High-Fidelity Blade-Resolved Wind Plant Modeling

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Background and Importance

With rapid advances in high performance computing, high-fidelity models for complete wind farm simulation are becoming feasible. Current simulation technologies use only low fidelity models that do not incorporate the blade geometry directly. Using full rotor models for wind energy simulation has become a grand challenge problem for the DoE's Exascale Computing Project (ECP). This work bridges the gap between current technologies and ECP's ExaWind.

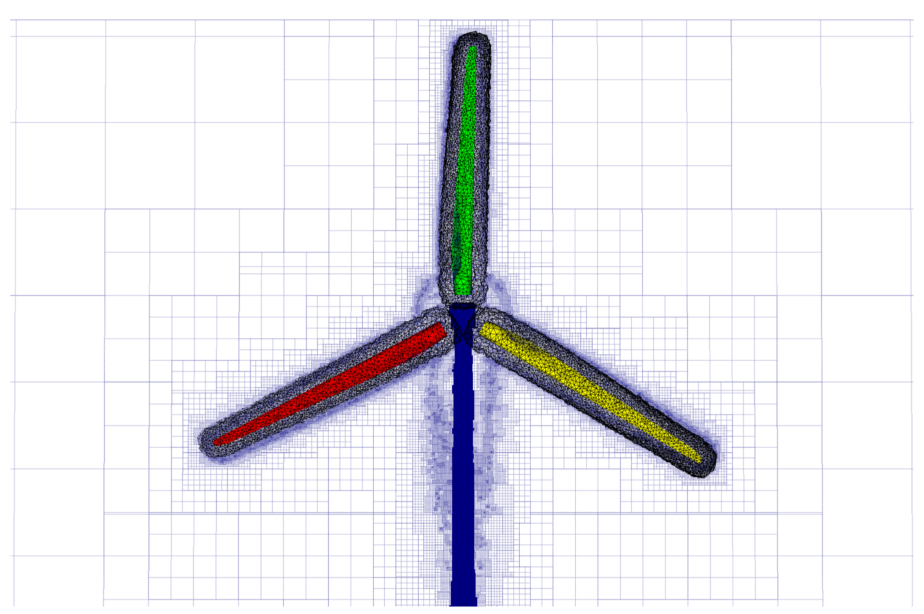


Figure 1 – Wind turbine overset mesh system: one replicated unstructured blade mesh, one unstructured tower mesh, adaptive off-body mesh

Dual-Mesh Dual-Solver Paradigm

- Near-body solver: NSU3D
  - Implicit solver - Newton-Krylov and multigrid
  - DDES and ALE
  - Complex geometry
  - Scales up to 32k cores
- Off-body solver: dg4est
  - Explicit solver
  - High-order Cartesian DG solver
  - High Computational Efficiency
  - Dynamic h/p-AMR capabilities through p4est octree-based framework
  - Physics: Coriolis and Gravity
  - Scaling on Mira up to 1 million ranks

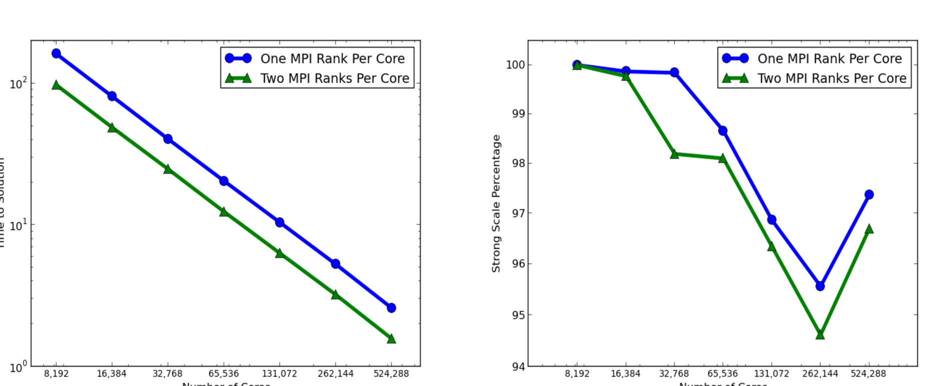


Figure 2 –Time to solution and strong scaling of off-body static mesh solver to over one million MPI ranks on DOE ALCF Mira supercomputer for 84 billion unknowns

