Numerical Investigation of Flatback Airfoils Drag and Noise Reduction by a Splitter Plate

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Abstract. In this paper the aerodynamic and aeroacoustic characteristics of a wind turbine airfoil have been numerically investigated. The modified versions of TU Delft DU97-W-300 airfoil with a flatback trailing edge and a splitter plate were selected. IDDES method was introduced and provided good results compared with the experimental data with regard to the lift. Aeroacoustic analysis focused on the amplitude and frequency of noise associated with the vortex-shedding tone from the trailing edge wake. The results showed that wake flows were significantly effected by the addition of a splitter plate to the flatback trailing edge, and lead to reduction on both drag and noise.

1. Introduction

In recent two decades, as the needs of wind power increase, the size of wind turbines increases significantly. The larger wind turbine blades have to meet more stringent aerodynamical and structural requirements. Employing thick airfoils (typically the maximum thickness-to-chord ratio $> 25\%$) in the blade inboard section helps reduce the specific weight as a function of rotor diameter and enlarge structural efficiency [1,2], but introduces risks of premature flow separation on the upper surface [3] and of highly sensitive to boundary layer transition triggered by surface soiling. Several studies show that thick flatback airfoils (blunt trailing-edge) can mitigate the steep adverse pressure gradient on upper surface by shifting some of the pressure recovery to the airfoil wake, and suppress the early onset of thick airfoil aerodynamic stall [1,3,4], and therefore increase achievable maximum lift coefficient and lift curve slope [5]. Further more, flatback airfoils have less sensitivity of the lift characteristics to surface soiling [5] which is becoming increasingly important for wind turbine robust design.

Although flatback airfoils have significant advantages over the normal sharp trailing edge ones, they have some notable undesired characteristics. Aerodynamically, flatback trailing edge causes abrupt dynamic pressure drops at the airfoil behind wake region, so that results in an increase of base drag. Even at small angle of attack, strong vortices shed periodically at both the top and bottom edges of the flatback trailing edge. This leads to more remarkable unsteady flows over the airfoil and corresponding aerodynamic force fluctuation. Besides the aerodynamic loss, the flatback trailing edge brings aeroacoustics problem. In general, there is a pair of counter-rotating vortices detaching periodically from the upper and lower edge of the base even at low angle of attack. This periodic coherent vortex shedding results in massive unsteady pressure fluctuations and act as a major acoustic
noise source of wind turbine. Compared with a normal sharp trailing edge thick airfoil, a flatback airfoil generally products much higher noise magnitudes especially at the low frequency ranges. Since the wind turbine noise is harmful to the households and living creatures nearby, it will bring restrictions to decide the locations of wind turbine farms [6].

Because of the above factors, the next generation wind turbine design has to solve both the excessive base drag problem and the high magnitude - low frequency noise problem of flatback airfoils. In previous investigations, some flatback trailing edge modifications were demonstrate to be helpful for drag reduction and noise reduction. Most typical of those modifications are splitter plates, wedges, cavities, wavy trailing edge and so on [7-10]. Among them, the splitter plate as a very simple one, is essentially an accessory thin plate attached vertically to and at the center of the flatback trailing edge [4]. Previous experimental researcher have examined aerodynamic and aeroacoustic performance of flatback airfoils with a splitter plate [11,12], together with the effects of splitter length, attachment angle and edge serration. A splitter plate attached to a flatback trailing edge airfoil interferes with the interaction between the upper and lower vortices shedding from trailing edge, and moving them farther away from the trailing edge. The strength and shedding frequency of the main vortex system is also affected. These are the main mechanism of reducing drag and noise by a splitter plate. In computational study, the various methods have been compared for simulating the aerodynamics and aeroacoustics of flatback airfoils. Since the unsteady separated flow and vortices shedding is the key of base drag and noise of flatback airfoils, 2D RANS method was illustrated to be deficient [13]. Direct numerical simulation and large-eddy simulation were considered to be prohibitively costly for the Reynolds numbers range relevant to wind turbine applications (a half to several millions). The RANS-LES is found to be compromise and relatively less expensive computational tools for drag investigation of flatback airfoils [13], and also found to be adequate for predicting noise radiation [14].

In the remainder of this work, two flatback versions of TU Delft DU97-W-300 airfoil with or without a splitter plate on the trailing edge (DU97-flatback, and DU97-splitter) are studied, at a Reynolds number based on airfoil chord of 3,000,000. IDDES which is one of the popular RANS-LES methods, is used to resolve the attached turbulent boundary layer as well as the detailed vortex shedding behaviors around the airfoil trailing-edge region and nearby wake. The far-field acoustics is computed by the model of Ffowcs-Williams and Hawkings (FW-H model). The noise frequency and amplitude are analysis by Fourier transform using source-field data obtained from the IDDES.

2. Methods and test cases

IDDES [15] is used to predict the aerodynamic performance of DU97-flatback and DU97-splitter airfoils. The method is based on k-ω SST turbulence model, and combined with $\gamma - Re_\lambda$ model [16] for transition prediction. The noise prediction is performed by the FW-H model [17], which is extended from Lighthill’s acoustic analogy. In present cases as shown in [14], turbulence boundary layer trailing edge noise, laminar boundary layer vortex shedding noise, and blunt trailing edge vortex shedding noise are the main sources of airfoil self-noise.

