Validation of an Actuator Line Method for Tidal Turbine Rotors

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ABSTRACT

Computations of the blade loading and the local flow field around the Model Rotor Experiments In Controlled Conditions (MEXICO) rotor are presented using an actuator line method, implemented within the open source code OpenFOAM. The nacelle and near wake mesh refinement are shown to have little influence on the computed blade loads but a significant impact on the near wake flow field. In addition, the blade loads and near wake flow field calculated with 3 different distributions of the Gaussian smearing parameter $\epsilon$ are compared with experimental measurements. Local chord and lift coefficient scaled smearing distributions are shown to yield a significant improvement in the representation of the computed tip vortices and also a small improvement in the blade loading prediction, when compared with a spanwise constant smearing distribution. Despite these improvements in performance prediction, the performance of the rotor is shown to be more strongly influenced by the tip correction factor, where considerable improvement is still required before actuator line methods can represent real rotors with sufficient accuracy.

KEY WORDS: Actuator Line Method; MEXICO; OpenFOAM; Rotor Aerodynamics; Blade Loading; Tip Vortices.

INTRODUCTION

The actuator line method (Sørenson and Shen, 2002) is particularly appealing as a computationally efficient technique for the representation of wind and tidal rotors. Viscous effects are captured through 2D aerodynamic data as a sub grid model, thus avoiding the necessity of resolving the rotor blade boundary layers. This 2D data is then used to build a virtual representation of the rotor blades, which are then rotated through a fixed grid to simulate the interaction of the rotor with the flow. The sub-grid blade model is both kinematically and dynamically coupled to the flow field calculation. However, the accuracy of the actuator line method in representing real rotors remains uncertain, in particular due to 3D flow effects that are not represented in the original 2D aerodynamic data. In this study, a comparison is made of the calculated blade loads and resulting flow field between the actuator line method and the Model Rotor Experiments In Controlled Conditions (MEXICO) rotor, with the aim of assessing the accuracy of the actuator line method for future wind and tidal rotor computations. Particular focus is placed on the mesh sensitivity, Gaussian load smearing and tip correction factors that are often applied in actuator line computations.

The MEXICO rotor is a 3 bladed horizontal axis 4.5m diameter rotor that was placed in the 9.5m $\times$ 9.5m open section of the Large Low-speed facility (LLF) of the German-Dutch Wind Tunnels (DNW) in 2006. Subsequent analysis of the experimental data from the MEXICO experiments took place under IEA Wind Task 29 Muxnext as an international collaborative project. The first phase of this project ended in 2011 with several aerodynamic codes validated and the source of many uncertainties highlighted (Schepers et al. 2012). In the MEXICO experiments, the rotor was operated at rotational speeds of 324.5 rpm and 424.5 rpm and at yaw angles between $+30^\circ$ and $-30^\circ$ for tunnel speeds of 10 m/s, 15 m/s and 24 m/s. These tunnel speeds were chosen to achieve a turbulent wake state, design condition and post-stall conditions for the rotor. In this report, only the results for the design condition (a tunnel velocity of 15 m/s, a rotational speed of 424.5 rpm, tip speed ratio of 6.67 and zero yaw, at a blade pitch angle of -2.3$^\circ$) will be presented.

Like the NREL Phase VI rotor experiments, the MEXICO rotor was highly instrumented. Measurements of the blade pressure distribution were taken at 25%, 35%, 60%, 82% and 92% of the blade span, with a total of 148 Kulite pressure sensors distributed between these spanwise stations. At a rotational speed of 424.5 rpm, stereo particle image velocimetry (PIV) measurements were also taken in the vicinity of the rotor plane to complement the measured blade loading. The location of the radial PIV traverses considered in this work are shown in Fig. 1, along with the coordinate system adopted. These PIV measurements represented a considerable addition over previous experimental data sets such as the NREL phase VI experiments and was the primary reason for selecting the MEXICO rotor dataset to validate the actuator line method.

NUMERICAL METHOD

In the MEXICO experiments compressibility effects were found to be negligible (Schepers et al. 2012) and hence in this investigation the incompressible Reynolds Averaged Navier-Stokes (RANS) equations were solved for the mean flow variables. To achieve closure of the RANS equations, the kinematic eddy viscosity $\nu_t$ was calculated using