THE EFFECT OF GURNEY FLAP ON FLOW CHARACTERISTICS OF VERTICAL AXIS WIND TURBINE

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Recently, Gurney Flap (GF) has been used to improve the performance of Horizontal Axis Wind Turbine (HAWT) by enhancing its lift coefficient. Compared to HAWT, the research on GF application for Vertical Axis Wind Turbine (VAWT) is very limited. Moreover, most work studied a GF geometry attached to the trailing-edge of a stationary airfoil, without considering the rotating effect experienced by VAWT. For this reason, a three-straight-bladed VAWT rotating blades with GF is studied by transient RANS simulation together with a stress-blended eddy simulation turbulence model to investigate the GF height effect and the flow characteristics near the blade trailing-edge. Results have shown that by introducing the blade rotating, an optimum GF height is found to be 3% of the blade chord, slightly higher than 2% chord in a stationary airfoil case. In addition, the presence of GF can suppress deep stall of VAWT blades, thus eliminating negative instantaneous moment coefficient and improving the turbine performance.

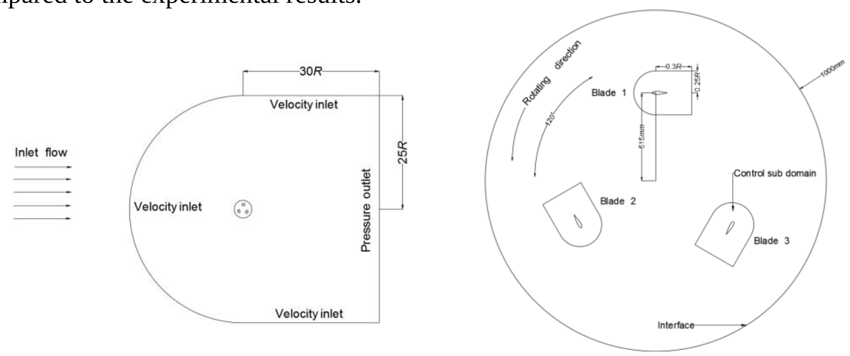
Keywords: Stress-blended eddy simulation; Vertical axis wind turbine; Gurney flap; Delayed flow separation.

1. Introduction

There are increased researches for Vertical Axis Wind Turbines (VAWTs) nowadays due to its outperformance in urban area applications than Horizontal Axis Wind Turbines (HAWTs).[1] However, VAWTs still need to improve its efficiency and self-starting ability, to compete with HAWTs commercially. One possible solution is to introduce a passive device such as Gurney Flap (GF) at the blade trailing-edge to enhance its lift coefficient. For a stationary single airfoil, the existence of GF will generate counter-rotating vortices downstream with a significant flow turning over leeward of the flap[2], leading to the decreases of wake momentum deficit and the increases of lift force. Recently, GF has been applied in HAWTs to improve the performance of turbine blades with smaller chord length.[3] Results showed that blade with GF indeed can increase the power generation of the wind turbine compared to those with no GF installed. In case of VAWTs, there are limited studies on the GF application.[4-5] Most researches presented merely focused on the outcome of power coefficient increment (by referring to the work of Liebeck [2]), rather than further analyzing and explaining its underlying flow physics and characteristics. Moreover, previous work did not consider the rotating effect that could have significant impact on blade-wake interaction and power production of VAWT due to unsteady power conversion at high angle of attack (AoA) in dynamic stall regime.[6] The blade rotation will also affect the performance of GF geometry at different AoA.[7] Hence, the optimum GF geometries obtained from a stationary single airfoil may not be viable for the VAWT applications. Therefore, this study intends to investigate the effect of GF height on the performance of a three-straight-bladed VAWT, and also to realise its underlying flow physics and characteristics.

2. Methodology

Computational Fluid Dynamics (CFD) are used to solve unsteady flow around a two-dimensional model of a rotating three-straight-bladed VAWT with NACA0021 airfoil as cross-section profile featured in the study of Castelli *et al*.[8] A Gurney Flap is mounted at the trailing-edge of the airfoil. The GF width is fixed at 0.33% of the airfoil chord (*c*). The GF height is varied from 1%, 1.5%, 2%, 3% to 4% of *c*, measured from the lower point of the trailing edge wall. The free stream velocity is set to be 9 *m/s*. This study is conducted at an optimum tip speed ratio (*TSR*) of an original airfoil without GF (i.e. *TSR*=2.64). The simulation is carried out with a pressure-based solver due to low-speed incoming flow. After preliminary study, a stress-blended eddy simulation (SBES) turbulence model with transition shear-stress transport (SST) is chosen as it gave the smallest deviations while compared to the experimental results.[8]



(a) Overall Computational Domain (b) Rotating core sub-domain

Fig. 1. Detailed computational domain and sub-domains of the simulation.