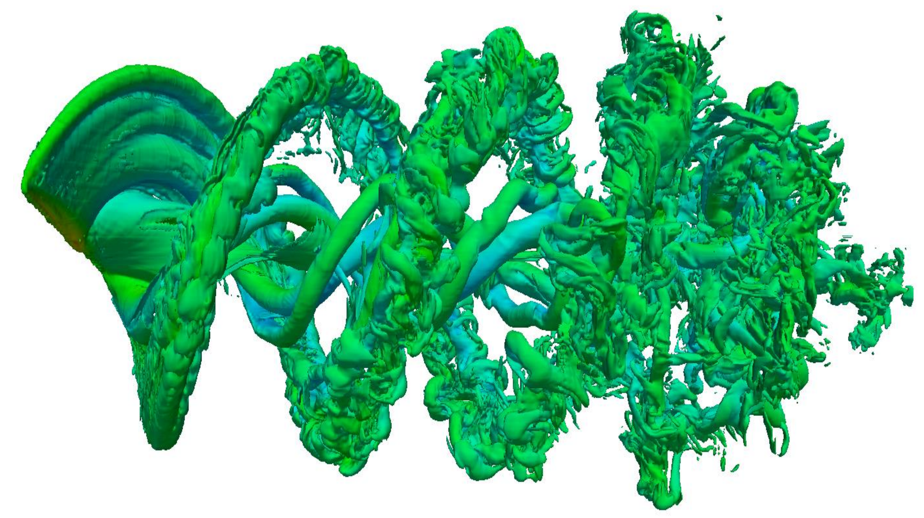


Figure 3 – NREL Phase VI simulation with uniform inflow of 10 m/s using a static mesh and the CartDG flow solver

Impact

- Enable single turbine to complete wind farm control: power optimization and turbine longevity/reliability
- Accurate detailed loading, wake interactions and atmospheric turbulence effects
- Validate and improve effectiveness of lower fidelity models
- Tool for wind plant siting, environmental effects
- Straight forward path to incorporate additional effects: transition, roughness, icing, acoustics

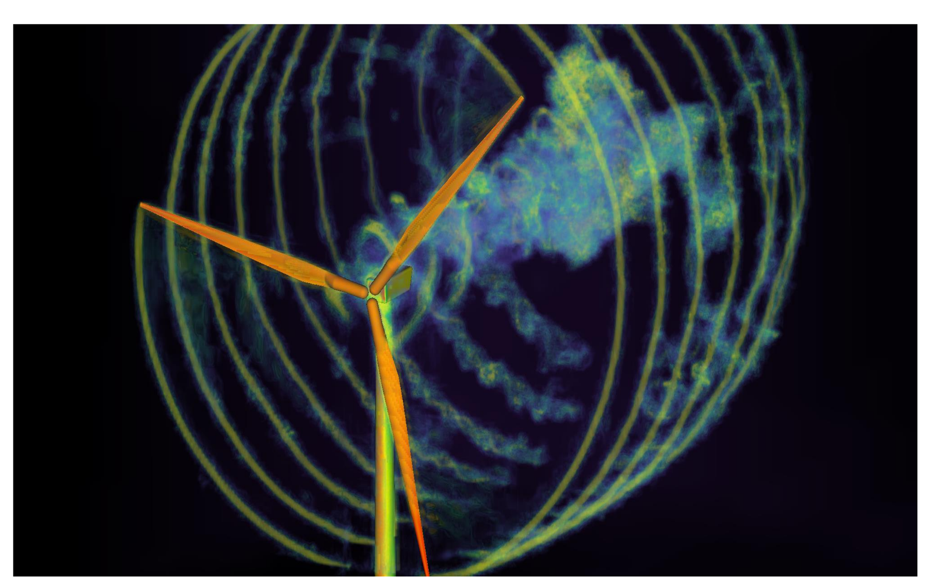


Figure 4 – Siemens SWT-2.3-93 wind turbine simulation with volume rendering of vorticity (colored by vorticity)

