© Universiti Tun Hussein Onn Malaysia Publisher's Office

PAAT

http://publisher.uthm.edu.my/ojs/index.php/paat

e-ISSN: 2821-2924

Progress in Aerospace and Aviation Technology

Airflow Characteristic of UAV Quadcopter Propeller Blade Using Computational Fluid Dynamics (CFD)

Najma Nazlifah Azizan[1], Azwan Sapit[1,*]

[1]Department of Mechanical Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia.

*Corresponding Author

DOI: https://doi.org/10.30880/paat.2022.02.02.002
Received 13 December 2022; Accepted 23 December 2022; Available online 31 December 2022

Abstract: In this study, the main focus is to study of air flow characteristic of UAV quadcopter propeller at incorporate blade profile using variable angle of attack (AoA) and revolution per minute (RPM) with its twisted blade using Computational Fluid Dynamics (CFD) / Ansys tool. Three propellers have been designed which Propeller 1 is untwisted while Propeller 2 and 3 twisted at certain angle. Three speeds which are 4000 rpm, 6000 rpm and 8000 rpm have been set for each propeller are being analysed using ANSYS Fluid Flow (fluent). The result shows the different thrust force generated by three propellers and Propeller 2 (33.6757 N) has the highest thrust force generated compared to Propeller 1 and 3 especially at 8000 rpm. This is due to the suitable twisting angle profile that has been set at the Propeller 2 at this operating speed. For comparison, Propeller 3 produce the highest thrust force of 18.44 N at 6000 rpm exceeding Propeller 2 which is 17.81 N. To summarize, each propeller blade profile has a distinctive aerodynamic performance and should be adopted by matching the flight operating condition. Higher rpm generates higher thrust force, and increase lift and drag coefficient.

Keywords: Airflow, thrust force, propeller blade, quadcopter, UAV, ANSYS

1. Introduction

Unmanned Air Vehicle (UAV) is a common device that are used in develop country across the world based on the economic cost and growth of technology. A quadcopter is a short form for quadrotor helicopter which is commonly known as quadrotor. Quadcopter is the most used UAV in many activities which they have four propellers that provide to the quadcopter. Basically, UAV is a flying vehicle that can be remotely or programmed to conduct autonomous task [1] which do not need a pilot to control instead all people who learned to fly the UAV start at young age. Previously, the usage of UAV only limited for military purpose but nowadays, the function becomes variety that can be used for other activities such as photography, regional mapping and entertainment media [2]. A few features offered such as small size, low cost and easy manoeuvrability of these system have made them potential in avionics industry [3] and become the most useful avionic in the 4th industrial revolutionary. They are divided into several categories such as Fixed-Wing, rotary-wing, flapping-wing, and blimp. But UAV that use rotary wing are very favourable because they can balance the force generated by rotor when flying and also can follow specified trajectory, do vertical landings and take offs as well as hovering [4] that is what made them popular in UAV market. UAV like quadcopter has four propellers which two of them rotate in clockwise while the other two rotate in counter clockwise creating a torque that can be cancelled each other [5] This torque also can create rotational movement for quadcopter.

In order for the UAV to fly high and stable, few factors should be taken into consideration such as power source that consist of battery or fuel, rotors, propeller and a frame. The frame of the UAV must be lightweight for it to increase the flight length. The power source must be withstanding the long-term flight and also in light weight as well as rechargeable so that the UAV can be used again. Another important thing is the propellers that are going to be the focus

Corresponding author: azwans@uthm.edu.my

of this study. The design and rotation of propeller really plays an important role for the thrust and lifting force of the UAVs [6]. The propellers need to be carefully selected because the wrong propeller geometry and profile can impact the flight characteristic and efficiency of the UAV. There are a few factors affecting the propellers efficiency such as number of blades, revolution per minute (RPM), propeller diameter, blade outline, camber and angle of attack (AoA), and pitch/diameter ratio [7].

2. Methodology

This chapter will discuss the flow and methods that will be used to guarantee that the scope of study and objective of the study are met or achieved.

2.1 Geometry Model of Propeller

There are 3 propellers being designed and used to analyse the angle of attack, lift and drag coefficient by testing it with different speed, revolution per minute (RPM). The one propeller has untwisted design of propeller while the other 2 are twisted.

