

The Performance of Airfoil with Lift Fan During Vertical Take-Off and Landing (VTOL) Condition

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Abstract - This study investigated the performance of electric drive ducted lift-fan propeller in the airfoil during vertical take-off and landing (VTOL) condition. The experiment was conducted using subsonic wind tunnel in two configurations; with and without electric ducted fan (EDF), with three different speeds of lift-fan (50W, 100W and 175W). Three different types of Reynolds number (1.4×10^5 , 2.8×10^5 , and 4.1×10^5) were used to study the aerodynamics forces. The results indicated that airfoil fitted with 175W EDF with low Reynolds number produced significant lift to drag ratio. Thus, it is suitable for vertical take-off and landing (VTOL) purposes.

Keyword- Vertical Take-off and Landing (VTOL), lift-fan propeller, subsonic wind tunnel

1.0 INTRODUCTION

Nowadays, the fact that airfoil that can create lift is a common in the field of aerodynamics. However, the concept and the design of the airfoil that able to create a vertical or short take-off is still new. Generally, aircraft with a vertical take-off and landing (VTOL) wing airfoil is the one that can hover, take off, and landing vertically (Rougeau, 2014). The classification includes helicopters and other aircraft with powered rotors, such as cyclogyros or cyclocopters, tail sitter and tilt rotors. Some of the VTOL aircraft can be operated in other modes such as CTOL (conventional take-off and landing), STOL (short take-off and landing), and/or STOVL (short take-off and vertical landing) (Antosh et al 2014).

Generally, the conventional fixed wing aircraft, like commercial aircraft, are generating lift by forward movement of the entire aircraft. The wings fixed in relation to the fuselage generate lifting force to achieve flight; whereby the conventional rotary aircraft like helicopter, generated lift by rotating multiple blades connected to a shaft. The blades generated lift as the rotational speed increases to achieve flight. Helicopters are considered the most efficient VTOL aircraft due to low disc loading.

The benefits of the vehicles with VTOL are they can be deployed from a variety of environments, whereas conventional airplanes required a runway. Also, in surveillance applications, a VTOL vehicle can hover over a target for extended periods of time (Austin, 2010). There are a lot of functions of a ducted lift fan according to research by Tian, 2010. The first and foremost is to provide safety for the personnel handling the UAV (Unmanned Aerial Vehicle) by preventing any physical contact between the human and the rotating propeller at high speed. The duct also serves to protect other parts of the aircraft structure. For instance, in the event that the UAV lose control and crash to the ground, the fan duct can absorb most of the impact and protect the propeller blade from any damages. In addition, the fan duct also helps to prevent the spinning propeller from damaging other part of the aircraft structure. For an open fan propeller configuration, flow passing through the propeller slipstream may experience natural contraction, causing an increase in the far wake velocity, which led to additional power losses. Diffuser section of the ducted fan propeller helps to reduce this power loss by restraining the contraction of the slipstream. Theoretically, the expansion ratio which depends on both diffuser (duct) angle and length can be increased without limit to attain maximum performance benefit (Rutkowski & Krusz, 2013).

Lift fan propeller either ducted or inducted type are able to assist in lift with correct design and modification. In this current work, electric duct fan attached inside the airfoil is evaluated with the aim to investigate the performance of lift-fan inside the airfoil to generate the vertical take-off and landing (VTOL) purposes.

2.0 EXPERIMENTAL SET UP

2.1 Wind tunnel set up

The entire tests are conducted in an open circuit subsonic wind tunnel as shown in Fig. 1. The sizing of the tunnel test section is

300mm x 300mm x 600mm, provided with transparent test section walls for visualization and measurement purposes. The model fitted onto the axis balance which integrated with the test section as shown in Fig. 2. The maximum velocity at the test section is 50m/s.

The flow enters the wind tunnel through a settling chamber containing a honeycomb and screen is put after the inlet before the contraction cone. Large scale turbulence is reduced by honeycomb strengthens. Honeycombs straighten the flow by reducing the lateral velocities where the screen reduces the axial turbulence. Fine screen breaks the existing turbulence into the smaller vortices. A sufficient

distance is provided that these small disturbances die out before they reach the model.



