the other two does not have twisting blade. Each of propeller are set into three different speed of rotation which is 4000 rpm, 6000 rpm and 8000 rpm. Table 2 summarize the propeller conditions using for the simulation. Each of propeller are set into three different speed of rotation which is 4000, 6000 and 8000 rpm. The design of the propellers shown in Fig. 2.

Table 2 – Parameter of propellers

Propellers	1	2	3
Angle of Attack	30	45	45^o at root 25^o at mid -15^o at tip
Twisting	No	No	Yes



30^o AOA without twisted blade $\quad$ 45^o AOA without twisted blade



45^o AOA with twisted blade

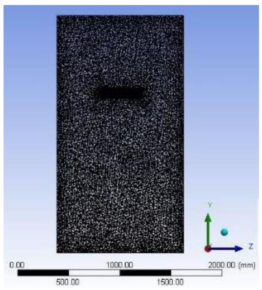
Fig. 2 – Design of the propellers

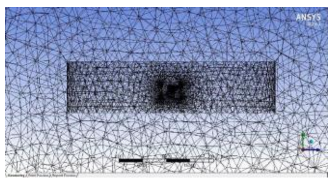
3. Simulation Setup

The simulation work using Ansys Fluent to perform the numerical work. The geometry designed previously was transferred to the Ansys Fluent software with saving the file into IGS format. The geometry needs to mesh first before proceeding to the simulation work. To realize the movement of the propeller, the sliding mesh technology was applied to the design in computational domain. The surface repair and refinement process are performed throughout the simulation environment.

3.1 Meshing

The quality of the mesh is very important because it can affect the calculation accuracy and the computational convergence speed directly. The computational domain was meshed at first with the sequence of the line surface to the body. The propeller surface size that is big due to its curvature make the works need to be done to reduce the curvature especially split and merge of the surface. The computational domain and meshing result were shown in Fig. 3. The size element and nodes were varied by control the diameter size of the mesh. The name selection is set to the main part to setup the boundary conditions. Size nodes used is 141628 while size element is 755652.





Computational domain $\quad$ Propeller's meshing

Fig. 3 – Meshing of the computational domain

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3.2 Simulation Parameter Setup

The model that has been used this research paper is a propeller with 2 different characteristic which is angle of attack and twisting blade. The model is in the 3-dimension. The velocity for inlet is set up for 15 m/s and each propeller are rotate in three different speed. Table 3 show the parameter setup that has been used for the simulation work.

Table 3 – Setup for simulation work

Parameter	Values
Time	Transient
Time step	0.0015
Number of time step	50
Max iteration per time step	15
Viscous model	k-epsilon (realizable)
Near wall treatment	Scalable wall function
Flying medium	Air
The density of air, ρ	1.225 kg/m^3
Velocity inlet, V	0.5 m/s
The viscosity of fluid, μ	1.7894e-05
Type of air flow	Turbulent

4. Results and Discussion

In this section, an elaboration of graphical data and numerical data on the effect of the characteristic of airfoil parameter which are thrust force, lift, and drag coefficient will be presented. This section discussed the explanation of methodology that was used to complete the simulation study on the effect different parameter of the propellers on the airfoil characteristics.

4.1 Data Verification

Validation is important in a research, to show that the data obtained in the result are similar or almost the same to show the result can be trusted. In this research paper, the validation is made in 2-dimension airfoil of NACA version. Since, the propeller is created from the airfoil design for the blade, the NACA 0012 airfoil model was selected. The result simulation data was compared to the experimental data that are taken from the official website NASA research.

The designs were tested for 3 different angle of attach which is 0, 4, and 8 degrees. The velocity and pressure contour are shown in the further below. Table 4 below shows the comparison for both experimental and simulation result obtained throughout the software. The value of lift and drag coefficient, C_d and C_l were obtained. Fig. 4 and 5 shows graphically the comparison between experimental and simulation results for the verification purpose.

