Stochastic Wake Model Based on POD Analysis

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Abstract

Large eddy simulation data is analyzed to investigate a new stochastic modeling approach for the wake of a wind turbine. To grasp the spatio temporal dynamics a proper orthogonal decomposition (POD) is applied. The dynamics of the weighting coefficients of the POD mode are analysed and modeled by different stochastic models. The analysis and the modeling is optimized to reproduce correctly three different load aspects. It is shown that only the dynamics of a few POD modes are necessary for a good model, additionally a turbulent background field is needed. The minimal number of necessary POD modes depends on the load cases. These stochastic wake models are proposed for long time load studies.

Keywords: *wake model, proper orthogonal decomposition , stochastic dynamics, loads of wind turbines*

For wind energy wake effects play a more and more important role as wind turbines are mainly operating wind farm configuration. Wake modeling through fully resolved simulations based on the Navier-Stokes equations is computationally very expensive due to the many scales relevant to turbulent flows. The most detailed dynamical simulations which can be computed in reasonable times are large eddy simulations (LES) combined with simplified turbine models, such as actuator disk or actuator line models [1-8] Even though these simulations have proven to be an efficient tool for the investigation of specific research questions, LES are still too time consuming for most practical applications. In particular, long-time studies cannot be performed with such demanding CFD tools. Therefore, much simpler wake models are needed which strongly reduce the computational costs. In this contribution we will present a possibility how such simpler model can be extracted from the CFD calculations, thus the focus of the work is on the this concept. In particular we show how different approach can be combined to obtain such desired models which can be seen as an alternative to the dynamic wake meandering model [9-11].

The dynamic approach is to analyze and to model wind turbine wakes using modal decompositions, see also [7,12-16], which describe the velocity field $u(y,z,t)$ as a linear superposition of spatial modes $\Phi_j(y,z)$ with time-dependent weighting coefficients $a_j(t)$

$$u^{(N)}(y,z,t) := \langle u(y,z,t)\rangle_t + \sum_{j=1}^{N} a_j(t)\phi_j(y,z)) \approx u(y,z,t).$$

The obtained POD modes are combined with simple stochastic models for the weighting coefficients. Since we are mainly interested in the impact of the wake flow on sequential turbines, aeroelastic simulations of a wind turbine in the wake are performed. Original LES, truncated PODs and stochastic models (uncorrelated noise, a spectral noise and an adapted Ornstein-Uhlenbeck process for the coefficients $a_j(t)$) are used as inflows and the results are compared for different numbers of modes included. Furthermore, we investigate the problem of missing turbulent kinetic energy in the modeled wake flow, which is a principle shortcoming of reduced order models based on modal decompositions. We illustrate that it is principally possible to capture the small-scale properties of the flow by adding a homogeneous turbulent field to the wake structure modeled by the POD-based approach.

To show the quality of the models we evaluate three quantities of the turbine model, namely the torque, the thrust and the yaw moment. Looking at the rainflow counting histograms, shown in Fig 1, we conclude that the original wind field, given by the LES simulations, is best reproduced by 6 modes for the torque and thurst, whereas 20 modes are needed for the yaw moment. Note always a turbulent background field had to be added.

We conclude that simple stochastic POD model can be set up, which enable to perform long time studies in an efficient way. For different aspects of loads on a turbine different modes are needed, thus we propose that aspect specific models have to be set up. Like in our case presented here such models can be extracted from high cost numerical CFD calculations, which never can be extended to very long time periods.

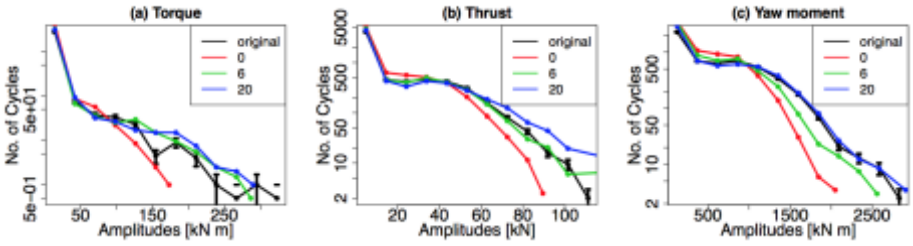

Fig. Rainflow counting histograms for different loads and different numbers of modes included in the spectral model 0 and the results from the wake filed of the LES simulation (original). To the POD wind fields, a turbulent background filed was added.

[1] Mikkelsen, R.: Ph.D. thesis, Technical University of Denmark, 2003.
[2] Calaf, M., Meneveau, C., and Meyers, J.,Physics of Fluids, 22, 015 110 (2010).
[3] Lu, H. and Porte-Agel, F., Physics of Fluids, 23, 065 101 (2011).
[4] Wu, Y.-T. and Porte-Agel, F. Boundary-layer Meteorology, 138, 345–366 (2011).
[5] Porté-Agel, F.,et al., Journal of Wind Engineering and Industrial Aerodynamics, 99, 154–168 (2011).
[6] Goit, J. P. and Meyers, J., Journal of Physics: Conference Series, 524, 012 178 (2014).
[7] VerHulst, C. and Meneveau, C., Physics of Fluids, 26, 025 113 (2014).
[8] Witha, B., Steinfeld, G., and Heinemann, D.: High-resolution offshore wake simulations with the LES model PALM, Wind Energy- Impact of Turbulence, (2014).
[9] Larsen, G. C., Madsen, H. A., Thomsen, K., and Larsen, T. J., Wind Energy, 11, 377–395 (2008).
[10] Madsen et al., 2010; Madsen, H. A., Larsen, G. C., Larsen, T. J., Troldborg, N., and Mikkelsen, R., Journal of Solar Energy Engineering, 132, 041 014, (2010).
[11] Keck, R.-E., et al.., Wind Energy, 18, 111–132 (2015).
[12] Andersen, S. J., Sorensen, J. N., and Mikkelsen, R., 14, 1–24 (2013).
[13] Bastine, D., Witha, B., Wächter, M., and Peinke, J., Energies, 8, 895–920 (2015).
[14] Hamilton et al., 2015, 2016; Hamilton, N., Tutkun, M., and Cal, R. B., Physics of Fluids, 28, 025 103 (2016).
[15] Iungo et al., 2015; Iungo, G. V., Wu, Y.-T., and Porte-Agel, F., Journal of atmospheric and oceanic technology, 30, 274–287 (2013).
[16] Sarmast, S., et al. Journal of Fluid Mechanics, 755, (2014).