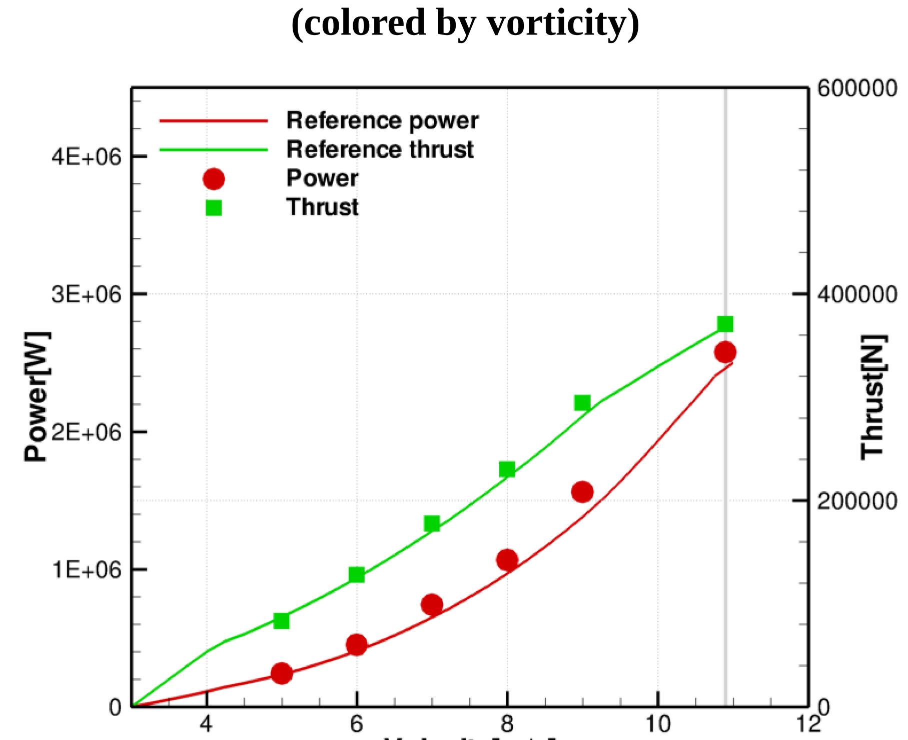


Figure 5 – Siemens SWT-2.3-93 power and thrust convergence results for various uniform inflow velocities

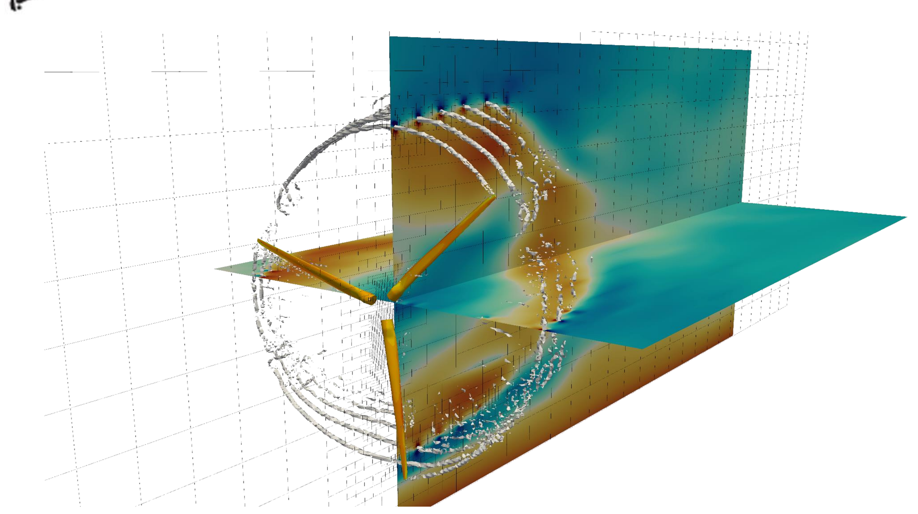


Figure 5 – NREL 5MW wind turbine simulation with atmospheric inflow conditions

High-Fidelity Modeling

- Increased accuracy for improvement of
  - Wake deficits
  - Detailed blade loading
  - Structural response and control
- Blade sublayer resolution
  - Better stall prediction

