Experimental Study of the Turbulent Wake Flow of a One Meter Scale Research Wind Turbine in a Large Boundary Layer Wind Tunnel

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Abstract

Experiments are performed to investigate the turbulent axisymmetric wake with rotation, and associated turbulent flow processes relevant to wind energy conversion, downstream of a one meter diameter research wind turbine in the University of New Hampshire (UNH) Flow Physics Facility (FPF), a large boundary layer wind tunnel (with a 16 m^2 test section cross-section). The initial set of measurements will be carried out in the free stream of the wind tunnel, and will include a pitot tube survey to assess wake axisymmetry and wall (boundary layer) effects, as well as quarter wake measurements using a 2D X-wire constant temperature anemometer to resolve high frequency velocity fluctuations. The goal is to provide detailed measurements of the downstream evolution of the wake of wind turbines, over long development distances under controlled conditions, and to produce benchmark open data sets for numerical model verification and validation (V&V).
Keywords: *Validation Data, Scale Model, Wake Study, Axisymmetric Wake*

Introduction

With the increasing rate of construction of large wind farms, accurate numerical models are needed to predict and maximize power production. Validation data for these models are needed across different scales, one of them being the "as-large-as-possible" scale in boundary layer wind tunnels. The Flow Physics Facility (FPF) at the University of New Hampshire (UNH), a large flow-physics quality turbulent boundary layer wind tunnel, provides an excellent testing environment at this scale due to its large size, with test section dimensions of 6.0 m wide, 2.7 m tall (at inlet), and 72 m long. A one meter diameter research turbine was designed at UNH and will be used for detailed wake measurements. The wind turbine model was based on the NREL 5MW reference turbine, with some modifications to ensure sufficiently high blade chord Reynolds number for turbine performance to become Reynolds number independent. The data collected will be similar to those produced by Krogstad et al. [1], but with a lower blockage ratio, just under 5% based on rotor swept area, and longer development fetch.
At full scale, atmospheric turbulence interacts with turbine wakes causing wake meandering and rapid disorganization of the tip and root vortex flow. The shear layer of the wake itself produces turbulence that also affects wake motion and tip and root vortex behavior. With so many interactions, it is useful to simplify the problem and study wakes within the controlled environment of a large wind tunnel, which can then be used for CFD model validation. Here, inflow turbulence can be set to a low level by placing the turbine model upstream in the tunnel, or the wind turbine can be placed far downstream in an artificially thickened boundary layer. The experiments will offer a detailed look at the behavior of the turbulent axisymmetric wake flow with rotation. Data from these tests can also be used to compare to analytically derived similarity solutions, e.g., the scaling function for the mean swirling velocity, $W_{\max} \propto x^{-1} \propto U_o^{3/2}$, indicating that the mean swirl decays faster than the mean velocity deficit $U_o \propto (U_\infty - U_{cl}) \propto x^{-2/3}$ [2].

Methods

The initial measurements will be carried out with the model turbine placed in the free stream near the beginning of the test section. First, a pitot tube survey will be used to measure mean wake velocity profiles. These data will be used to assess the axisymmetry of the wake and determine when boundary layer effects from the walls of the test section become significant. The profiles will measured along a crosshair traversing path downstream of the turbine along the vertical and horizontal centerlines as shown in Figure 1. Measurements will be taken at 1, 3, 5, 7, 10, 15, and 20 diameters downstream of the turbine rotor plane.

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This will give insight as to the available downstream distance for higher resolution two-component velocity and turbulence measurements. Estimates based on previous wake measurements performed in the FPF [3] suggest that the boundary layer will most likely start to affect the wake of the one-meter turbine at around 20 diameters downstream (c.f. Figure 2). Following the pitot tube survey, a 2D X-wire constant temperature anemometer will be used to measure streamwise and azimuthal velocity components of the quarter wake and resolve turbulence characteristics.

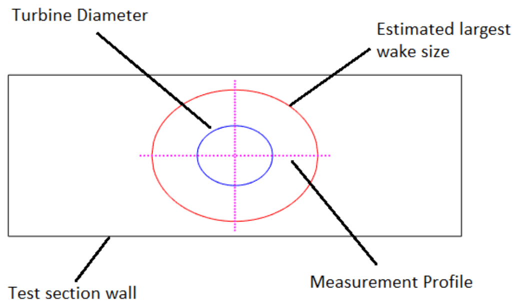

Figure 2 - Diagram of Pitot Tube Measurements. The "largest wake size" was estimated at 20 turbine diameters downstream of rotor plane based on previous measurements [2].

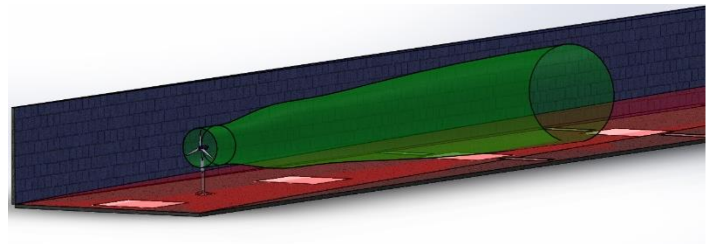

Figure 1 - Visualization of Turbine Wake and Boundary Layer Growth in UNH Flow Physics Facility.

The proposed work will allow for detailed validation leading to improvement of wind turbine aerodynamics models for numerical simulations, which are a key building block for complex array simulations, as part of an integrated V&V protocol that encompasses a range of scales and physical phenomena. The proposed work has the potential to reduce the cost of wind energy because more accurate wake modeling leads to more accurate wind plant performance estimates.

The following turbine-scale flow phenomena can be investigated with this turbine model in the FPF:

- Wake Development (wake growth, velocity deficit recovery – covered in this study)
- Inflow effects (turbulence intensity, turbulence spectrum, coherence, shear, veer)
- Skew and meander of aggregate wake (with turbine placed in boundary layer)
- Wake vorticity diffusion and dissipation
- Tower/rotor/nacelle wake interactions
- Asymmetry effects (ground plane, yaw, tilt, cone-angle)

The flow phenomena listed above correspond to those identified in a V&V Phenomena Identification Ranking Table (PIRT) developed by DOE under leadership of NREL [4]. The PIRT is used to prioritize physical phenomena and to identify gaps between technical requirements and models. The flow phenomena that can be studied in this setup generally have high importance at the application level, but generally low model adequacy at in terms of physics, code trustworthiness and validation. This makes the turbine wake experiments timely and necessary.

Results

A one-meter turbine model in a large boundary layer wind tunnel (low blockage, long fetch) is used to obtain detailed measurements of the downstream evolution of the wake flow under controlled conditions. Open data sets for numerical model verification and validation (V&V) will be produced. The turbine model is currently being fabricated, with experiments to begin in August/September 2017. We expect to have initial wake data by October 2017, in time for this conference.

References

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