High Fidelity Blade-Resolved Wind Plant Modeling

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Motivation & Goals

DoE Wind Vision: A New Era of Wind Power in the United States
Previous Work

University of Wyoming
- Jay Sitaraman-2013
  ARMY’s HELIOS
Multi-Mesh, Multi-Solver Paradigm

Near-Body Mesh:
- Complex geometries
- Commercially-available grid generation
- Targets near-wall viscous turbulent flow

Off-Body Mesh:
- High-order accuracy
- Solution adaption
- Targets far-field wake
Multi-Mesh, Multi-Solver Paradigm

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(a) $V = 7\text{ m s}^{-1}$

(b) $V = 10\text{ m s}^{-1}$
Solvers

Near-Body Solver: NSU3D
- Finite-Volume 2nd-order accuracy
- RANS SA / DDES turbulence models
  - Rotation correction
- Agglomeration multigrid
- Line-implicit solution acceleration

Off-Body Solver: dg4est
- High-Order DG FEM
  - High computational efficiency
- AMR: p4est
  - hp-adaption
- LES
- Coriolis & Gravity
High-Order Overset Mesh Interpolation

**TIOGA - Topology Independent Overset Grid Assembler**

- Generate receptor node lists
- High-order donor inclusion test
- High-order interpolation weights
- Convert interpolation weights

Wyoming Wind and Aerospace Applications Komputation Environment
Mesh Refinement Study

Results: NREL 5MW

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Mesh Points</th>
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<tbody>
<tr>
<td>Coarse*</td>
<td>474,383</td>
</tr>
<tr>
<td>Coarse</td>
<td>360,148</td>
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<tr>
<td>Medium</td>
<td>927,701</td>
</tr>
<tr>
<td>Fine</td>
<td>2,873,862</td>
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</table>
Results: NREL 5MW

VisIt Libsim:
  In-situ visualization
Results: NREL Phase VI
Results: NREL Phase VI

- $p = 1$
  - 2nd-order

- $p = 1 - 4$
  - 2nd- to 5th-order
Results: NREL Phase VI

$p=1$
$2^{nd}$-order

$p=4$
$5^{th}$-order
Results: Siemens SWT-2.3-93
Results: Lillgrund Wind Farm

48 Wind Turbines

- 1.55 billion DOFs
- 22,464 cores
- Domain 10 km x 10 km
- Smallest Element 7E-6 m (7 micrometers)
- 10 magnitudes of spatial scales
Results: Weak Scaling Study

<table>
<thead>
<tr>
<th>Turbine Count</th>
<th>Efficiency</th>
<th>Revs</th>
<th>Near-Body Cores</th>
<th>Off-Body Cores</th>
<th>Total Cores</th>
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<tbody>
<tr>
<td>6</td>
<td>1.0000</td>
<td>1.374</td>
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<td>720</td>
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<td>1.194</td>
<td>33,408</td>
<td>11,520</td>
<td>44,928</td>
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</table>

6 Turbines
Near-Body

96 Turbines
Off-Body

Overset
Results: CFD & Atmospheric Coupling

• NCAR WRF
Final Remarks

- Blue Waters Fellowship:
  - 50,000 Node-Hours
  - Perform 6 wind turbine case

- Blue Waters Proposal:
  - Moderate (50 Turbines)
    325,000 Node-Hours
  - Large (200 Turbines)
    1,000,000 Node-Hours
Final Remarks

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Wind Farm Simulations Using an Overset hp-Adaptive Approach with Blade-Resolved Turbine Models

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Blade-resolved numerical simulations of wind energy applications using full blade and tower models are presented. The computational methodology combines solution technologies in a multi-mesh, multi-solver paradigm through a dynamic overset framework. The coupling of a finite-volume solver and a high-order, hp-adaptive finite-element solver is utilized. Additional technologies including in-situ visualization and atmospheric micro-scale modeling are incorporated into the analysis environment. Validation of the computational framework is performed on the NREL 5MW baseline wind turbine, the unsteady aerodynamics experimental NREL Phase VI turbine, and the Siemens SWT-2.3-88 wind turbine. The power and thrust results of all single turbine simulations agree well with low-fidelity model simulation results and field experiments when available. Scalability of the computational framework is demonstrated using 6, 12, 24, 48, and 96 wind turbine wind plant set-ups including the 48 turbine wind plant known as Lilgrund. Demonstration of the coupling of atmospheric micro-scale and CFD solvers is presented using the NCAR WRF solver and the NREL SOWFA solver. Comprehensive validation with measurements will be the focus of future research of the computational framework.

A high-order discontinuous-Galerkin octree-based AMR solver for overset simulations

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Department of Mechanical Engineering
University of Wyoming

The goal of this work is to develop a highly efficient off-body solver for use in overset simulations. Overset meshes have been gaining traction in recent years and are being used increasingly to simulate very complex large-scale problems. In particular we focus on a dual-mesh, dual-solver overset approach that combines specialized flow solvers in different regions of the flow domain: near-body and off-body. The near-body flow solver is designed to handle complicated geometry, anisotropic elements, and unstructured meshes. In contrast, the off-body solver is designed to be high-order, Cartesian, and use adaptive mesh refinement (AMR). The high-order discretization used for the off-body solver is based on the discontinuous Galerkin (DG) method. To get the most efficiency out of the method, a Cartesian grid is employed and tensor product basis functions are used in the DG formulation. The dense computational kernels allow this solver to obtain a near-constant cost per degree of freedom for a wide range of p-orders of accuracy. To further enhance the capabilities of the off-body solver, the DG solver in linked to an octree-based AMR library called p4est; this gives the ability for h-adaptation via non-conforming elements, p-adaptation is also implemented in which each cell can be assigned a different polynomial degree basis. Combined h and p refinement is necessary for overlapping mesh problems where the off-body solver mesh must connect to the low-order near-body solver, since both mesh resolution and order of accuracy must be matched in the overlapping regions. To demonstrate the efficiency, accuracy, and capabilities of the DG AMR flow solver we simulate Ringbloch flow and the Taylor-Green vortex problem. Finally, to demonstrate the overset capabilities a NACA 0015 wing case and a NREL PhaseVI wind turbine case are simulated.
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