Aerodynamic analysis of Wind Turbines Rotors with High Lift Airfoils by Using Pre-conditioned WENO Scheme

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Abstract: The objective of this paper is to carry out the aerodynamic analysis of wind turbine rotors by using a high order accurate preconditioned weighted essentially non-oscillatory (P-WENO) scheme to solve the compressible Navier-Stokes equations in non-inertial coordinate system with Spalart-Allmaras one equation turbulence model. The NREL Phase VI rotor with S809 airfoil was considered as testing configuration and the wind tunnel data from NASA Ames were used to verify the validity and accuracy of present method. The grid refinement test was performed firstly on surface pressure coefficients, normal and tangent forces of blade sections and rotor shaft torque. In addition to S809 airfoil, the flow simulations and aerodynamic analysis of rotors with high lift airfoils DAE21 and FX63100 are also implemented to study the effects of airfoil sections on aerodynamic performance of wind turbine rotors are also carried out.

Keywords: wind turbine aerodynamics, rotor, blade, airfoil, preconditioned WENO scheme.

1 Introduction

To design a high-efficiency wind turbine rotor, the accurate numerical prediction for the rotor aerodynamic performances can serve as a quicker and lower-cost alternative as compared to wind tunnel experiments. Past studies applied CFD for wind turbine analysis have provided essential information in the design process of turbine rotor. Due to the three-dimensional nature of the low Mach number flow phenomena, most numerical schemes developed for compressible Navier–Stokes equations are often inefficient or even inaccurate since the convective terms of the time dependent system of equations become stiff. In our previous works [1,2], an implicit preconditioned WENO scheme for steady viscous flow computation was presented. With the P-WENO scheme, the stiffness problem and slow convergence can be overcome and meanwhile high-accuracy for all speeds of flow can be maintained. The P-WENO scheme was used to simulate flows of the NREL Phase VI Rotor using a parallel strategy by adopting a block-domain decomposition method for the patched multi-block grid system. In present work, the grid refinement test and aerodynamic performances of rotors with high lift airfoils are studied.

2 Results and discussion

The NREL Phase VI Rotor consists of two blades with a rotor diameter of 10.058 m. Due to cyclic conditions, only one of the two blades is modeled. The influence of the other blade is included by using periodic boundary condition at the cyclic plane of the computational domain. The computation domain extends to 4 and 12 blade lengths upstream and downstream, respectively, from the rotor plane. In our simulation, a patched multi-block grid system with 193 blocks is adopted and these blocks are divided into two grid systems, the inner grids and outer grids. A C–H type inner grid with 369x45x231 grid points is considered as the benchmark fine grid system, which consists 369 points on blade surface in chordwise direction, 45 points in normal direction, 231 point spanwise direction. The computational results of shaft torque are shown in Table 1. For the grids with 249 and 151 points in chordwise and spanwise direction respectively, increasing grid points in normal direction up 45 can reduce the relative error to 4.52%. If we fix 45 points in normal direction and vary the chordwise and spanwise points from 169 to 309 and from 101 to 191 respectively, the grid points increase from 739200 to 1636800 points, the relative errors vary in the range from 5.32% to 0.46%. Other comparison and analysis for surface pressure and sectional forces of blade will be included in the full paper.

Table 1, comparison the shaft torque in grid refinement test

Inner grid	Shaft torque(nt-m)	Relative error
169×45×101	986.42	5.32%
249×45×151	978.92	4.52%
309×45×191	932.23	0.46%
369×45×231	936.55	0(base)
249×29×151	2225.21	137%
249×37×151	1060.78	13.3%
249×65×151	956.86	2.17%

The lift/drag ratios of airfoil DAE21 and FX63100 are 1.59 and 1.79 respectively, which were characterized as high stall angle and low cruise drag airfoils and commonly used in gliders and unmanned aerial vehicles [3]. The comparisons of shaft torque among the rotors with S809, DAE21 and FX63100 airfoils are shown in Fig 1. The experiment data [4] are also included. The rotor with DAE21 airfoil achieved the highest shaft torque in the range of wind speed less than 20m/s. For higher wind speed, the effects of airfoil on rotor shaft torque are not significant. Although the DAE21 airfoil increased the shaft torque markedly, it also induced high root flap moment of blades. Other aerodynamic analyses are shown in full paper.

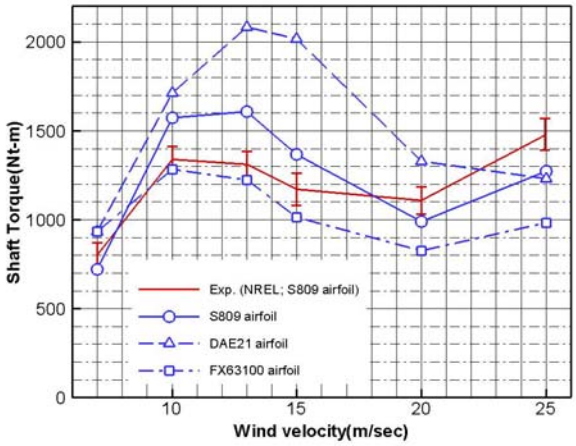

Figure 1. A comparison of shaft torque among rotors with different airfoils.

3 Conclusion and future work

The flow simulation and aerodynamic analysis of wind turbine rotors were performed by using preconditioned WENO scheme to solve the compressible Navier-Stokes equations in non-inertial coordinate system. A multi-block grid system with 249x45x151 grid points was selected by taking the computing time and accuracy into account through grid refinement test. The rotor with DAE21 airfoil can achieve the highest shaft torque in the range of wind speed less than 20m/s. For higher wind speed, the effects of airfoil on rotor shaft torque are not significant. The current results will be used in future work for the optimization of wind turbine blade.

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