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HIGH-FIDELITY BLADE-RESOLVED WIND FARM SIMULATIONS

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EXECUTIVE SUMMARY

Wind energy is becoming an emergent renewable energy source throughout the world. Costs have dropped dramatically over the past two decades, making wind energy a desirable alternative to fossil fuels. Improvement in wind energy application simulation technologies may have a profound economic impact through improved wind plant efficiency. The goal of this work is to develop state-of-the-art aerodynamics modeling techniques using high-fidelity blade-resolved turbine models to simulate complete wind farms. The numerical methods in this research utilize multiple mesh and multiple computational fluid dynamics flow solvers coupled in an overset framework.

RESEARCH CHALLENGE

High-fidelity numerical simulation of wind energy applications is becoming a precedent for future technologies, not only for the wind energy sector but also for lower-fidelity modeling as well. The need for high-fidelity simulation using a complete geometric description of wind turbines with tower and nacelle is essential for capturing the true aerodynamic nature of the flow, which is highly turbulent and chaotic. This is especially important in the study of downstream wake effects on wind turbines that cause the primary decrease in wind plant power production efficiency. Wind farm simulation is a truly multiscale problem; the smallest turbulent structures are on the order of microns and the largest scales present from atmospheric turbulent inflow are on the order of tens of kilometers. To simulate ten orders of spatial magnitude, tens to hundreds of thousands of computing cores are required to approach this grand challenge problem.

METHODS & CODES

The numerical methods developed in this research utilize an overset grid paradigm where multiple meshes and multiple flow solvers are used in a coupled manner to enable efficient simulation of this truly multiscale problem. Nearly all software used on our framework is developed in-house at the University of Wyoming with the exception of the p4est adaptive mesh refinement framework developed by Carsten Burstedde, et al. [1]. The two flow solvers developed at the University of Wyoming are NSU3D, an unstructured 3D finite-volume solver, and dg4est, a high-order discontinuous Galerkin finite-element solver. The overset solver used is TIOGA, developed by Jay Sitaraman of Parallel Geometric Algorithms, LLC. The complete framework is known as the Wyoming Wind and Aerodynamics Applications Komputation Environment (WwAaKE3D).

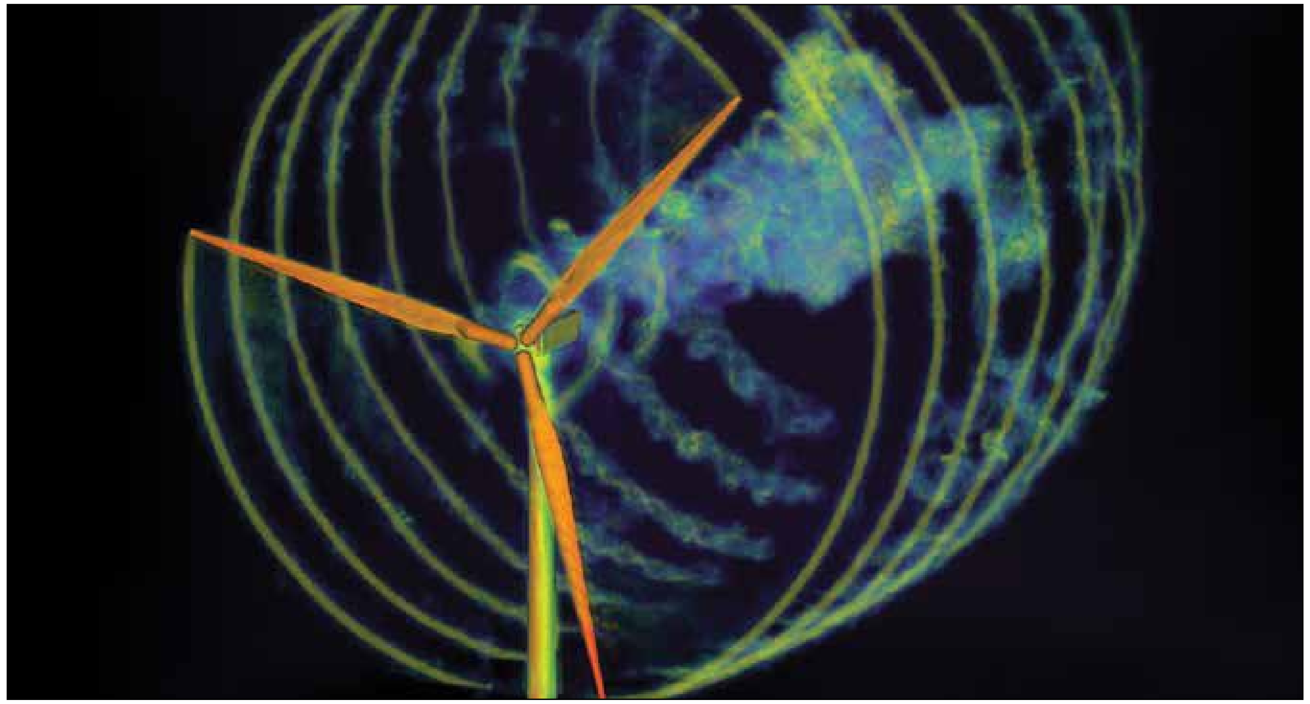

Figure 1: Volume rendering of vertical wake structures generated downstream of a Siemens SWT-2.3-93 wind turbine with uniform inflow.

RESULTS & IMPACT

This research enabled the largest complete wind farm simulations to date using a high-fidelity blade-resolved turbine model. This demonstrates the capability for large-scale simulations of entire wind farms and serves as a milestone for high-fidelity methods in a multi-scale problem spanning 10 orders of spatial magnitude.

WHY BLUE WATERS

Blue Waters offers a unique environment not only as a computational resource but also for its expert project staff. The design of Blue Waters makes it an excellent machine geared toward scientific output rather than just its flop rate. Blue Waters allowed us to perform large-scale wind farm simulations using tens of thousands of compute cores. In addition, the project staff provided excellent insight for optimization and maximizing throughput.

PUBLICATIONS AND DATA SETS

Kirby, A., et al., Wind Farm Simulations Using an Overset *hp*-Approach with Blade-Resolved Turbine Models. *Proceedings of the 23rd AIAA Computational Fluid Dynamics Conference* (AIAA Aviation, Denver, Colo., June 5–9, 2017), DOI: 10.2514/6.2017-3958.

Brazell, M., A. Kirby, and D. Mavriplis, A high-order discontinuous-Galerkin octree-based AMR solver for overset simulations. *Proceedings of the 23rd AIAA Computational Fluid Dynamics Conference* (AIAA Aviation, Denver, Colo., June 5–9, 2017), DOI: 10.2514/6.2017-3944.

Andrew Kirby is a fifth-year Ph.D. student in mechanical engineering at the University of Wyoming. He is working under Dimitri Mavriplis and expects to graduate in December 2017.