Table 1 - Parameter of propeller

Parameter	Propeller 1	Propeller 2	Propeller 3
Angle, θ	50°	30° at root, 55° at mid and 5° at tip	45° at root, 65° at mid and 20° at tip
Twisted	No	Yes	Yes

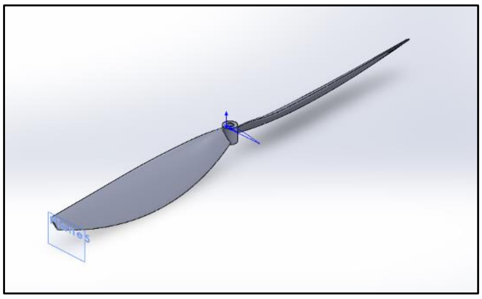


Fig.1 - Propeller 1 without twisted blade

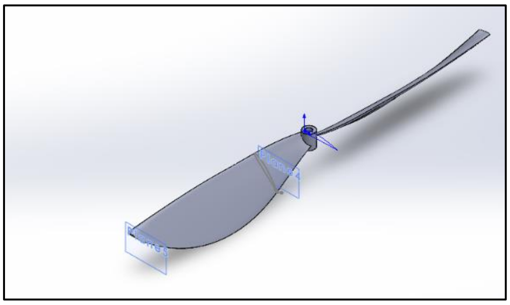


Fig. 2 - Propeller 2 with twisted blade

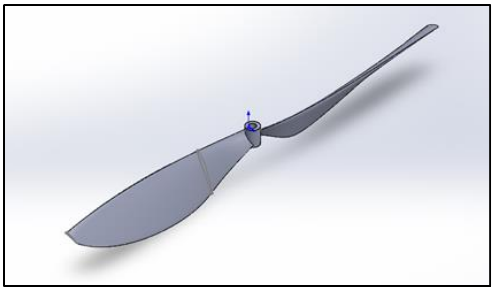


Fig. 3 - Propeller 3 with twisted blade

2.2 Simulation Setup

In this study, Computational Fluid Dynamics (CFD) by ANSYS Fluent software was implemented. Typically, engineering simulation begins with a drawing that describes the design. Once completed, the geometry files are transferred to the ANSYS software, where they are saved in the STEP format. Then, import the simulation into one of the ANSYS-provided software packages that is fluent and suited for fluid or air movement.

