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The Effects of Wake Dynamics and Trailing Edge Flap on Wind Turbine Blade

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1. Introduction

Wind power devices are now used to produce electricity, and commonly termed wind turbines. Load and performance calculations of wind turbines are usually performed by the Blade-Element/Momentum (BEM) method. However, the wake effects and the wake-blade structure interactions are less considered in most wind turbine analysis. This research studied a dynamic wake and blade interacted wind turbine. The Peters dynamic wake theory [1,2] was applied. The effects of the wake and the configuration of the modern trailing-edge-flap (TEF)[2] on the wind turbine blade were analyzed. The lift and the stresses distribution on the blade were performed by using semi-analytic and numerical wake theory and the ANSYS-FORTRAN APDL method.

For a small wind turbine analysis, Jenq et al. [3] studied the blade root stresses of a composite material blade for a 1KW wind turbine. The blade element theory and finite element method was applied. Wang and Chang [4] presented the TEF effects on a rotor blade. The Peters' dynamic wake theory was first considered in the TEF blade. The blade-wake interaction was also included in their work. Madsen et al. [5] considered a 5-MW wind turbine operating in a turbulent condition. They found that the TEF could reduce 37% fatigue loading compare with the tradition blade.

In the present study, we considered the blade-wake-interaction (BWI) and the TEF span length, index angle on a turbine blade. The aerodynamic loads and the stresses on the blade were studied. The wake dynamic theory, BEM, and the ANSYS-FORTRAN APDL method were employed. Results were correlation with a small turbine for blade stress distribution. The blade lift distribution was also compared with numerical results from [6]. Finally, the wake and the TEF configuration effects on a 5MW turbine blade in the lift distribution and stresses were presented in this work.

2. Wind turbine blade-wake-interaction analysis

2.1 Peters' Wake Dynamics Theory

Peters et al. [1,2] were able to successfully consider the aerodynamic characteristics generated by the TEF. They set up a matrix equation that brought together with wake induced flow and blade motion. By using the Glauert function to expand the induced flow on the airfoil, one can derive a matrix formulation of the equations for an airfoil for generalized deformation. Inside the matrix, L_n represents the generalized forces caused by the generalized airfoil motion.

2.2 BWI Analysis using FORTRAN and APDL

The shell 181 element was used in the ANSYS analysis. The flow chart for calculating of the BWI with TEF effects was shown in Fig.1. According to the authors knowledge, it is the first time to consider the blade deformation induced lift associated with the wake effect. The iteration of the blade-wake interaction was carried out by the FORTRAN based APDL. The results are shown in next section.

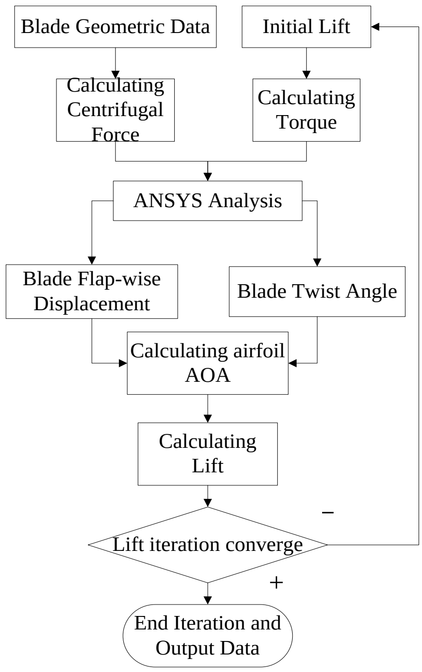

Fig.1 Flow chart of Wake-structure interaction analysis

3. Results and Discussion

3.1 Comparison of small turbine stress distribution

The BWI APDL code was applied in our present model and compared with a 1KW wind turbine blade stress distribution [3]. The left stress contour plot in Fig. 2 was for present BWI APDL model, the right one was from Ref. [3]. Generally speaking, the stress distribution agrees with each other, but the BWI effect reduces the blade root stress as shown on Fig. 2. This is probably due to wake induced down-wash decreases the lift on the blade.