Table 4 – The result for data verification

Angle of attack	C_l (exp.)	C_l (sim.)	C_d (exp.)	C_d (sim.)
0	Approx. 0	1.69E-06	0.00819	0.008066
4	0.4316	0.434848	0.00823	0.009026
8	0.8873	0.860613	0.01050	0.012004
12	1.2605	1.260388	0.01201	0.017550

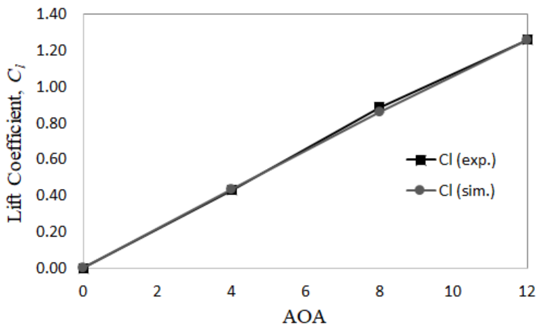

Fig. 4 – Experimental data and simulation results for C_l

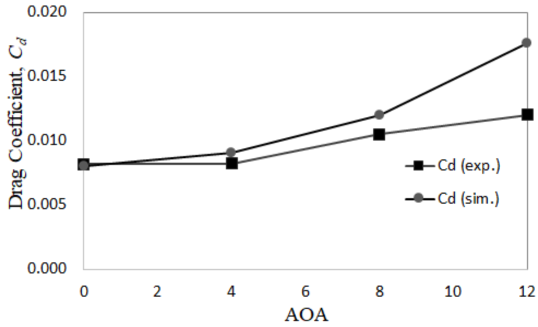

Fig. 5 – Experimental data and simulation results for C_d

Both figures for lift and drag coefficient comparison shows a good agreement between experimental data and current simulation results. For the drag coefficient, the data is slightly different for both data especially for 12 degree of angle of attack. Even though there are a little bit different, the data is still valid, and simulation still can be accepted.

4.2 Thrust Force

Velocity inlet has set for 15 m/s to simulate the thrust force acting on propeller. The simulation had run for 3-D model to obtain the thrust force and analyzed the lift and drag coefficient for each propeller design. As mentioned, three different speed of propeller's rotating were 4000, 6000 and 8000 rpm. Table 5 shows the value of thrust force obtained from the simulation and it was plotted graphically as in Fig. 6.

Table 4 – The result for data verification

RPM	Thrust force, N		
	Propeller 1	Propeller 2	Propeller 3
4000	25.66130	29.86953	7.60324
6000	61.93440	72.51562	18.73863
8000	110.71272	125.98659	35.33145

For rotational speed 4000 rpm, we get the least value of thrust force which is 25.66 N. For 6000 rpm, the thrust force we get is 61.93 N while when the rotational at its maximum speed which is 8000 rpm, the thrust value it gets is 110.71 N. It shows that the rotational speed is increase, the thrust force that creates by propeller is also increase. From the table, it shows that propeller 2 has higher value of thrust force compared to the propeller 1 and 3 for every rotational speed. It shows that propeller 2 produce the most propulsive power to lift against the velocity of air.

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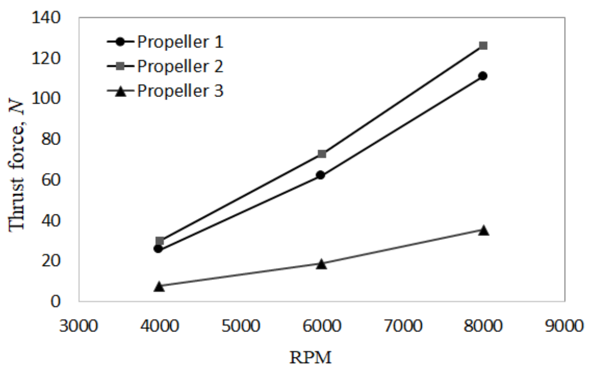

