11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

MODELLING EFFECTS OF FREESTREAM TURBULENCE ON DYNAMIC STALL OF A PITCHING AIRFOIL

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Key Words: *Large-Eddy Simulation, Turbulence Intensity, Wind Turbine, Dynamic Mesh.*

Wind turbines operate in turbulent atmospheric boundary layer. It is of great interest to understand the effects of turbulence on the aerodynamic characteristics. There are two reasons for this. (1) In steady winds (i.e. quasi-steady conditions), upstream turbulence may affect transition, separation on the turbine blade. (2) Wind turbines operate in yaw in large time-scale variations of wind direction, and the blades operate in a periodically oscillating condition and dynamic stall occurs frequently. Such conditions may significantly affect wind turbine performance. The generated oscillating forces lead to accumulating fatigue reducing their expected service life.

Currently, many of the prediction tools for wind turbine performance use 2-D airfoil data measured from wind tunnels for a smooth inflow condition [1]. Reynolds Averaged Navier-Stokes (RANS) approaches tend to produce significant errors compared with the experimental data, in particular in deep stall situations [2]. In order to obtain a more accurate prediction on the flow over a pitching airfoil, an Large-Eddy Simulation (LES) approach is adopted. As baseline simulations, static and pitching NACA 0012 airfoils are simulated and the results are validated against experimental data [3,4]. The Reynolds number *Re* based on the chord *c*, and freestream velocity U_∞, is 135, 000 for both the static and pitching airfoils. The angle of attack is 10^o for the static airfoil and $\alpha = 10^o + 15^o \sin(\omega t)$ for the pitching airfoil. The pitching frequency is presented as the reduced frequency, $k_{red} = \omega c/(2U_\infty)$, which is 0.025 – 0.1 for this study. The pitching axis is a quarter chord downstream from the leading edge.

Firstly, flows around a pitching airfoil were investigated. The pimpleDyMFoam solver in OpenFOAM was used for the dynamic mesh, in which the diffusivity γ in the Laplacian operator is ‘Quadratic’ (i.e. $\gamma = 1/l^2$, where l is the cell centre distance to the nearest selected boundary). The lift, drag and moment hysteresis are in good agreement with the experimental data [3] at three different reduced frequencies, i.e. k_{red} = 0.025, 0.05 and 0.1. The laminar separation bubble diminishing and boundary layer suppression on the pitching airfoil are illustrated through the surface pressure, skin friction and flow visualisation. The leading edge vortex is quantified in terms of its convective speed and shedding frequency and compared with those in literature [3].

Secondly, the effect of freestream turbulence on the flow over static and pitching airfoils is studied. The inflow turbulence generation [5] is used for LES. The surface pressure, skin friction, lift, drag and moment coefficients show that the effect of upstream turbulence is significant. For the static airfoil, the separation bubble is diminished as the turbulence level increases resulting in an increase of the lift to drag ratio. For the pitching airfoil, the magnitudes for maximum drag and minimum moment decrease with the increase of the freestream turbulence. This is mainly attributed to the suppression of separated flows in turbulent flows. The most evident impact of freestream turbulence occurs on the lift coefficient, i.e. the lift coefficient increasing by $\Delta C_L \sim 0.2$ with the increase of freestream turbulence during the downstroke. A similar trend is found from experimental works [6]. The snapshots of the vorticity field at different incidences also confirm that freestream turbulence has an evident impact on the flow around the pitching airfoil. The separated flows during the downstroke are disturbed and suppressed by freestream turbulence resulting in the lift increase.

To the authors' knowledge, this is the first attempt for applying an LES calculation on the flow over a pitching airfoil at the moderate Reynolds number, i.e. *Re* = 135, 000, considering freestream turbulence effects. Using pimpleDyMFoam solver requires very good quality of mesh near the airfoil, in particular near the sharp trailing edge. Requiring massive computational resources for such work makes these tasks even more challenging. About 700 hours (wall-clock time) were required to simulate a few cycles of pitching motion using 96 cores.

In summary, the capability of LES implemented in OpenFOAM is demonstrated successfully for highly separated flows at deep stall.

Acknowledgements: YK acknowledges provision of a Ph.D studentship from FEE, University of Southampton. All the computations were performed on supercomputers IRIDIS3 and HECToR. We are grateful to the EPSRC HECToR RAP for granting the HECToR CPU time.

REFERENCES

[1] J.N. Sørensen, Aerodynamic aspects of wind energy conversion. *Annu. Rev. Fluid Mech.*, **43**: 427–448, 2011.

[2] J.A. Ekaterinaris and F.R. Menter, Computation of oscillating airfoil flows with one and two-equation turbulence models. *AIAA J.,* **32**(12): 2359–2365, 1994.

[3] T. Lee T and P. Gerontakos, Investigation of flow over an oscillating airfoil. *J. Fluid Mech.,* **512**: 313–341, 2004.

[4] K. Rinoie and N. Takemura, Oscillating behaviour of laminar separation bubble formed on an aerofoil near stall. *Aeronaut. J.,* **108**: 153–163, 2004.

[5] Y. Kim, I.P. Castro and Xie, Z.T., Divergence-free turbulence inflow conditions for large-eddy simulations with incompressible flow solvers. *Comput. Fluids.* **84**: 56–68, 2013.

[6] X. Amandolèse and E. Széchényl. Experimental study of the effect of turbulence on a section model blade oscillating in stall. *Wind Energy*, **7**: 267–282, 2004.