Numerical Analysis of Influence of Gurney Flaps Applied to Wind Turbines

Zhang Zhenyu（张震宇）*, *Zhou Hanwei*（周翰玮）, *Wang Tongguang*（王同光）

Jiangsu Key Laboratory of Hi-Tech Research for Wind Turbine Design, Nanjing University of Aeronautics
and Astronautics, Nanjing, 210016, P. R. China

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Abstract: The effect of Gurney flaps with different heights on the S809 airfoil and NH1500 blade is numerically simulated. The influence of the Gurney flap is analyzed at different wind speeds and the comparison of the aerodynamic performance is given between the blades with and without the Gurney flap. The results demonstrate that a Gurney flap added on the blade can greatly increase the efficiency of the wind turbine especially at high wind speeds.

Key words: wind turbine; Gurney flap; flow control

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1 Introduction

Blade is one of the most important parts of a wind turbine. The blade aerodynamic performance significantly influences the efficiency of wind energy conversion[1]. Over the years, high-lift devices have attracted the attention of wind turbine blade designers and engineers as good blade design can improve the wind energy converting efficiency of wind turbine through aerodynamic enhancement. One of such devices is flaps. In consequence of influence of the boundary layers, vortices and flow separations, flows over the flap are very complicated, making the design of the device very difficult. Among all kinds of flaps, Gurney flap is relatively easily designed. The Gurney flap is a short flat plate attached to the trailing edge, which is perpendicular to the chord line on the pressure side of the airfoil (Fig. 1). The Gurney flap has drawn much attention over decades due to its effectiveness and simplicity.

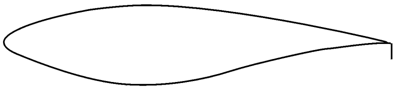

Fig. 1 Gurney flap configuration

Liebeck first conducted a wind tunnel test for Newman airfoil with Gurney flap in 1978[2], proving that Gurney flap could enhance the lift obviously with the maximum lift coefficient increased and the zero-lift angle decreased. Following his work, much research has been done on Gurney flaps[3-8]. The studies of Gurney flap application on wind turbine blades have also been carried out for years. Experiments with traditional airfoils such as NACA0014, NACA0020 and wind turbine profiles such as S809 with Gurney flaps were conducted[9-10], showing that the lift was enhanced and the flow separation was delayed by the Gurney flap.

In this paper, both S809 airfoil with Gurney flap of different heights and the NH1500 blade with a 4% chord height Gurney flap are used to investigate the Gurney flap effects based on computational fluid dynamics (CFD) simulations in two-dimensional (2-D) and three-dimensional (3-D) conditions, respectively.

2 Computational Method

The numerical simulations are performed

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* **Corresponding author**: Zhang Zhenyu, Lecturer, E-mail: zyzhang@nuaa.edu.cn.

using ANSYS FLUENT. The governing equations are the incompressible Reynolds average Navier-Stokes (RANS) equations, which take the form

$$\frac{\partial W}{\partial t}=-\frac{1}{\Omega}[\oint_{s}(F_{e}-F_{v})\mathrm{d}s-\int_{\Omega}Q\mathrm{d}\Omega]$$

where W is the conservation variables, F_e the convective fluxes, F_v the viscous fluxes, and Q the source term of body force[11].

By consideration of its ability in both fully developed flow and along the boundary layer regions, the SST k-ω turbulence model is chosen to enclose the RANS equations[12].

The meshes are generated by the Integrated Computer Engineering and Manufacturing Code for CFD (ICEMCFD). Approximately 150 000 cells were generated for the 2-D airfoil and 850 000 cells for the 3-D blade. Fig. 2 shows the mesh in the whole flowfield and the mesh zoomed on the boundary layer for the airfoil. Fig. 3 shows the fluid domain and boundary condition, followed by the surface mesh in Fig. 4 for the 3-D blade.

