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Experimental Characterization of an Axisymmetric Swirling Wake

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Abstract

Swirl's modification of wake behavior can complicate efforts to validate wind turbine simulations. Previous work shows increased swirl modifies wake behavior. Relatively few studies examine this flow with minimal complicating effects. S-PIV will be utilized to examine how wake strength and swirl couple to effect wake behavior. Initial results show wake strength, as well as swirl, is determined by both generator solidity and rotation speed. Further study can lead to better understanding of wake behavior and modeling across multiple scales.

Keywords: *wakes, turbulence, wake behavior, particle image velocimetry, wind turbine arrays*

Introduction

Preliminary work by this group has shown that increases in swirl modify wake behavior, in particular, wake strength, growth rates, and decay rates[1]. While extensive work has been performed in the classical case of the axisymmetric wake[2,3] work performed in the swirling wake has yet to reach parity. As such, studies such as this are needed to not only understand how swirl specifically modifies wake behavior but also to aid validation efforts of wake flow simulations. The overall goal of this project is to study the swirling axisymmetric wake with minimal flow artifacts to better understand how swirl modifies turbulent structure. The objective of the work presented here is to utilize Stereoscopic Particle Image Velocimetry (S-PIV) to characterize how wake generator solidity and rotation speed couple to effect wake strength, swirl, and hence mean wake behavior.

Experimental Approach

All work for this study will be carried out in The University of Wyoming open return wind tunnel. The swirling wake will be produced using a custom designed wake generator consisting of an enclosed servo motor that will be wire mounted in the test section to minimize flow artifacts. The wakes will be produced by rotating porous disks 3.8 cm (1.496 in) in diameter of varying solidity. The rotational rate will be controlled by a Faulhaber speed controller operated via LabView with off body speed measurement provided by a laser tachometer. PIV data will be obtained using a LaVision PIV system with 2 cameras to capture stream wise velocity profiles in a 20 cm x 20cm (7.87 in x 7.87 in) region. Vector fields will be obtained by processing the raw images with LaVision's DaVis processing software from which all relevant data can be extracted. The data presented here is derived processing approximately forty case of four hundred images each to produce contour plots of wake and swirl strength. All cases presented were performed at a wind tunnel velocity of 30 m/s with various combinations of wake generator solidity and rotation speed.

Current Results

As seen in Figure 1, a contour plot displays changes in wake strength, $Re_{\Delta U}$, versus rpm in the x axis and solidity on the y axis. This contour plot displays two interesting attributes, first increases in solidity are not the sole factor for increasing

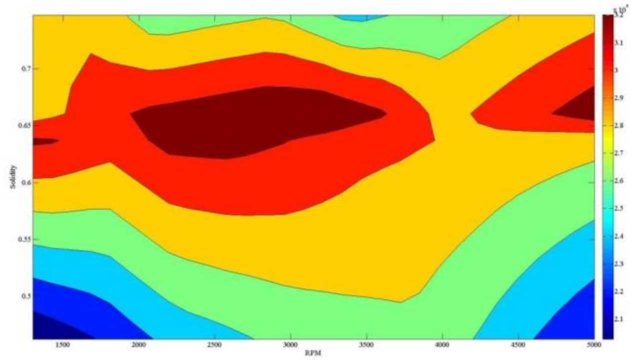

Figure 1 Wake Strength Contour at 30 m/s

wake strength. Second, changes in rotation speed may increase or decrease wake strength. Figure 2 shows a similar contour plot displaying changes in swirl number, the ratio of tangential momentum addition to axial momentum deficit convected by the wake . Like Figure 1, appreciable increases in rotation speed are not the sole factor when determining increases in swirl strength. As one moves to higher solidity despite approaching nearly 5000 rpm, the tangential momentum addition is relatively small when compared to wake strength.

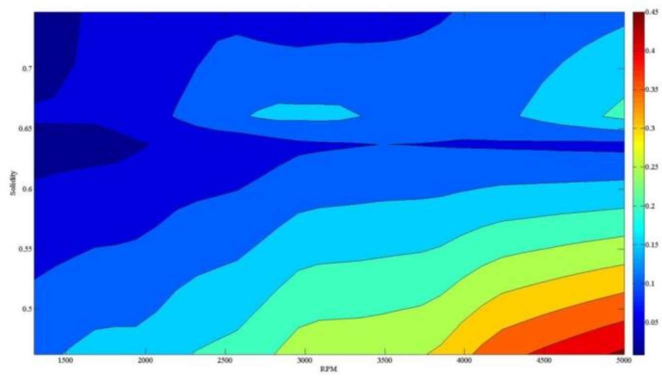

Figure 2 Swirl Strength Contour at 30 m/s

Conclusions and Future work

To conclude, data was synthesized of nearly forty unique combinations of solidity and rotation speed to generate trends of wake characteristics. Figure 1 shows that increases in wake strength are more than a function of solidity. Similarly, Figure 2 shows that significant increases in rotation speed alone do not produce large swirl strength. Future work will utilize these findings to guide strategic case selection. S-PIV will be used to examine cases where wake strength or swirl are held constant to examine how/if these two characteristics couple to jointly determine mean wake. This information will prove valuable as researchers seek to improve modeling and understand wind turbine wake physics across various scales.

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