Fig. 6 – The graph of thrust force against rotational speed

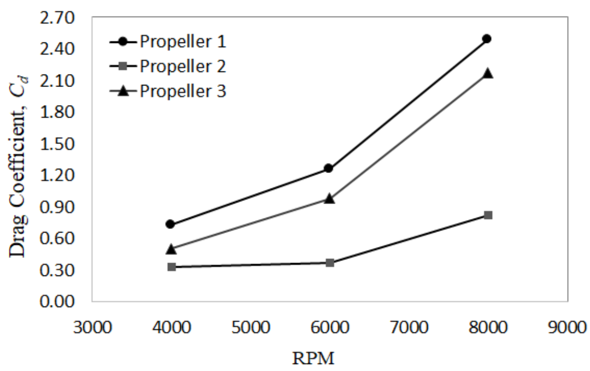

Fig. 8 – Drag coefficient, C_d against rotational speed

4.3 Lift and Drag Coefficient

The following results, Table 5 and 6 were showing the comparison of the lift and drag coefficient respectively for each propeller simulated.

Table 5 – Lift coefficient for the simulated propellers

RPM	Lift Coefficient, C_l		
	Propeller 1	Propeller 2	Propeller 3
4000	41.89599	48.76657	12.41345
6000	101.11739	118.39285	30.59367
8000	180.75546	205.6924	57.6840

Table 6 – Drag coefficient for the simulated propellers

RPM	Lift Coefficient, C_d		
	Propeller 1	Propeller 2	Propeller 3
4000	0.73289	0.33683	0.50426
6000	1.26247	0.37346	0.98464
8000	2.48824	0.82289	2.16961

From the tables, both lift and drag coefficient was increase when the rotational speed for the propeller increased. Comparison in term of trend for lift coefficient, the propeller 2 have the highest list coefficient and propeller produced the lowest lift coefficient for all the three cases of rotating speed. For the drag coefficient, propeller 1 provide the highest drag while the propeller 2 had the lowest drag. It shows clearly in Fig. 7 and 8 for the comparison of lift and drag coefficient against the rotating speed. The angle of attack and the rotational speed can be affecting the result of lift, drag coefficient and the thrust force. Propeller 2 shows the highest thrust force produced due to angle of attack and without twisted blade.

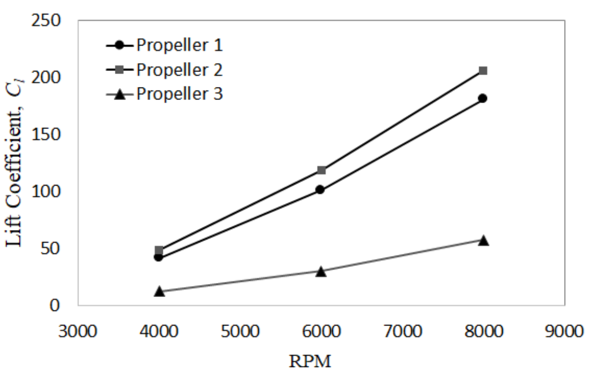

Fig. 7 – Lift coefficient, C_l against rotational speed

5. Conclusion

Simulation on aerodynamics drone propeller analysis by using computational fluid dynamics was performed successfully. The objective of this study has achieved, which to study the aerodynamic characteristic of the drone's propellers design. The aerodynamic characteristic that was determine during the simulation were thrust force, lift, and drag coefficient. From the aerodynamic characteristic determination, propeller 2 has shown a high propulsive power which is highest value of thrust force and lift coefficient, at the same time have the lowest drag coefficient compare to the other two propellers simulated. Propeller 3 have a twisted blade was compared to the propeller 1 and 2 and the results shows that it had the lowest thrust force especially at the 4000 rpm. With the thrust force was only 7.6 N, this propeller produces a low power of propulsive force to lift.

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