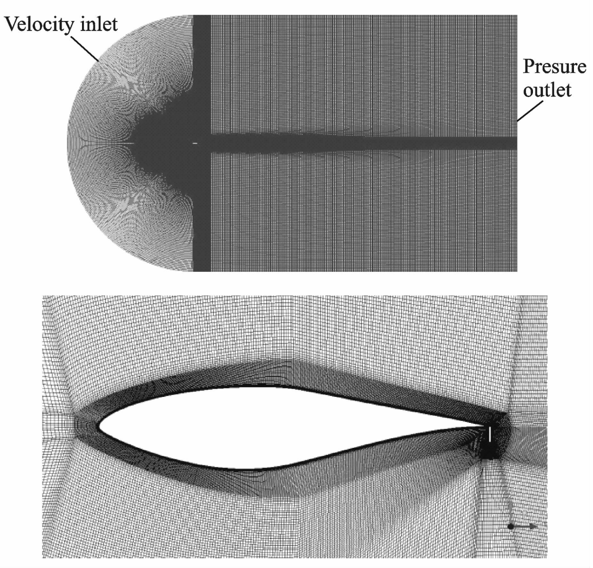


Fig. 2 Fluid domain mesh of 2-D case

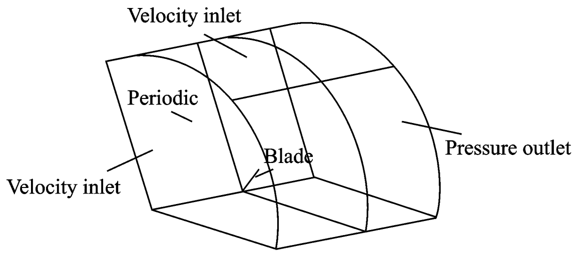


Fig. 3 Fluid domain and boundary condition of 3-D case

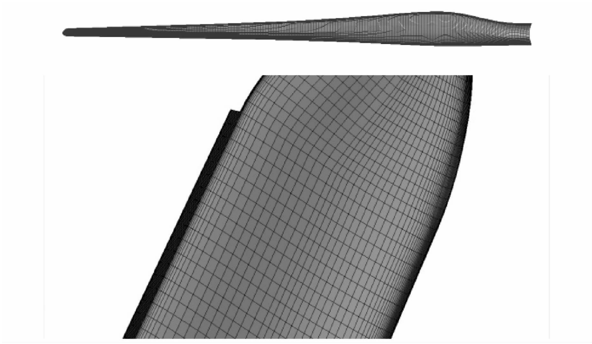


Fig. 4 Surface mesh of blade and Gurney flap

3 CFD Results and Discussion

3.1 Airfoil with Gurney flap

As the first part of the analysis, the aerodynamic characteristics and flow structures of S809 airfoil with Gurney flap of different heights are studied. The chord length of the S809 airfoil model is 1 m.

Fig. 5 shows the calculated lift coefficients of S809 airfoil with Gurney flap of 1%, 2%, 3%, and 4% chord heights at a Reynolds number of 30 000. Compared with the experimental results of a clean S809 airfoil, it is obvious that the lift coefficient is increased by the Gurney flap with the increased height of Gurney flap, with one exception for the 4% height when the angle of attack is larger than 14°. In addition, the results in Fig. 5 also indicate the difference of stall performance, that is, the stall starts at 14° for the clean airfoil, whereas the stall starts at 16° for the airfoil with 1% , 2% and 3% chord height Gurney flaps, respectively. Besides, the stall performan-

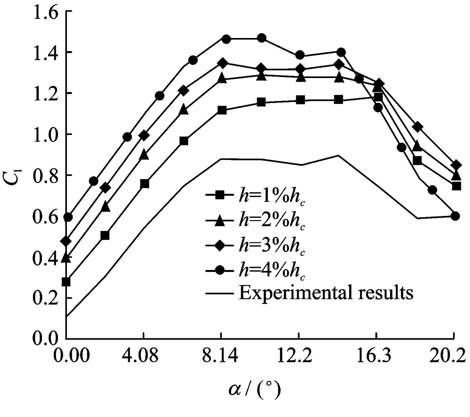


Fig. 5 Calculated lift coefficients of airfoils with Gurney flap compared with experimental results of a clean airfoil

ce of airfoil with 4% chord height Gurney flap is worse than that of the clean airfoil.

Fig. 6 gives the streamlines around the airfoil with Gurney flap of 4% chord height, in which a separating bubble appears in front of the Gurney flap and a pair of reverse vortices appear behind the Gurney flap initially at the 0° angle of attack. This streamline result is similar to other computational and experimental results provided in Refs. [3, 7]. The lower vortex begins to break down at 12. 2°, and finally disappears at 18. 1°, where a airfoil tailing-edge vortex is produced by the separation on the airfoil upper surface and is possibly pushed upwards by the vortex generated by the Gurney flap.

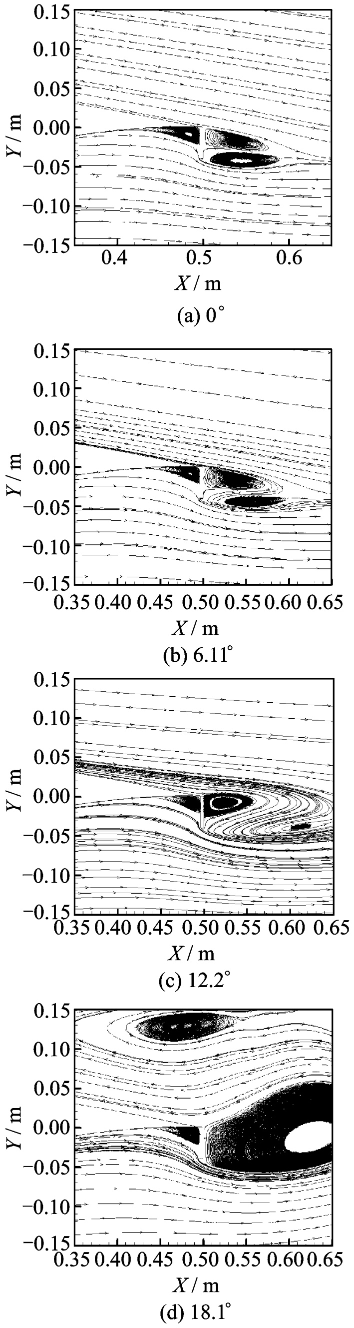


Fig. 6 Streamlines around the Gurney flap for the angles of attack of 0°, 6. 11°, 12. 2°, and 18. 1° at Reynolds number of 30 000

