GE-International Journal of Engineering Research
Vol. 4, Issue 2, Feb 2016 IF- 4.007 ISSN: (2321-1717)

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MODELLING THE EFFECTS OF ENDPLATE ADDITION ON THE MI-VAWT1 AIRFOIL BLADE AT LOW WIND SPEED

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ABSTRACT

Endplates has been used on aircraft wings to reduce drag and increase lift. However, the application to wind turbine blades are limited. This study investigated the effects of end plates on the lift coefficient of the straight bladed vertical axis wind turbine blade. Modelling and simulation with the XFOIL program at low Reynolds number ranging from 332000 to 964000corresponding to the low wind velocity range experienced by wind turbines was undertaken. Lift coefficient values were simulated for angle of attack ranging from 0^o to15^o.The percentage difference in lift coefficient with and without endplates at 0^o, 5^o, 10^o and 15^o angle of attack was 0%, 3.9%, 4.4% and 33%, respectively, for the MI-VAWT1 airfoil at all Reynolds numbers.

Keywords – endplates, lift coefficient, vertical axis wind turbine

1. INTRODUCTION

Wind energy is one of the more feasible options as a renewable energy alternative for small island Caribbean countries [1]. With the growing effects of global warming Caribbean island governments has been investing in wind turbines [2]. The practical advantages of being able to operate with wind flow from any direction and having the generating unit close to the ground makes the vertical axis wind turbine (VAWT) a better choice for small islands. However, the major disadvantage is the low efficiency when compared to the horizontal axis wind turbine. With an improved efficiency thestraight bladed Darrieus vertical axis wind turbine (SB-VAWT) can be very attractive for its low cost and simple design [3].

Selection of airfoil is one of the most critical factors in achieving better aerodynamic performance. Airfoil related design changes has the potential for increasing the efficiency and the cost effectiveness of SB-VAWTs making them prospective candidates for diversified urban and rural applications [4]. Research showed thatconventionally-used old NACA 4-digit symmetric airfoils were not suitable for smaller capacity SB-VAWT [4]. Rather, it was advantageous to utilize a high-lift and low-drag asymmetric thick airfoil such as the MI-VAWT1. This was more suitable for low speed operation typically encountered by SB-VAWT [4, 5]. In this study the performance enhancement characteristic with the addition of end plates to the MI-VAWT1 airfoil was investigated and modeled to determine the increase in lift coefficient at relatively low Reynolds number.

2. END PLATE EFFECTS

The use of endplates as a possible means of improving the aerodynamic characteristics of un-swept wings has been investigated by Shawn Roberts 1966, Elliott Reid 1925 and Donald Riley 1951[6, 7, 8]. The results indicated that the endplate provided an increase in the lift-curve slope, a reduction in the induced drag, and an increase in the maximum lift coefficient of the basic wing. Theoretical and empirical analysis on endplate effects concentrated mainly on predicting the lift curve slope and the induced drag as related to the aircraft industry [9]. Few research focused on the effect of endplates on the lift drag and maximum lift drag ratios. However, the favorable effects of endplates on the lift and induced drag suggested the possibility of using endplates as a means of increasing the lift drag and maximum lift drag ratios of airfoil blades used in SB-VAWT [8].

It is well established that tip vortex caused downwash that modified the pressure distribution on the airfoil surface and increased the induced drag [10]. Tip vortices modify the local flow-field by creating an induced horizontal velocity that decreased the local angle of attack. The total drag coefficient, C_D, for a wing can be expressed by:

$$C_D = C_{D.p} + C_{D.f} + \frac{C_L^2}{(\pi.e.AR)} \quad (1)$$

where*e* is the span efficiency, $C_{D.p}$ is the drag component of the total aerodynamic force over the wing surface, $C_{D.f}$ is the drag caused by friction, *AR* is the aspect ratio, and $\frac{C_L^2}{(\pi.e.AR)}$ is the induced drag [8].

The use of endplate deterred the flow from the high pressure region on the airfoil to reach the low pressure region on the outside of the wing. Also, the endplate slowed down the flow near the airfoil tip. This decrease in velocity reduced the pressure drop on the low pressure side of the wing corresponding to the vortex core.

3. MI-VAWT1 AIRFOIL WITH ENDPLATE MODELING

The majority of available theory and theoretical modeling of airfoil with endplate attached weredeveloped for the testing of aircraft wings. With respect to the SB-VAWT the major drawback with the available theoretical data was that the aircraft wings do not experience varying angles of attack like that of the SB-VAWT blade. Also, aircraft wings experience much higher Reynolds numbercompared to theSB-VAWT [3].