2.1. Airfoils geometry and test conditions

In this paper, the test airfoil DU97-flatback is generated by symmetrically thickening of original sharp trailing edge TU Delft DU97-W-300 airfoil. This method symmetrically increases the thickness from the maximum thickness of the base airfoil to the trailing edge without changing the maximum thickness and the original middle camber line. DU97-flatback airfoil has a chord of 0.91 m, and a trailing edge width to chord ratio of 10%. The numerical simulations are carried at an angle of attack 4°, freestream speed 56.5m/s, and Reynolds number based on chord $Re_c=3,000,000$. Adding a splitter plate whose length is equal to flatback width on DU97-flatback trailing edge, DU97-splitter airfoil as shown in figure 1 is generated.
2.2. CFD method and computation mesh
The computation of this work is based on OpenFOAM code [19]. IDDES and $\gamma - Re_{\theta}$ model are combined to solve the unsteady vortex dominated flows over DU97-flatback/DU97-splitter airfoils, and the boundary layer transition. Similar combination of RANS-LES and transition model was reported as early as 2010 [18]. In this work, a newly proposed combination method [20] in 2019 is used. This method introduces correction to length scale and therefore can avoid the abnormally decrease of turbulence kinetic caused by the combination of the two models.

Body-fitted cut-cell Cartesian mesh is generated as shown in figure 2. The finest meshes near the trailing edge have the cell size 0.125% chord (about 1 mm). The near wall mesh is refined with the 1st layer thickness 0.0003% chord. As in figure 3 the spanwise size of 3D domain is 25% chord. The total mesh cell number is about 16.5 million for DU97-flatback and 17.5 million for DU97-splitter airfoil.

3. Results and discussion

3.1. Aerodynamic characteristics
Aerodynamic characteristics are computed with time step 0.0002s and 5000 steps. Since the flow is unsteady, the lift and drag coefficient convergence history as shown in figure 4 illustrates the unsteady fluctuating. The averaged lift and drag coefficients are compared with experiment results [11] in table 1. The computed lift coefficient is a little larger than the experiment result for both DU97-flatback and DU97-splitter airfoil. When a splitter plate is attached to the flatback trailing edge, the drag coefficient
decrease about 40%, but the lift coefficient also decreases a little. Meanwhile the drag and lift fluctuation of DU97-splitter is smaller than DU97-flatback.

The comparison of instantaneous Q-criterion contour in the near-field domain is shown in figure 5. For DU97-flatback airfoil, the contour illustrates the trailing edge vortex-shedding. For DU97-splitter airfoil, the separated flows region near the trailing edge is cut apart into two small ones by the splitter plate, and leads to weaker separated flows. In addition, the effective camber of DU97-splitter airfoil is a little smaller than that of DU97-flatback. These explain why DU97-splitter airfoil has smaller drag and lift coefficient.

| Table 1. The lift coefficient results of experiment and computation in this work |
|---------------------------------|-----------------|-----------------|-----------------|
|                                 | Experiment corrected | Calculation of this work |
|                                 | α    | Cl    | Cd   | α    | Cl    | Cd   |
| DU97-flatback                   | 4.12° | 0.833 | 0.0598 | 4.0°  | 0.882 | 0.0565 |
| DU97-splitter                   | 4.23° | 0.762 | 0.0327 | 4.0°  | 0.837 | 0.0337 |

**Figure 4.** Comparison of force coefficient convergence history, red curve -- DU97-flatback airfoil, blue curve -- DU97-splitter airfoil, angle of attack 4°, freestream speed 56.5m/s, Reynolds number based on chord 3,000,000.

**Figure 5.** Comparison of instantaneous snapshot in the near-field domain, Q-criterion=60000 contour colored by velocity magnitude when Time=1.0s, (a) -- DU97-flatback, (b) -- DU97-splitter.

3.2. **Noise characteristics**
FW-H model is employed to predict the trailing edge vortex-shedding noise. A penetrating surface is set up as shown in figure 6 to provide noise source data. The noise observer is located according to the existing experiment report [11], at the symmetry plane of the airfoil model, at a distance 3.12 meters from the trailing edge and at an angle of 112 degrees from the streamwise (x) axis. The observer collects noise signal at sampling frequency 5000Hz and in 1.0 second.

The figure 7 shows the calculation results of the narrow band sound pressure level (SPL) spectrum in the frequency range of 0-2000Hz. The predicted fundamental frequency of the sound pressure spectrum is 150Hz due to the vortex shedding at that frequency. There is also a second peak at frequency of 300Hz. The two frequency are very close to experiment results [11]. The addition of the splitter plate causes a little higher fundamental frequency and the reduction of that peak from 93 dB to 80 dB, while a little lower frequency of the second peak.

![Penetrating noise source surface](image)

**Figure 6.** The noise source surface for far-field acoustics prediction.

![Comparion of sound pressure level](image)

**Figure 7.** Comparison of sound pressure level, red curve -- DU97-flatback airfoil, blue curve -- DU97-splitter airfoil.

4. Conclusions
The aerodynamic and aeroacoustic characteristics of DU97-flatback and DU97-splitter airfoil have been numerically investigated by IDDES and γ-Reθ transition model. The calculation predicts good drag and lift compared with the experimental data. A splitter plate at flatback trailing edge can significantly effect the flows near the trailing edge, and cause smaller fluctuation of aerodynamic force. Meanwhile the splitter plate can reduce drag by about 40% and noise by 13dB.

Acknowledgments
The authors gratefully acknowledge the National Supercomputer Center in Tianjin (NSCC) for the computational resources on TH-1A cluster.
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