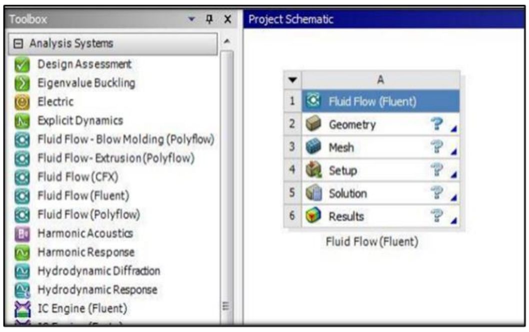


Fig. 4 - The fluid flow (fluent) ANSYS software

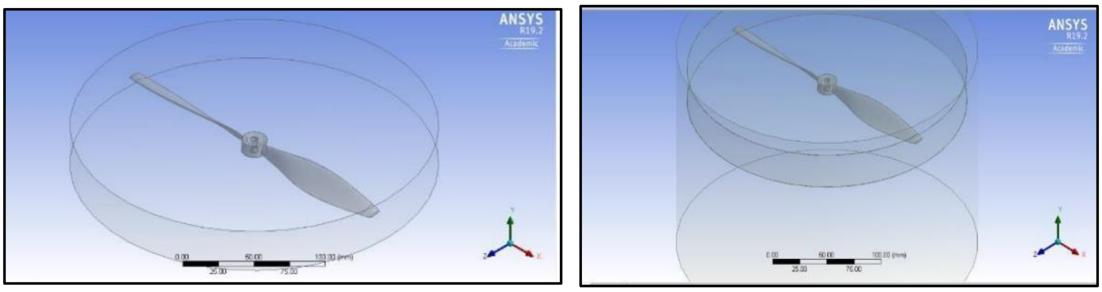
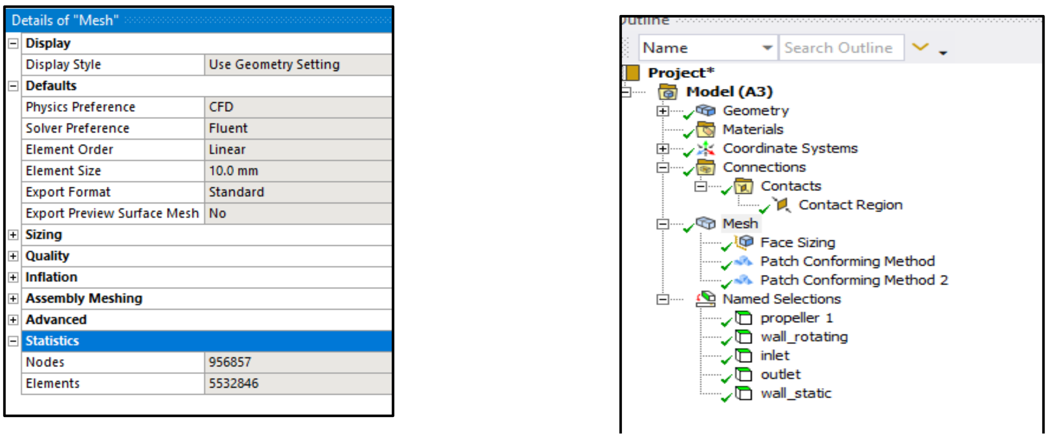


Fig. 5 - Creating enclosure 1 and enclosure 2

This study was followed by a wind tunnel analysis. The tunnel must be designed in such way that the wind blows in just one direction. In reality, the wind tunnel method forces air around the target, giving the impression that it is moving. Strong fans blow air through tube when this method is utilised, and the object is securely fixed within to prevent movement. Enclosure 1 is set as rotating domain and enclosure 2 is static domain.

2.3 Meshing

Before the numerical simulation, the propeller, and its entity, as well as the computational domain, must be defined. The mesh quality is critical since it has a direct effect on the calculation accuracy and computational convergence speed. Below are detail of mesh and the named selection to the face of the enclosure.



Details of "Mesh"	
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
Element Size	10.0 mm
Export Format	Standard
Export Preview Surface Mesh	No
Sizing	
Quality	
Inflation	
Assembly Meshing	
Advanced	
Statistics	
Nodes	956857
Elements	5532846

Fig. 6 - Details of mesh and project outline

The size nodes used are 956857 while elements are 5532846. The sizing element can be adjusted to set the size of nodes and elements. The smaller the size element of meshing the detail the mesh. Besides, the meshing skewness is less than 0.84 so the result is still acceptable.

2.4 Simulation Parameter Setup

Table 2 shows the parameter for the simulation. The propeller model used in this study work has three distinct characteristics which are angle of attack, twisting blade and speed, RPM. The model is three-dimensional. The inlet velocity is set to 30m/s. Each propeller rotates at three distinct speeds which are 4000 rpm, 6000 rpm, and 8000 rpm.

Table 2 - Parameter value

Parameter	Parameter Value
Propeller rotation	4000 rpm, 6000 rpm and 8000 rpm
Time	Steady
Gravity	9.81 m/s^2
Flying medium	Air
Specified operating density	1.225 kg/m^3
Density of air, ρ	1.225 kg/m^3
Velocity inlet, v	30 m/s
Viscous model	k-epsilon (realizable)
Flying medium	Air
Type of airflow	k-epsilon
The viscosity of fluid, µ	1.7894e-05

3. Results and Discussion

3.1 Validation Using 2-D Airfoil Simulation

In this research paper, the validation is made in 2-dimensional airfoil of NACA version. The airfoil model that has been chosen to create the propeller is NACA 4412. The simulation is made in Ansys Fluent software in 2-D form by using various angles of attack which are 0, 5, 10, 15, and 20. The result can be seen in Fig. 7 and Table 3.

