Evaluating Instantaneous Wake Center Position Determination Techniques for Data from High Fidelity Simulation Models

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Abstract

With the rise in need for accurate, dynamic, and unsteady wake models for wind farm design and analysis, a suitable method to determine instantaneous wake center position is necessary for complete validation. Four methods of determining instantaneous wake center position are compared using data from Large Eddy Simulations (LES) in SOWFA [1]. Qualitative analysis shows that methods that use convolution make a simplifying assumption about the shape of the overall wake, decreasing accuracy. In contrast, the common method of fitting a Gaussian shape using least squares and a simplistic center of mass calculation provide suitable estimates of the wake center, but the applicability of each method may vary depending upon the planned use.

Keywords: *Dynamic, Computational Fluid Dynamics, Wake Center Determination*

Introduction

In the United States, renewable energy goals include 20% grid penetration from wind energy by the year 2030 [2]. With this large demand in wind energy, the cost of energy is paramount in its continual growth. Research into increasing the density of wind turbines in a wind farm has shown the potential to decrease the cost of energy. However, when wind turbines are close together they begin to negatively affect power production in the form of a velocity deficit or wake. Modelling these wake effects efficiently has been most commonly done with low fidelity models with a top hat shape [3, 4] or medium fidelity eddy viscosity models [5]. However, it has been shown in [6] that there exist many forms of dynamics and uncertainty, most notably wind direction uncertainty, that are not accounted for in these steady state models without post-processing.

Many dynamic models have been introduced that attempt to model wake meandering [7, 8], wake dynamics induced by each turbine [9, 10], and even dominant modes in a wake [11, 12]. However, with these dynamic and unsteady wake models, validation becomes more complex for a number of reasons, including difficulty in determining quantitative measures describing the wake center position. This work will provide a comparison between various instantaneous wake center position techniques by analyzing the wake center position from data generated in NRELs software SOWFA [1].

Methods

Four methods for determining wake center position are compared, including fitting a Gaussian shape using linear least squares, convolving a Gaussian shape with points interpolated using linear interpolation and bilinear interpolation, and a center of mass calculation that calculates a uniformly weighted average of all points below a certain threshold of wind speed. Each of these methods will be compared by analyzing horizontal flow field slices at a hub height of 90m to determine wake center position 6D downwind. Data from the LES simulation software SOWFA [1] will be used to provide for the flow field modeling of a wake generated by NRELs 5MW turbine [13].

Results

Figure 1 shows the performance of each method for a 40s time period measured on a horizontal line perpendicular to the oncoming wind direction, located at hub height, and 6D downwind of a NREL 5MW turbine. Although all four methods qualitatively track the observed wake center position, it can be seen that since the center of mass method estimates wake center by taking a uniformly weighted average of points, the wake center is more responsive to smaller wake deficits. Gaussian convolution with linear interpolation and Gaussian fitting with least squares have similar performance, deviating significantly from each other only when there is a dispersed wake. It may also be seen from 511–513s that both convolution methods are often influenced strongly by components of the wake that are Gaussian shaped.

Note that since the flow field is generated using the same interpolation method as convolution with bilinear interpolation, the comparison to the flow field is a biased measure. The full presentation will contain a complete description on each method, more detailed results comparing them, and discussion on their relative utilities.

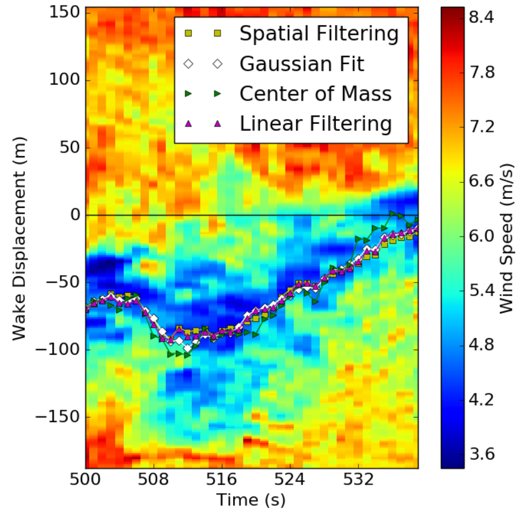

Figure 1: A comparison of methods is shown plotted against the flow field from SOWFA. The flow field is generated using a bilinear interpolation of SOWFA data at 6D downwind to enable equally spaced plotting.

Conclusions

Four methods for computing the wake center position from high fidelity SOWFA data have been compared. Both convolution methods may not represent wake center position well due to a tendency to over-fit to Gaussian shapes. Similarly, the center of mass method is influenced equally by small wake deficits and large wake deficits that are below a threshold. Thus, the center of mass method may represent the wake center position of a top-hat shape wake, but may not provide a good estimate for non–uniform wake models. Finally, the common method of wake center position determination using a Gaussian least squares fit performed well, but is not as reactive to well mixed wake deficits

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