Fig. 1: The experimental setup with open circuit low speed wind tunnel



Fig. 2: The model fitted onto the axis balance in the test section

2.2 Design specification

NACA 23012 airfoil is used in this study. The NACA 23012 airfoil develops a reasonably high maximum lift and a low profile drag, which results in unusually high value of the speed-range index. Moreover, the pitching-moment of the airfoil is quite small. There are two design of airfoil; one is plain airfoil, and the other one is

airfoil equipped with electric ducted fan (EDF) fitted perpendicular to the chord line (see Fig. 3 and Fig. 4). All the two airfoils are design with chord length and span at 220mm and 185mm respectively.

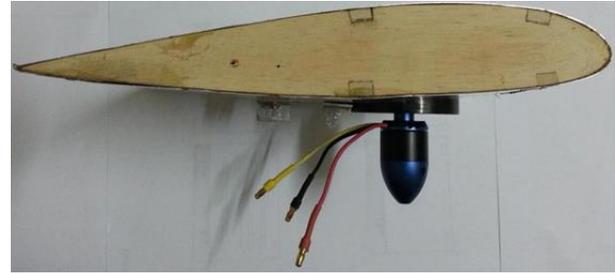


Fig. 3: Side view of the airfoil fitted with EDF

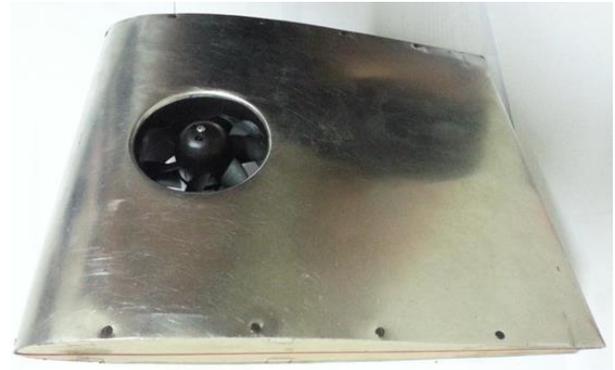


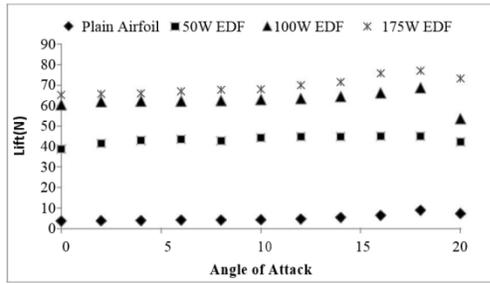
Fig. 4: Top view of airfoil fitted with EDF

The electric ducted fan (EDF) used in this study has a maximum power rating of 175 Watt , approximately similar to 3500 KV with 55g weight.