Table 3: The result of 2-D simulation

Angle of attack	C_L (result)	C_D (result)
0	0.0095	0.00132
5	0.0209	0.0032
10	0.0325	0.00364
15	0.0423	0.00592
20	0.0467	0.00837

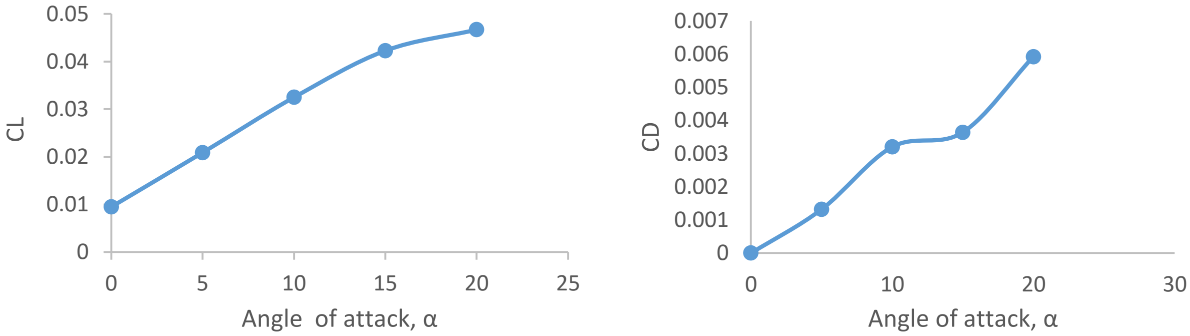


Fig. 7: Graph angle of attack against C_L and graph angle of attack against C_D

From Fig. 7, we can see that the graph shows the increment as the angle of attack increase the lift coefficient also increase same goes to the drag coefficient. When compared to data previously publish, the trend and the value match with acceptable margin of error.

3.2 Thrust Force

To simulate the propeller thrust force, the velocity inlet has been set to 30 m/s. The simulation was run on a three-dimensional model to calculate thrust force and analyze lift. Each propeller design has a different coefficient of resistance. as well as the rotational speeds of the propellers were 4000, 6000, and 8000 RPM. The thrust force value is shown in Table 4 obtained through simulation and represented graphically.

Table 4 - Thrust force value for all propellers

Propeller	Speed, RPM	Thrust force, N
1	4000	6.0657
	6000	16.1112
	8000	31.0875
2	4000	4.6999
	6000	17.8152
	8000	33.6757
3	4000	8.0724
	6000	18.4441
	8000	32.9427

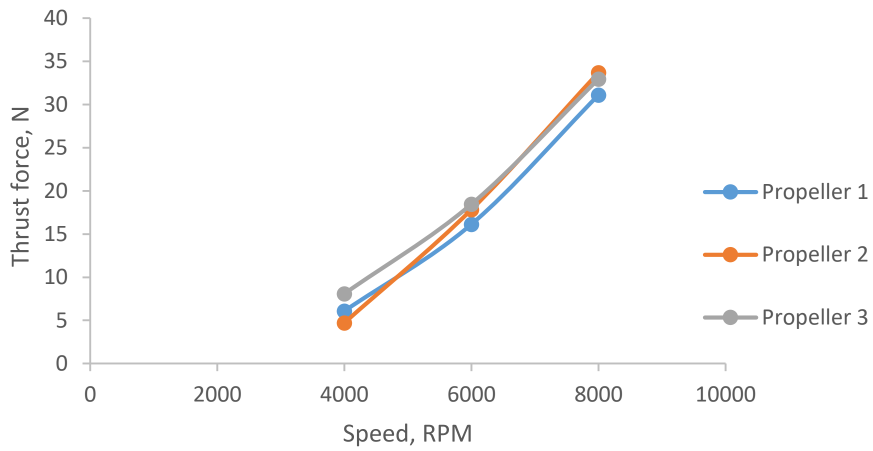


Fig. 8 - Comparison of thrust force on Propeller 1, 2 and 3

Fig. 8 shows that all of the propellers thrust force increase as the speed of the propeller increase by 4000 rpm, 6000 rpm and 8000 rpm. This trend showed in related research paper such as the experimental research done by [8]. For the Propeller 1 (red line), the graph increases steadily starting at 4000 rpm with thrust force 6.0657 N, at 4000 rpm with thrust force 16.6112 N while Propeller 2 at 4000 rpm has 4.6999 N. Propeller 1 without twisted blade seems to have lower thrust force compared to Propeller 2 and 3. From the first segment (4000 to 6000 rpm) By looking at the graph, we can see that Propeller 2 has lower thrust at the speed 4000 rpm (4.6999 N) compared to others but increase gradually as the speed increase. Propeller 3 has the highest thrust force at the speed due to the higher twisting angle than others.

