International Journal of Offshore and Polar Engineering (ISSN 1053-5381)
Copyright © by The International Society of Offshore and Polar Engineers
Vol. 36, No. 1, March 2026, pp. 65–74; https://doi.org/10.17736/ijope.2026.jc953

http://www.isope.org/publications

Scale Resolving CFD Simulations of Aerodynamic Performance of Wind Turbines

Vladimir Krasilnikov and Lucia Sileo
Ship Hydrodynamics, Department of Ships and Ocean Structures, SINTEF Ocean
Trondheim, Norway

In this paper, the authors describe their validation and verification exercises with the novel Scale Resolving Hybrid (SRH) turbulence model, also known as the Hybrid Temporal Large Eddy Simulation, in application to the CFD analysis of aerodynamic performance of wind turbines. Focusing on the two benchmark cases – UAE reference wind turbine and DTU 10 MW wind turbine – investigations include the prediction of rotor thrust and torque, blade bending moment, pressure distributions at different sections along the blade span, as well as vorticity field in the rotor wake. The SRH model is shown to provide a good balance between the accurate prediction of integral loads on the turbine and high-fidelity resolution of field variables. Accurate prediction of blade pressure distribution under varying operating conditions is an essential result for the analysis of unsteady blade deformations and the resulting fatigue loads. Detailed resolution of vortex structures in rotor wake as observed in the experiment remains a challenge due to the need for very fine spatial and temporal resolutions. The latter aspects will be addressed in future studies, particularly regarding full scale operating conditions.

INTRODUCTION

With the increasing size and complexity of wind energy farms —both onshore and offshore—computational fluid dynamics (CFD) methods are routinely employed to analyze wind turbine performance. These high-fidelity modeling techniques help deepen our understanding of the physical phenomena underlying turbine operation, improve the predictive accuracy of faster engineering tools, and provide input to data-driven models used in digital twins. In the aerodynamic part of the problem, several challenges remain, including the accurate prediction of loads on individual rotor blades, the structural response of blades and tower, modeling of the dynamic rotor wake, and the interaction between the rotor and anisotropic turbulent wind fields (Lee et al., 2018). A particularly difficult aspect is resolving interactions between turbulent structures of varying scales, which play a critical role in all the aforementioned phenomena (Paskyabi et al., 2023). The traditional Reynolds-averaged Navier-Stokes (RANS) method, when applied with accurately resolved rotor geometry and isotropic turbulence closure models, provides good predictions of turbine forces and moments (Stergiannis et al., 2017; Hoem, 2018; Sileo et al., 2023). However, RANS methods reveal deficiencies in resolving the vorticity field in the rotor wake (Krasilnikov and Sileo, 2023a). As an alternative, the Lattice-Boltzmann Method (LBM) has gained popularity in wind turbine simulations and is applied using both fully resolved rotor models and simplified representations such as the Actuator Line (AL) method (Ribeiro et al., 2024). As an alternative to RANS, the Lattice-Boltzmann equation method (LBM) has gained some popularity in wind turbine calculations where it is used with both the fully resolved rotor model and simpler representations like AL (Ribeiro et al., 2024). To investigate wake interactions within a wind farm, where accurate far-wake resolution is essential, the AL model is often coupled with the Large Eddy Simulation (LES) technique (Martinez-Tossas et al., 2015; Sørensen et al., 2015; Lee et al., 2018). However, the AL approach depends on lookup tables for blade load calculations and, even when supplemented with blade tip corrections, fails to capture vorticity detachment from realistically shaped blades. A comparison between a fully resolved CFD model using the Delayed Detached Eddy Simulation method and the Blade Element Momentum and AL/LES approaches is presented in Ehrich et al. (2018) for the NREL-5MW reference turbine. While all methods show good agreement in predicting sectional forces at the blade mid-span, significant discrepancies appear at the blade root and tip. More importantly, large differences are observed in the standard deviations of both sectional and integral forces and moments. These findings underscore the existing uncertainties in predicting time-varying blade load amplitudes, which are essential for fatigue analysis—even for fixed turbines. For floating wind turbines, unsteady flow phenomena become even more significant. Wave-induced motions alter the apparent wind speed experienced by the rotor, move the rotor in its own wake (de Vaal et al., 2014), and cause large-scale wake fluctuations that impact both the turbine performance itself and interactions with nearby turbines (Wise and Bachynski, 2020).

In the present work, the authors apply a CFD approach using a geometrically accurate rotor model to predict blade loads, pressure distribution, and the vorticity field in the rotor wake. Two methods are used to simulate rotor motion: the Moving Reference Frame (MRF) method, suitable for isolated rotors in steady, uniform wind; and the Sliding Mesh (SM) method, combined with the Overset Mesh (OM) technique, which supports scenarios involving arbitrary forced or wave-induced turbine motions. Among available techniques, the OM approach stands out for its meshing efficiency (with both structured and unstructured grids), flexibility in handling complex geometries, accurate boundary representation, and ability to adapt to dynamically changing flow conditions. Although alternative methods, such as the immersed boundary and cut-cell techniques, offer benefits in modeling deforming boundaries within Cartesian grids, they often entail higher computational costs, require sophisticated interpolation schemes, reduce near-boundary accuracy, and are generally less adaptable to changing flows. To model rotor rotation, the SM method is preferred over OM due to better flux conservation and significantly faster data interpolation across mesh interfaces—an impor-

Received September 9, 2024; updated and further revised manuscript received by the editors April 16, 2025. The original version (prior to the final updated and revised manuscript) was presented at the Thirty-fourth International Ocean and Polar Engineering Conference (ISOPE-2024), Rhodes, Greece, June 16–21, 2024.
KEY WORDS: Wind turbine, aerodynamic loads, wake, CFD, scale resolving turbulence.