For the purpose of modeling, the endplate effect on the lift coefficient is usually expressed as an increase in the aspect ratio of the basic wing. The amount of increase varied with the geometric characteristics on the endplate. To model the lift coefficient for a wing with endplate attached required a wing theory that would predict fairly accurate values of lift coefficient. The lift-curve slope can be expressed as:

$$C_{L\alpha} = \frac{c_{l\alpha}}{E_e + \frac{57.3\, c_{l\alpha}}{\pi A}} \tag{2}$$

whereE_e is the effective edge velocity correction, $c_{l\alpha}$is the section lift curve slope, and A is the wing aspect ratio [8].

The total drag coefficient,C_D(Donald 1951) is found from [8]:

$$C_D = C_{Dw} + \frac{C_L^2}{\pi A_e} + 2C_{Dep}\frac{S_{ep}}{S_W} + \Sigma C_D + C_{Dp} \tag{3}$$

where C_{Dw} is the wing profile drag coefficient, A_e is the effective aspect ratio, C_{Dep} is the endplate profile drag coefficient based on endplate area, S_{ep} is area of endplate without area of wing, S_W is area of wing and C_{Dp} is the parasitic drag coefficient.

The Lift-Drag ratio can be expressed as [8].

$$\frac{L}{D} = \frac{C_L}{C_{Dow} + \frac{C_L^2}{\pi A_e} + 2C_{D0ep}\frac{S_{ep}}{S_W} + \Sigma C_D + C_{Dp}} \tag{4}$$

The Lift coefficient at maximum lift-drag ratio can be expressed as [8].

$$C_{L(L/D)_{max}} = \sqrt{\pi A_e \left(C_{Dow} + 2C_{D0ep}\frac{S_{ep}}{S_W} + \Sigma C_D + C_{Dp}\right)} \tag{5}$$

The Maximum Lift-Drag ratio can be expressed as [8].

$$\left(\frac{L}{D}\right)_{max} = \frac{1}{2}\sqrt{\frac{\pi A_e}{C_{Dow} + 2C_{D0ep}\frac{S_{ep}}{S_W} + \Sigma C_D + C_{Dp}}} \tag{6}$$

4. XFOIL MODELING

The XFOIL 1.0 program was developed to combine the speed and accuracy of high-order panel methods with the new fully-coupled viscous/inviscid interaction method used in the ISES code developed by Drela and Giles 1987 [11, 12].Figures 1 to 4 shows four examples that were used to calculate the values for the lift coefficient obtained for the MI-VAWT1 airfoil using the XFOIL software without endplates at different values of Reynolds number. The program was again used to model the effects of the endplate on the lift coefficient of the airfoil blade at the respective Reynolds number.Table 1 shows the variation of lift coefficient for the MI-VAWT1 airfoil with increasing Reynolds number modeled with and without end plates for angle of attack ranging between 0^o to 15^o.

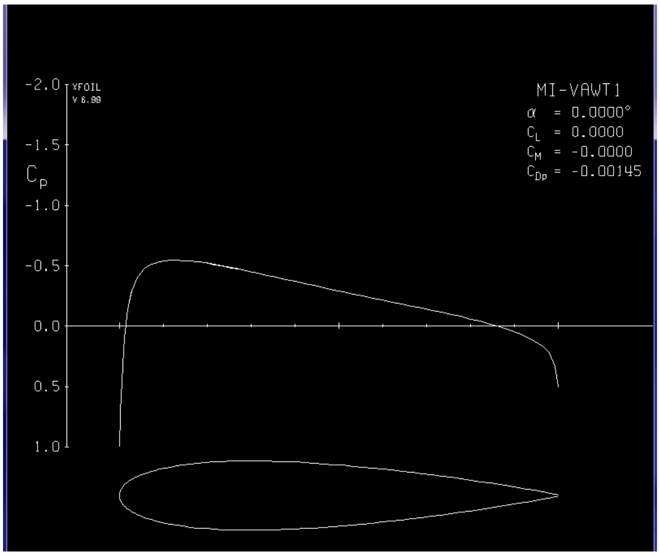

FIGURE 1: XFOIL SIMULATION AT REYNOLDS NUMBER OF 332000 AND ANGLE OF ATTACK 0^O.

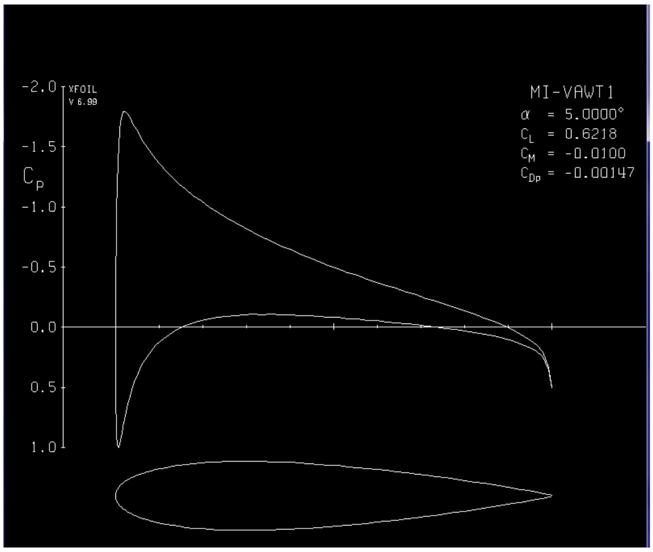

FIGURE 2: XFOIL SIMULATION AT REYNOLDS NUMBER OF 332000 AND ANGLE OF ATTACK 5^O.