In segment 2 (6000 to 8000 rpm), we can see that from the graph that Propeller 1 which has no twisted angle has lowest thrust force (16.1112 N) compared to Propeller 2 and 3. Propeller 3 recorded the highest thrust force at speed 6000 rpm (18.4441 N) while Propeller 2 has 17.8152 N that can function efficiently. At 8000 rpm Propeller 1 has 31.0875 N still cannot beat the other propeller. Propeller 2 has the highest optimum value of thrust force that can be generate which is 33.6757 N.

Based on the discussion have made and the comparison of graphs shown in Fig. 8. We can say that twisted propeller generates more thrust force compared to untwisted propeller. The best propeller is Propeller 2 that has twisting blade at root 30˚ degree, middle 55˚ degree and at tip 5˚ degree although Propeller 2 has bigger twisting but increasing the angle of attack after reaching maximum lift, on the other hand, causes a faster or slower lift drop. this follows the article from [10] Propeller 2 is recommended to be operated at speed 8000 rpm as it has the highest thrust force among others.

3.3 Lift and Drag Coefficient

From Fig. 9, it is shown that as the speed increase, the lift coefficient also increases. At 8000 rpm, Propeller 2 has the highest lift coefficient when compared to Propeller 1 and 3. In Fig. 10 the graph shows the speed increase, the drag coefficient also increases Propeller 2 has the lowest CD compared to Propeller 1 and 3 at 8000 rpm.

Table 5 - Lift and drag coefficient value

Propeller	Speed, RPM	Lift coefficient	Drag coefficient
1	4000	9.9032	-0.014914
	6000	26.3023	0.82053
	8000	50.7551	1.85501
2	4000	7.6732	0.1631
	6000	29.0860	0.2629
	8000	54.9807	0.8439
3	4000	13.1794	0.1804
	6000	30.1127	0.0732
	8000	53.7840	1.4062