3.2 Comparison of lift distribution

The lift distribution from the BWI APDL code was compared with numerical results from Ref. [6]. Fig. 3 illustrated the lift with (W/W) and without (N/W) wake effect from our present model. The red line denoted "lift (Ref.[6])" referring to the numerical results from Ref.[6]. Again, our BWI code predicts the same maximum lift with the Ref. [6].

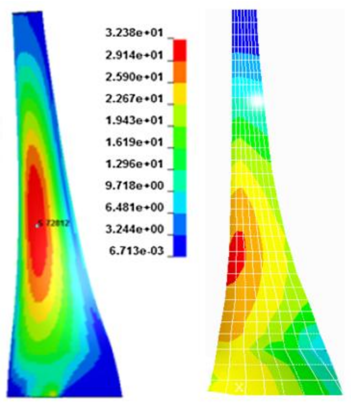

Fig. 2 Stress distribution of 1KW turbine blade.

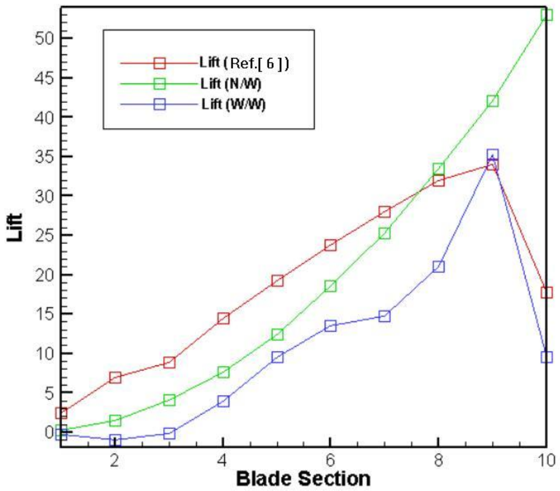

Fig.3 Lift distribution of a turbine blade.

3.3 TEF results

Finally, the BWI APDL code was applied in a 5MW turbine blade. The flap-wise displacement (meter) of the blade was shown in the upper of Fig. 4. The lower part of Fig.4 demonstrated the stress distribution of the blade. The stress distribution was rather smaller for the case considering the TEF case. The TEF effects for different index angle and span length were detailed in Table 1.

Table 1 5MW Turbine Blade TEF effects

Index-ang.(deg.)	10		30	
TEF mid-span	R/4			
TEF span	R/6	R/8	R/6	R/8
Lift max.(N/W)	8941/8807	8582/8777	10882/8797	9725/8770
Lift max.(W/W)	8904/8347	8269/8294	10310/8329	9313/8286
Displ. max.	2.916/2.63	2.835/2.6	3.19/2.502	3.04/2.52
Stress max.	2.8/2.5	2.7/2.5	3.3/2.5	3.0/2.5 (10^8)

Initial iterate / Final iterate

Table 1 showed the final iterating always converged to a smaller value compared with the initial given lift. This proved the APDL code and the concept of the blade structure-wake interaction played an important role in this problem. Also, the wake effect reduced the lift somehow as shown before. The TEF reduced the maximum stress on the blade and provided the better application of its kind in the wind turbines.

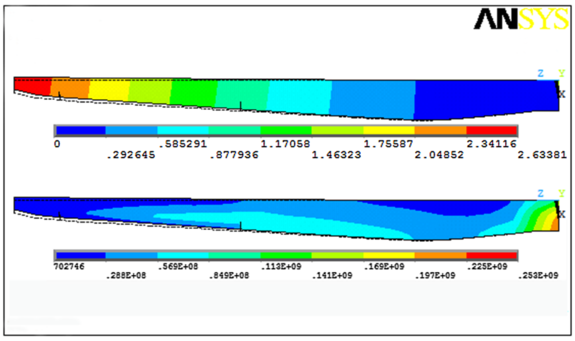

Fig.4 Displ. and stress distribution of a 5MW blade.

4. Summary

We conclude that the wake effect plays an important role in the wind turbine problem and it reduces the lift on the blade. The Blade-wake-interaction effect should be included in the iteration procedure, which usually ignored in the traditional CFD problem. The TEF may reduce the stress distribution as pointed out before. This kind of design proves its potential in the future wind turbine designs.

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