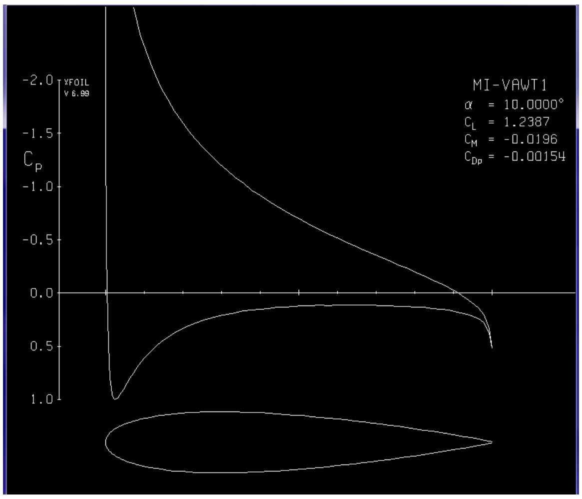

FIGURE 3: XFOIL SIMULATION AT REYNOLDS NUMBER OF 332000 AND ANGLE OF ATTACK 10^{O}.

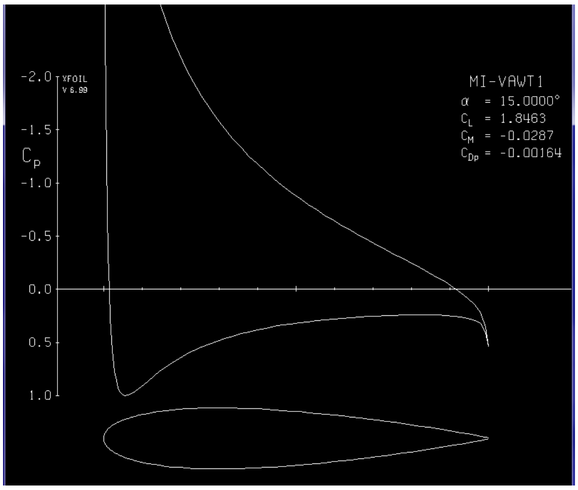

FIGURE 4: XFOIL SIMULATION AT REYNOLDS NUMBER OF 332000 AND ANGLE OF ATTACK 15^{O}.

TABLE 1: VARIATION OF LIFT COEFFICIENT FOR THE MI-VAWT1 AIRFOIL WITH INCREASING REYNOLDS NUMBER

Reynolds Number	Angle of Attack (^{o})	XFOIL Simulation - Lift Coefficient With endplate	XFOIL Simulation - Lift Coefficient Without endplate
332000	0	0	0.000
	5	0.6218	0.598
	10	1.2387	1.186
	15	1.8463	1.387
532000	0	0	0.000
	5	0.6218	0.598
	10	1.2387	1.186
	15	1.8463	1.387
731000	0	0	0.000
	5	0.6218	0.598
	10	1.2387	1.186
	15	1.8463	1.387
964000	0	0	0.000
	5	0.6218	0.598
	10	1.2387	1.186
	15	1.8463	1.387

5. DISCUSSION AND CONCLUSIONS

The effects of reduced drag and increase lift with the addition of end plated on aircraft wings has been well established. The effects of end plates on SB-VAWT has not been fully ventilated. The major difference between the aircraft and the wind turbine is that the angle of attack experienced by the aircraft wing do not change whereas the angle of attack of the SB-VAWT changes continuously as the turbine rotates. The XFOIL program was used to simulate the lift coefficient on a SB-VAWT at low Reynolds number ranging from 332000 to 964000. This corresponded to the comparatively low wind speed that the wind turbine will experience as compared to an aircraft. The simulated results on Table 1 showed that the lift coefficient increased exponentially as the angle of attack increased from 0^o to 15^o. The percentage difference in lift coefficient with and without endplates at 0^o, 5^o, 10^o and 15^o angle of attack was 0%, 3.9%, 4.4% and 33%, respectively, for the MI-VAWT1 airfoil at all Reynolds numbers. Increasing the angle of attack further was not investigated as the wind turbine would experience dynamic stall at higher angles of attach.

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