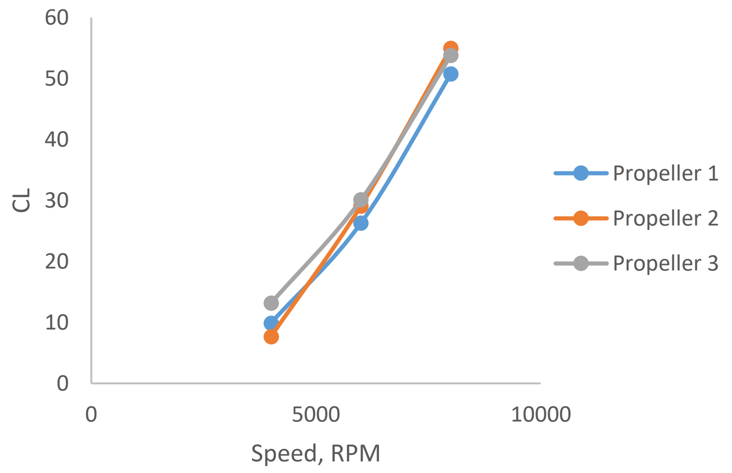


Fig. 9 - Graph speed, RPM against C_L for all propeller

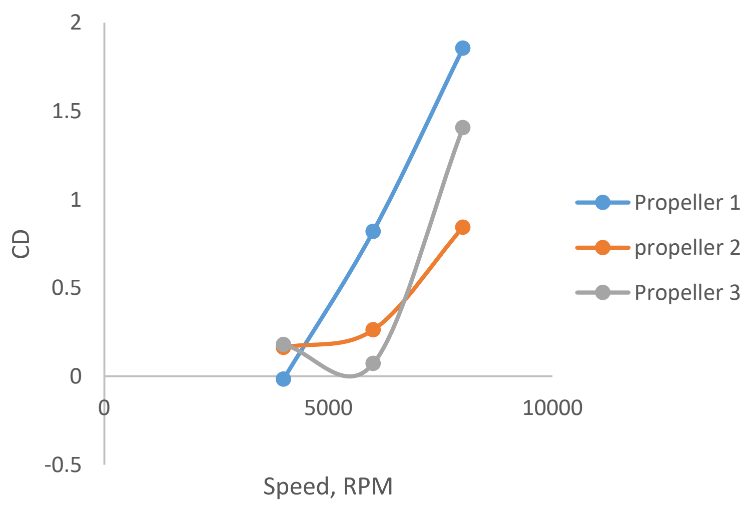
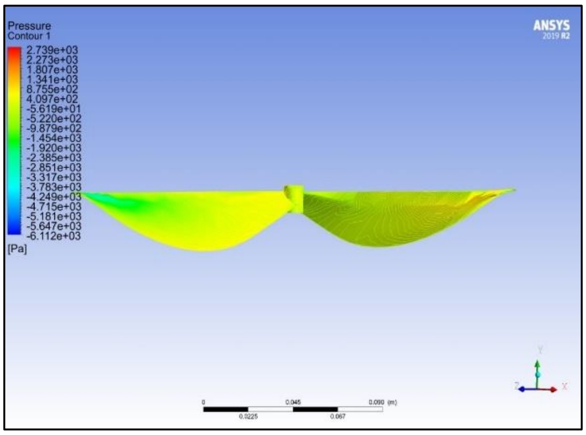


Fig. 10 - Graph speed, RPM against C_D for all propeller

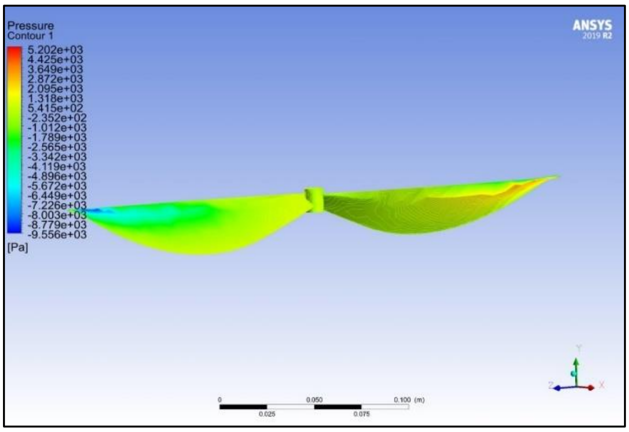
3.4 Pressure Contour

Based on Fig. 11, pressure at Propeller 2 also increases as the speed increases, especially at bottom of the propeller blade. At speed 4000 rpm the pressure at the tip is 273.9 Pa and has lowest pressure at root. The pressure differential between the top and bottom of the propeller provides thrust. The dark blue colour on the propeller blade indicates lowest pressure which act on the top surface around the edges which has the value of -1634 Pa. Higher pressure around the tip area because of the twisting of blade caused the tip travel faster than the middle part of the propeller. The pressure near the upper surface of the propeller is significantly lower than the pressure near the lower surface, and the pressure declines from the blade's root to its tip

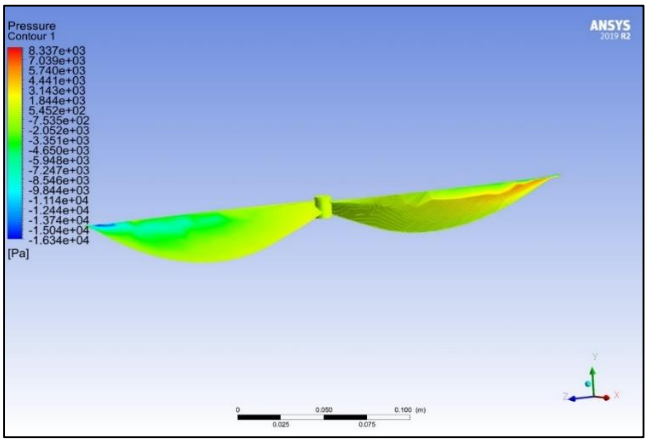
Furthermore, there is a zone of negative pressure on top of the airfoil, indicating that the air flowing over the top is sucking the blade upwards. It is feasible to determine that the negative pressure generated on the top surface of the propeller contributes more to lift creation than the high pressure generated on the bottom surface by comparing the measured pressure levels in this simulation. This trend showed in related research paper such as the experimental research done by [10].