A C-type grid topology is used and the computational domain is divided into three sub-domains (see Fig. 1), namely far field (non-rotating domain), rotating core sub-domain (rotating domain) and three control sub-domains with embedded blades. The first grid height on the blade surface is designed to satisfy a criterion of non-dimensional wall distance $\Delta y_1^+ < 1$ for transition SST turbulence model. A grid convergence study is conducted and it is found that a total number of 189,807 grids with 174 cells around one blade surface is able to produce CFD predictions in good agreement with available experimental results.[8]

3. Results and Discussion

Fig. 2 shows that in general the power coefficient (C_p) of VAWT will increase with the increase of the Gurney Flap height, with a maximum C_p value achieved at a height of about 3% of the chord. After that, the GF will lose its capability to increase the C_p further. Compared to a single stationary airfoil with an optimum GF height of 2% *c*, this optimum GF height is slightly higher, possibly due to the rotating effect and the wake-blade interactions. This confirms that those findings from a single stationary airfoil with GF are not applicable to the rotating wind turbine blade applications.

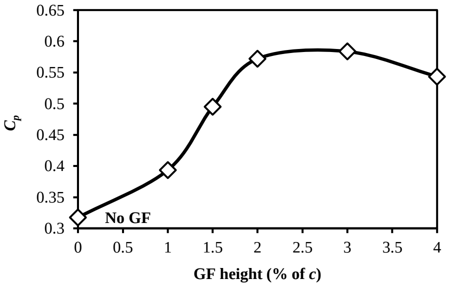


Fig. 2. Comparison of power coefficient of VAWT with and without GF at various GF heights.

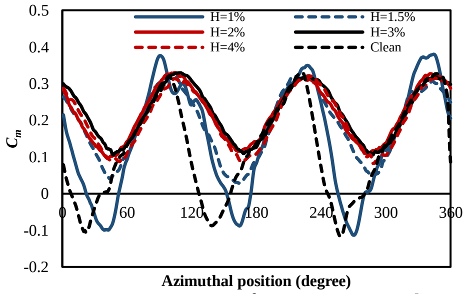


Fig. 3. Comparison of instantaneous total moment coefficients distribution of VAWT with and without GF at various GF heights.

Fig. 3 illustrates the instantaneous moment coefficients (C_m) distribution over one turbine revolution with different GF heights. The C_m distribution demonstrates that the addition of GF with a height equal to or higher than 1.5% of the chord can remove the negative value of C_m, resulting in an increased power output of the turbine. Moreover, the presence of GF can postpone the deep stall of turbine blades, indicated by a slower drop rate in C_m curves after reaching its maximum peak.

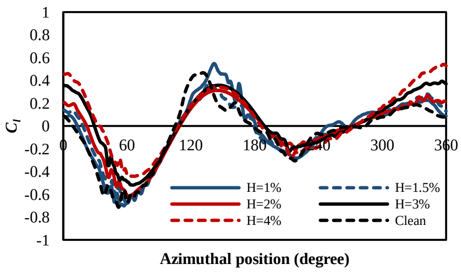


Fig. 4. Comparison of instantaneous lift coefficients distribution of one rotation cycle at various GF heights.

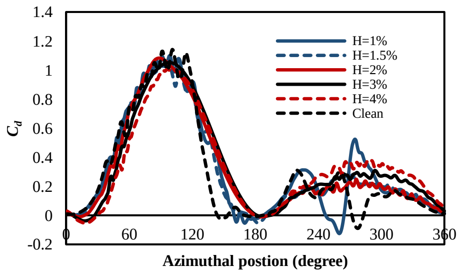


Fig. 5. Comparison of instantaneous drag coefficients distribution of one rotation cycle at various GF heights.

In order to further understand the effect of GF addition on turbine performance, distributions of instantaneous lift coefficient (C_l) and drag coefficient (C_d) of one selected blade over one rotation cycle are depicted in Fig. 4 and Fig. 5, respectively. It shows that the GF addition can reduce the fluctuation amplitude of C_l and delay the sudden increase of C_d at an azimuthal position of about 90°. This confirms that the GF can ease the deep stall of turbine blades. The unsteady behaviour of C_l and the rapid increment of C_d also suggest that the VAWT will start to experience the stall between azimuthal positions of 60^o-100^o, approximately.[7] Further investigation on the pathlines coloured by vorticity magnitude (not shown here) reveals that the GF addition can certainly introduce vortices in downstream which can change the adverse pressure gradient near the trailing edge. Moreover, the contours of root mean square error (RSME) velocity magnitude (not shown here) suggest that the GF can enhance the velocity magnitude over the suction surface side while decrease it on the pressure surface side. As a result, the flow separation can be delayed, and the total circulation of the blade will increase. Therefore, this lift enhancement which further leads to more power generation achieved by using the GF.

4. Conclusion

The effect of GF geometry at blade trailing edge and its optimum height on the performance has been studied for a three-straight-bladed VAWT. Results have confirmed that the GF addition of an optimum height (3% *c*) can significantly increase the power coefficient compared to original blade without GF. The rotation is found having small impact on optimum GF height compared to a stationary single airfoil (i.e. 2% *c*). The flow characteristics indicate that the GF addition can delay the deep stall of the turbine blades, and also can produce positive moment coefficients, thus resulting in an improved power coefficient.

Acknowledgments

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