Design and Performance of a Controllable One-Meter Scale Research Wind Turbine

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Abstract

A research wind turbine of one meter diameter was designed for the UNH Flow Physics Facility (FPF), a large flow physics quality boundary layer wind tunnel. The turbine design was carried out as an aero-servo model of the NREL 5MW reference turbine, with some modifications. The turbine will allow us to obtain data for multiscale model verification and validation, including wake data over long distances downstream.

The turbine was designed to precisely prescribe tip speed ratio, dissipate the generated electric power and produce high resolution performance data. Several candidate airfoil profiles were evaluated numerically with the goal of reaching Reynolds-number independence in turbine performance. The model turbine achieves Reynolds numbers based on blade chord greater than 100,000. The blockage ratio is less than 5% based on swept area.

Keywords: *Research scale wind turbine, Wake studies, Turbulent wake, Pitch control, Model validation*

Introduction

Increasingly large wind farms, both onshore and offshore, must be designed with flow-physics based numerical models, and validation data for these models are needed across a spectrum of scales. From a flow-physics perspective, there is a need for detailed experimental data for wind turbine wakes to improve our understanding of wakes and ultimately wind turbine array spacing.

The experiments enabled by the scale model turbine described in this paper will produce such validation data sets. This turbine will achieve similar Reynolds numbers as in the Krogstad et al. study [1]. However, due to the combination of turbine and facility sizes, the experiments will be able to move beyond some of the limitations of that study, in a few ways. The model turbine has much lower blockage ratio for similar turbine size, we will be able to obtain wake information much further downstream of the rotor, due to the size of the UNH Flow Physics Facility (W 6.0m, H 2.7m, L 72m). We will also be able to place turbines within a turbulent boundary layer and investigate phenomena such as wake meandering.

Methods

The turbine was scaled with respect to the NREL reference 5MW turbine defined in [2]. The scaled turbine is assumed rigid and the tip speed ratio between the full scale and model scale is held constant. The rotor diameter of the NREL turbine is 126 meters and thus the geometric scaling factor was set as the ratio of the full-scale turbine rotor diameter to the model rotor diameter which is 126:1.

The goals of the rotor design were: (i) to obtain kinematic similarity by operating at the same tip speed ratio for peak power coefficient, $(C_{p,max})$, (ii) to approximate rotor power and thrust coefficients of the prototype, and (iii) to achieve sufficiently high Reynolds number so that the turbine performance becomes Reynolds number independent. At the scale selected, *D=1m*, rotor power coefficients are typically significantly lower than for full scale, due the effects of low Reynolds number and associated low lift/drag ratios of airfoils. Reynolds number is the primary limiting factor in small scale airfoil performance, so to maximize the rotor power coefficient the blade chord was scaled appropriately to achieve sufficiently high Reynolds numbers (approximately *100,000-120,000* at the design tip speed ratio, $\lambda = 7$). However, as chord length is increased there is a tradeoff as the tip speed ratio at peak power coefficient will be reduced somewhat.

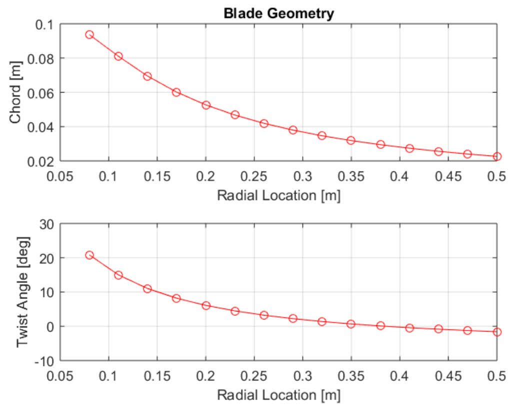

Figure 1: Blade chord and twist distribution as specified by optimum rotor theory - 1.35x chord scaling.

Airfoils designed by NREL [2] and Selig-Giguere[3] were examined for use on this turbine. The QBlade software implementation of XFOIL was used to calculate the airfoil polars. The NREL S801 and S826 were considered along with the Selig-Giguere SG6040. The S801 was ultimately chosen because of its good performance across the full range of Reynolds numbers and consistency of optimal angle of attack.

An optimal blade geometry was determined using optimum rotor theory without wake rotation as defined in Manwell et al. [4]. The chord distribution was then increased by 1.35 and 1.7 times (approximately 2x and 3x the geometrically scaled chord) to yield Reynolds number independent performance (estimated using Qblade). The twist distribution was kept the same. Chord and twist for one of the two blades produced is shown in Figure 1. The blades were manufactured from carbon fiber composite.

The overall design of the turbine is shown in Figure 2. The base of the turbine is a single axis force balance which measures thrust via a *Futek LSB302 – 50lb* load cell. The tower is a three tier 6061 aluminum assembly which threads into the top plate of the force balance. The tower has been studied to ensure that the wake is undisturbed by vortex shedding and that the structure's natural frequencies do not resonate with the frequency of blade rotation.

The nacelle houses a tapered bearing and a secondary housed bearing through which the driveshaft is inserted. The driveshaft is connected to the hub which holds three blade root and manual pitching mechanisms. The driveshaft is coupled to a *Futek TRS605 rotary* torque transducer which sits just downstream of the housed bearing. A *Parker Hannifin BE* series servo motor connected to the downstream side of the torque transducer to control tip speed ratio. The motor is controlled via a *Parker Compax3* series drive. Power is dissipated through a resistor bank.

Figure 2: The one-meter scale wind turbine design.

Results

The turbine is expected to generate high resolution performance curves (i.e. $C_P\ vs.\ \lambda$, $C_T\ vs\ \lambda$) as well as provide a similar wake profile to that of the full scale. These data sets, as well as detailed inflow and turbine parameters will then be made publicly available. Experiments will begin in August/September 2017.

Conclusions

A one-meter diameter turbine was designed and fabricated. The blades were designed using the NREL S801 airfoil. The turbine precisely controls tip speed ratio and experimentation with the turbine will produce high resolution performance curves and wake profile data sets for numerical model verification and validation.

References

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