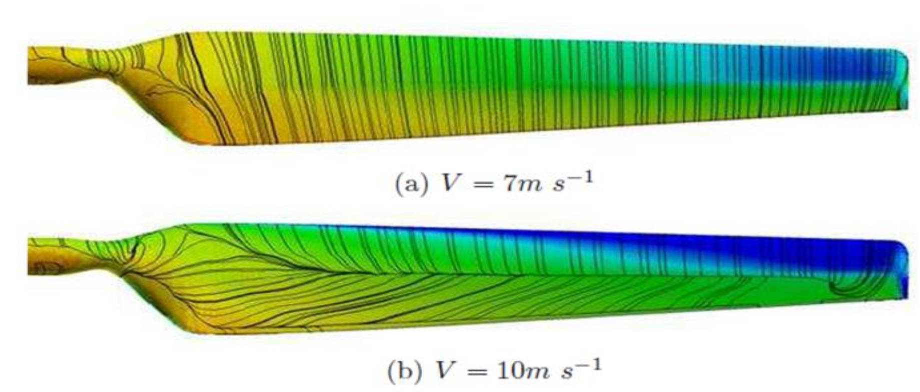


Figure 6 – Higher inflow velocity leads to stall which requires high-fidelity resolution to capture

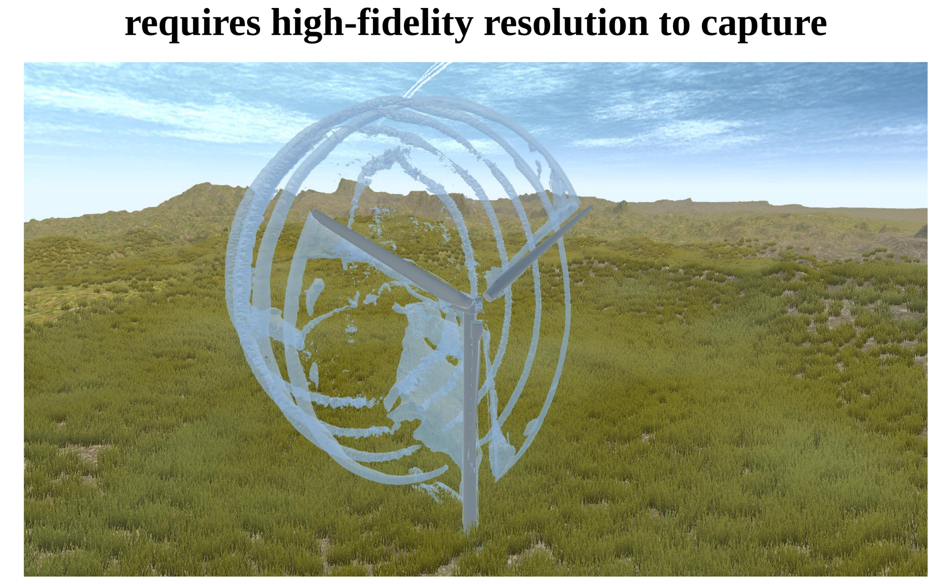


Figure 7 – Siemens SWT-2.3-93 wind turbine simulation with isocontour of velocity magnitude