a)



b)

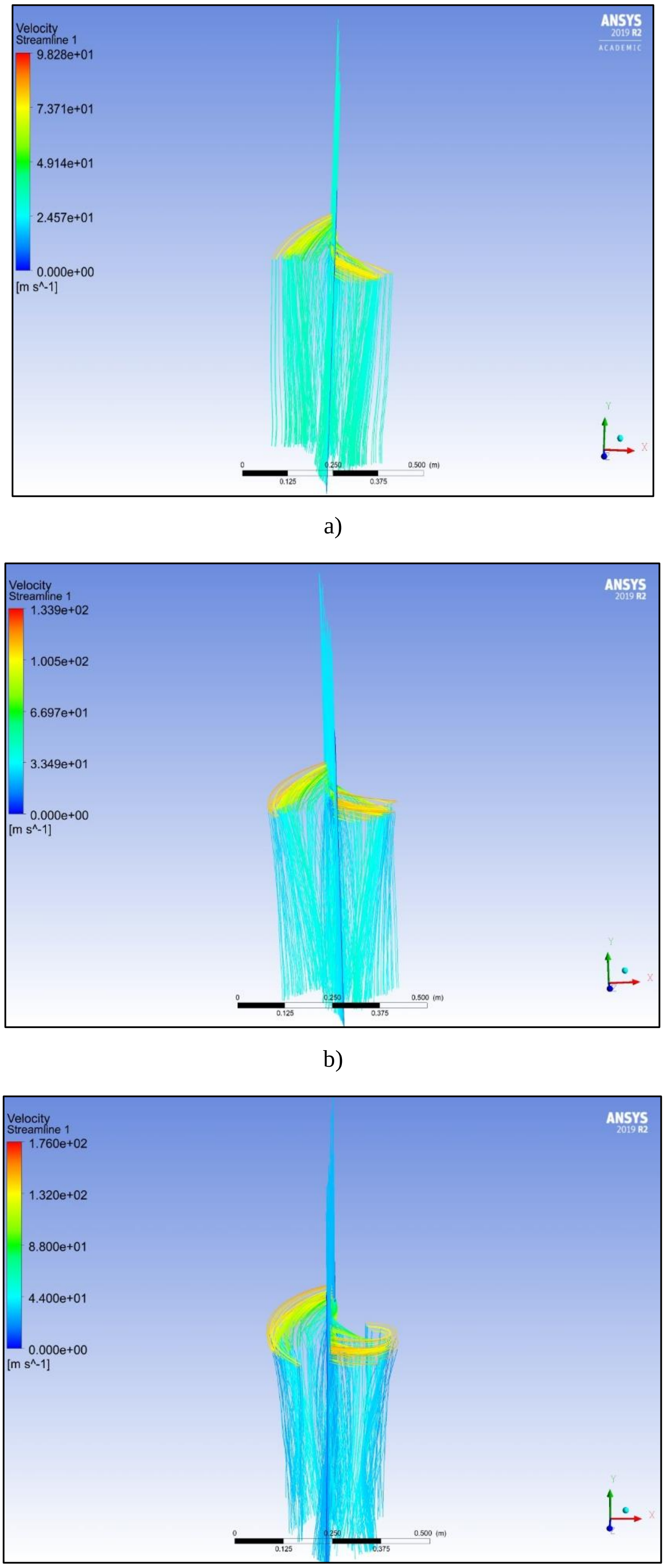


c)

Fig. 11 - Speed of propeller 2 at (a) 4000 rpm; (b) 6000 rpm; (c) 8000 rpm

3.5 Velocity streamline

Based on Fig. 12 which show Propeller 2 velocity streamline, the downward streamline at speed 4000 rpm is 24.57 ms^{-1}, at 6000 rpm is 33.49 ms^{-1} and 8000 rpm is 44 ms^{-1}. The velocity streamline is more intense at the rotating propeller as the yellow and red contour can be seen at the edge. The streamline can be observed more powerful as the speed increase and the propeller are trapped more air inside the rotating domain that led to the air flow pattern more turbulence especially at 8000 rpm.



a)

b)

c)

Fig. 12 - Velocity streamline of propeller 2 at speed (a) 4000 rpm; (b) 6000 rpm; (c) 8000 rpm

4. Conclusion

Airflow characteristic of quadcopter propeller blade was studied. By using 3 propellers with distinctive design that incorporate straight and twisting blade profile. Lift coefficient, drag coefficient and force generated was calculated. 3 different speed of blade speed also were chosen to represent the operating condition of the actual quadcopter, at 4000 rpm, 6000 rpm and 8000 rpm.