3. 2 Blade with Gurney flap

In this part, the aerodynamic characteristics and flow structures of a 1. 5 MW NH1500 wind turbine blade[10] equipped with Gurney flap of 4% local chord height is studied. The Gurney flap is attached perpendicular to the local chord line of the blade at the tailing edge. The computational results at the wind speeds of 4, 6, 8, 10 m/s are given here and then compared with the experimental data from Ref. [10].

In Fig. 7, comparing with the prototype blade NH1500 the wind turbine power output at different tip speed ratios (TSRs) is increased by the Gurney flap. In the range of TSRs considered, the increment in power output decreases with increased TSR corresponding to increased wind speed with a maximum value of 28% at the TSR of 7. 3.

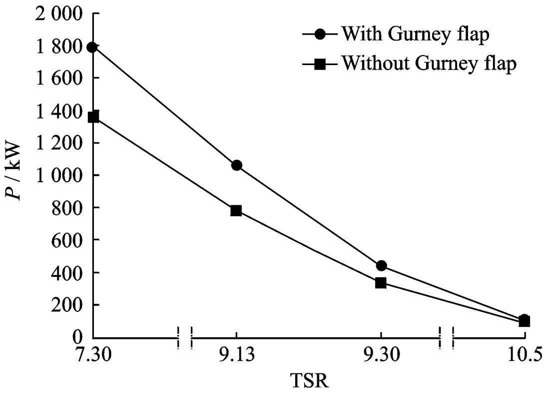
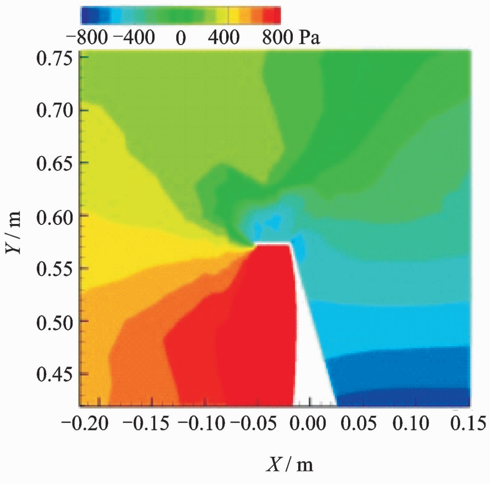
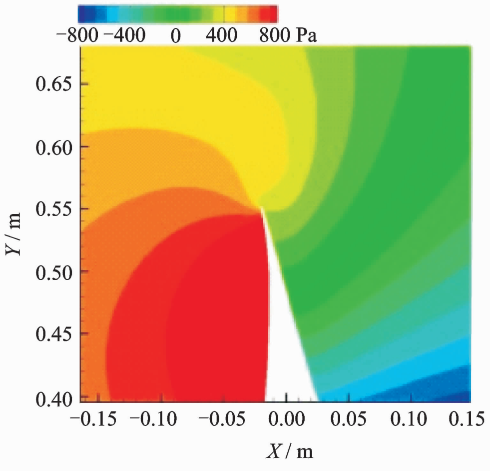


Fig. 7 Comparison of power between blade with 4% chord Gurney flap and NH1500 prototype

Fig. 8 shows the sectional pressure distribution at the local radius of 94% for NH1500 blade with and without Gurney flap at the wind speed of 6 m/s. It can be seen that there is an obvious difference in the pressure distribution around the section trailing edge between the blades with and without Gurney flap. There appears a low pressure area produced by the pair of reverse vortices behind the Gurney flap mentioned above.



(a) With Gurney flap



(b) Without Gurney flap

Fig. 8 Blade sectional pressure distribution at 94% span station for 6 m/s wind speed

4 Conclusions

Numerical simulations of both 2-D airfoil and 3-D blade with Gurney flaps have been conducted and the influence on the aerodynamic performance and flow structure of Gurney flap has been analyzed.

The aerodynamic performance of both airfoil and blade can be effectively enhanced by Gurney flap due to the separating bubble and reserve vortices produced by the Gurney flap, which increase the effective camber of the airfoil, leading to an increase in the pressure difference between the upper surface and the lower surface of the airfoil. The two reverse vortices increase the energy of the fluid on the upper surface, enhancing its ability to resist the adverse pressure gradient, and therefore reducing the separating area on the trailing edge.

Although, the CFD results about the Gurney flap presented in this paper has not been validated by specific experiment, the validation is to be carried out in our future work.

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