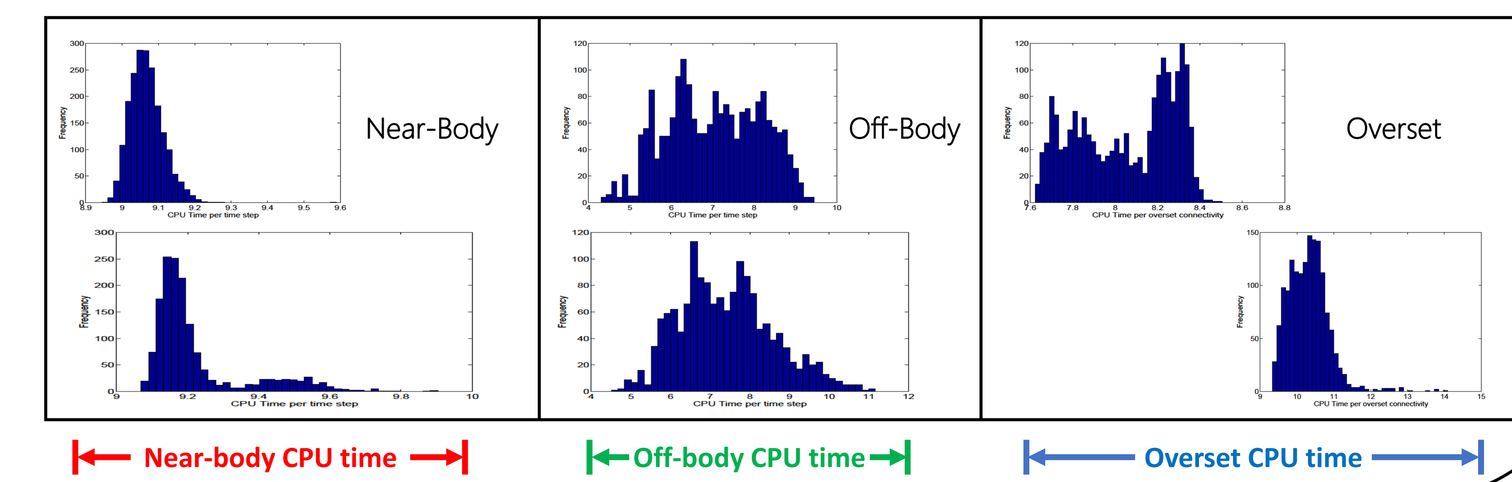
Related Work

- Link to atmospheric boundary layer LES simulations in complex terrain
  - One-way coupling to WRF-LES/SOWFA
- Fluid-Structure Interface
- Control model for wake steering
- Acoustic design optimization
- ONR research for ship wake interactions

Parallel Weak Scalability

The number of rotor revolutions achieved in 9.5 hours of wall-clock time is used for comparison in the parallel weak scalability test. The computational resources for each turbine is held constant.

	Turbine Count	Efficiency	Revs	Near-Body Cores	Off-Body Cores	Total Cores
25 mesh bodies →	6	1.0000	1.374	2,088	720	2,808
	12	0.9874	1.360	4,176	1,440	5,616
	24	0.9682	1.331	8,352	2,880	11,232
	48	0.9333	1.283	16,704	5,760	22,464
385 mesh bodies →	96	0.8686	1.194	33,408	11,520	44,928



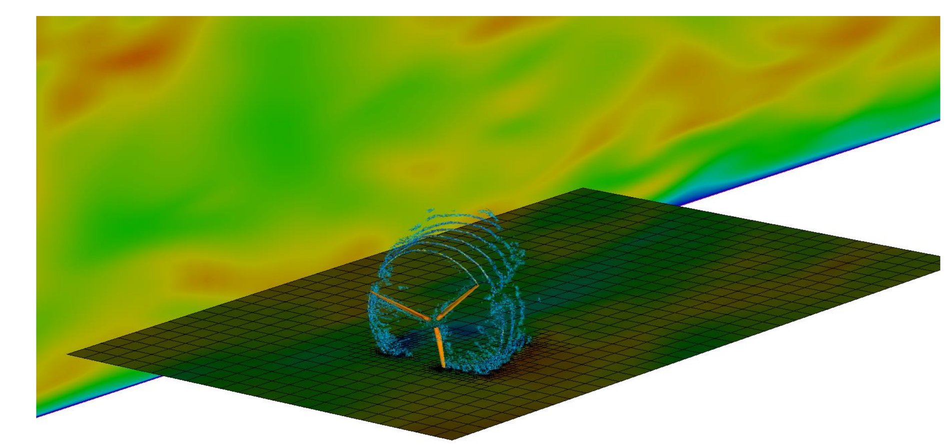


Figure 8 – Simulation of NREL 5MW with atmospheric inflow coupling using NCAR WRF