From the analysis, it is shown that Propeller 2 design is effective when the quadcopter operates at a very high rpm. It gives higher thrust and lift coefficient than others. The design of Propeller 2 which has moderate angle of attack propeller twisting profile believed to help. At 8000 rpm Propeller 2 generate highest thrust force of 33.6757 N, highest C_L of 54.98 and lowest C_D of 0.84, when compared to others propeller. When operating at medium speed of 6000 rpm, Propeller 3 is considered effective with thrust force of 18.44 N, C_L of 30.11 and C_D of 0.073.

Acknowledgement

The authors would like to express their gratitude to the Faculty of Mechanical and Manufacturing Engineering at Universiti Tun Hussein Onn Malaysia for supporting the completion of this research.

References

[1] Gynnild, A., & Uskali, T. (Eds.). (2018). Responsible Drone Journalism (1st ed.). Routledge. https://doi.org/10.4324/9781315163659.

[2] Priatmoko, M & Nirbito, Wahyu. (2019). Design Analysis of Ducted Propeller for Bicopter Drone Propulsion. IOP Conference Series: Materials Science and Engineering. 685. 012008. 10.1088/1757-899X/685/1/012008.

[3] Rhyhanul Islam Pranto, M., Hassan Dodul, S., Ilias Inam, M., Samiul Hassan Dodul, M., & Aftab Hossain, K. (2020). CFD Analysis of Flow Characteristics over Air-Propellers used in a VTOL AquaUAV Single-Bladed Darrieus Turbine View Project Numerical Analysis of a Single-bladed Darrieus Wind Turbine View project CFD Analysis of Flow Characteristics over Air-Propellers used in a VTOL AquaUAV. *International Conference on Mechanical, Industrial and Energy Engineering 2020*. https://www.researchgate.net/publication/347559039.

[4] Ucgun, H., Yuzgec, U., & Bayilmis, C. (2021). A review on applications of rotary-wing unmanned aerial vehicle charging stations. *International Journal of Advanced Robotic Systems*, *18*(3). https://doi.org/10.1177/17298814211015863.

[5] Nasa. (2020). *STEM LEARNING: Advanced Air Mobility: The Science Behind Quadcopters Reader-Student Guide*. www.nasa.gov.

[6] Kuantama, E., Moldovan, O. G., Ţarcă, I., Vesselényi, T., & Ţarcă, R. (2021). Analysis of quadcopter propeller vibration based on laser vibrometer. *Journal of Low Frequency Noise Vibration and Active Control*, *40*(1), 239–251. https://doi.org/10.1177/1461348419866292.

[7] Yuvaraj, S., C.J, T. R., Artūras, J., J, D. R., M, N., & P, K. (2019). *Design and Numerical Analysis of Five Blade Propeller for a Drone*.

[8] Othman, M. N. K., Razlan, Z. M., Wahid, Z. A., Shahriman, A. B., Zunaidi, I., Khairunizam, W., & Noriman, N. Z. (2019). Experimental study of UAV propeller Thrust generation for various Propeller Blade-Span and the relation.

[9] Kostic, C., & Rasuo, B. (2016a). Aerodynamic airfoil at critical angles of attack. *Vojnotehnicki Glasnik*, *64*(3), 784–811. https://doi.org/10.5937/vojtehg64-8048.

[10] Wu, Y. T., Qin, Z., Eizad, A., & Lyu, S. K. (2021). Numerical investigation of the mechanical component design of a hexacopter drone for real-time fine dust monitoring. *Journal of Mechanical Science and Technology*, *35*(7), 3101–3111. https://doi.org/10.1007/s12206-021-0632-y.