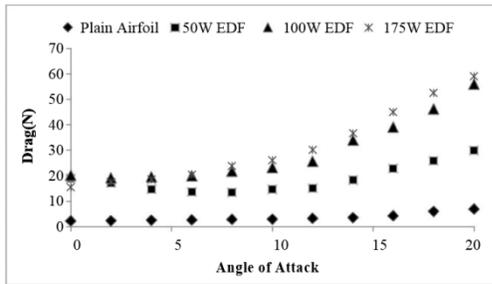
3. RESULT AND DISCUSSION

3.1 Effect of different EDF parameter

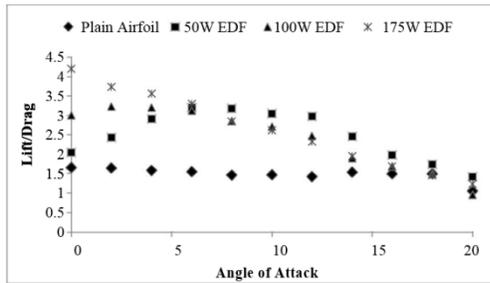
The airfoils for plain (without EDF), 50W EDF, 100W EDF and 175W EDF were investigated. The Reynolds number 2.8×10^5 was used. The results were depicted in Fig. 5. The results showed that airfoil fitted with 175W EDF produced the highest lift forces compared to others. The lift forces increased steadily for all cases until the airfoil stalled at an angle of 20° . In Fig. 5(c), it was observed that the airfoil fitted with EDF is suitable for vertical take-off from the angle 0° to 4° . The most effective case is the airfoil fitted with 175W EDF. However, there is no increment found after 6° angle of attack and the result showed that 175W EDF is not suitable for high angle of attack.



(a)



(b)



(c)

Fig. 5: Reynolds number at for all cases, (a) Lift forces versus α , (b) Drag force versus α , and Lift/Drag versus α

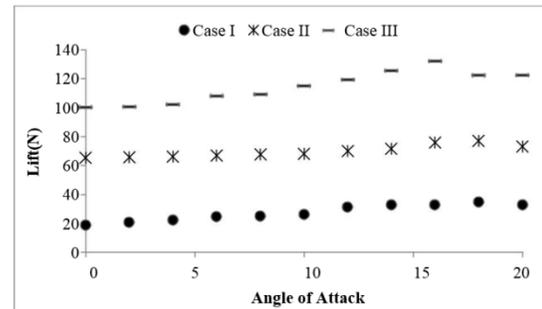
3.2 Effect of Reynolds number

Further investigation has been conducted to investigate the effects of different Reynolds number on 175W EDF. Table 1 showed the velocity magnitude, u , (m/s) in the range of 10m/s, 20m/s to 30 m/s. The electric ducted fan was performed at the 175 Watt correspond to 3500 KV.

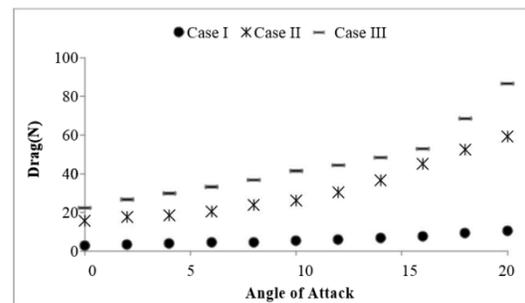
TABLE 1 : REYNOLDS NUMBER PROPERTIES

Cases	Velocity magnitude, u , (m/s)	Reynolds number (Re)
Case I	10	1.4×10^5
Case II	20	2.8×10^5
Case III	30	4.1×10^5

Fig. 6 showed the effects of different Reynolds numbers on airfoil fitted with 175W EDF. The lift forces for all cases were found to increase steadily. The high Reynolds number cases showed the highest lift forces compared to other two cases for this section. Meanwhile, the lift to drag ratio for the lowest Reynolds number case showed the highest value and decreased steadily according to the increment of the angle of attack. The results indicated that, the airfoil fitted with 175W EDF is more effective at a lower Reynolds number.



(a)



(b)

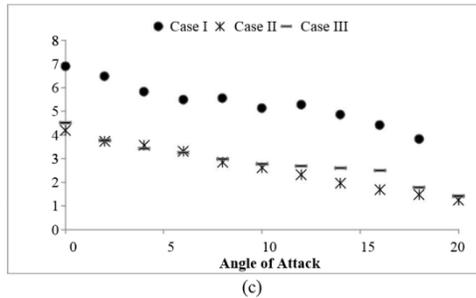


Fig. 6: Comparison with different Reynolds number for 175 W EDF case,
(a) Lift forces versus α , (b) Drag forces versus α , and (c) Lift/Drag versus α

4. CONCLUSION

The investigation of plain airfoil and airfoil fitted with EDF motor has been carried out in this study. The effects of different Reynolds number on airfoil fitted with 175W EDF has been analysed accordingly. The results indicated that airfoil fitted with 175W EDF with low Reynolds number produced significant lift to drag ratio. Thus, it is suitable for vertical take-off and landing (VTOL) purposes.

5. REFERENCES

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