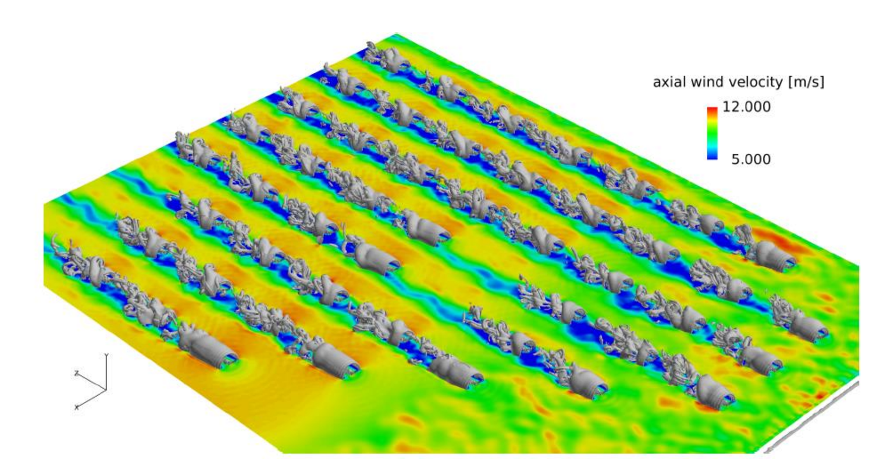


Figure 9 – Simulation of 48 wind farm with atmospheric inflow conditions using 3,840 cores after 30 revolutions

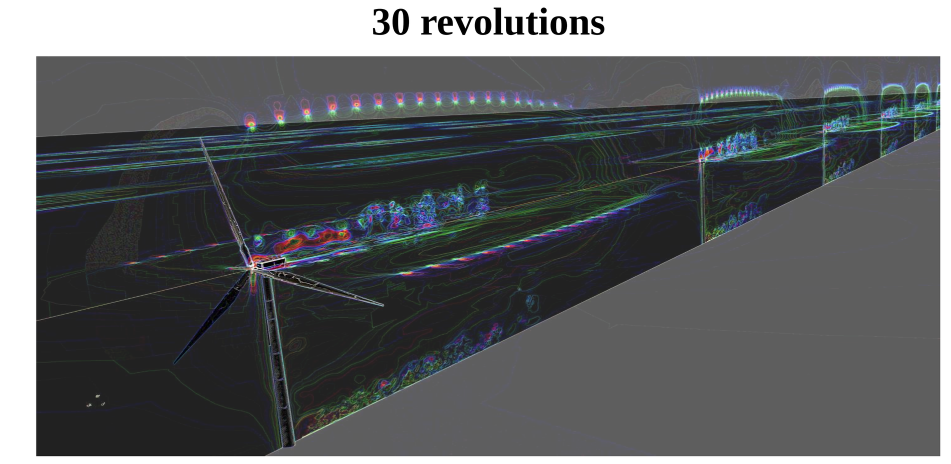


Figure 10 – Simulation of Lillgrund windfarm with uniform inflow conditions

Summary and Future Work

- Multiple flow solvers coupled by overset meshing
- Modular software interface written in C
- High-order dynamic h/p-AMR capabilities
- Successful wind farm simulation on 67,392 cores with 144 wind turbines
- Couple in WRF-LES/SOWFA
- Simulate large scale wind farm for long run times
- Future work: Split form Discontinuous Galerkin solver with turbulence modeling
- Future work: Couple NSU3D and FSI/CSD
- Future work: Wind turbine control module

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QR Code 1 – Animation of single wind turbine simulation with long wake analysis. Fourth-order LES with discontinuous Galerkin Split Form method.

QR Code 2 – Animation of Lillgrund wind farm simulation with 48 wind turbines. This simulation contains 10 magnitudes of spatial scales.

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