U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Industry Modeling/Simulation Gaps

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Turbine Modeling Challenges

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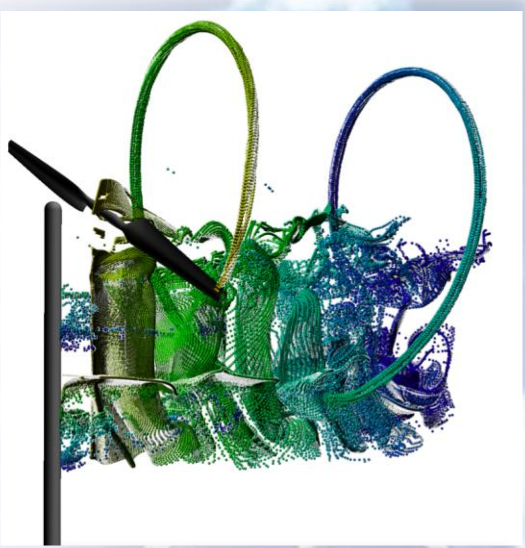
- **State-of-the-Art Tools Have Difficulty Predicting Turbine Rotor Aerodynamics**
  - **Linear Aerodynamics used extensively in integrated system design**
  - **Aeroelastic coupling with complex 3-D flow field is critical to performance estimate and cost-effective design**
  - **Advanced Computational Aero-Acoustics Prediction (CAA)**
  - **Required physics include separation, dynamic stall, blade loading, and acoustic emissions; sub-chord dimensional scale**
- **Advanced Structural Rotor Modeling**
  - **Simple reduced-order models, e.g., 3-DOF linear modal blade models are extensively used by industry**
  - **Geometrically nonlinear shell and reduced-order beam models for highly flexible blades needed for aeroelastic tailoring**
  - **Must include material-failure models, nonlinear buckling, uncertainty quantification, fully coupled fluid-structure interaction**
- **Integrated System Dynamics Simulation Modeling for both Load & Performance Prediction**
  - **Fully coupled FEM models capturing rotor, tower, platform and mooring dynamic behavior including non-linear response**
  - **Supporting Deep Water Offshore Platform Design**



Fully Coupled Multi Array Simulations with Fidelity and Scales from Atmospheric Inflow to Blade Boundary Layer

Offshore Floating Wind Turbine

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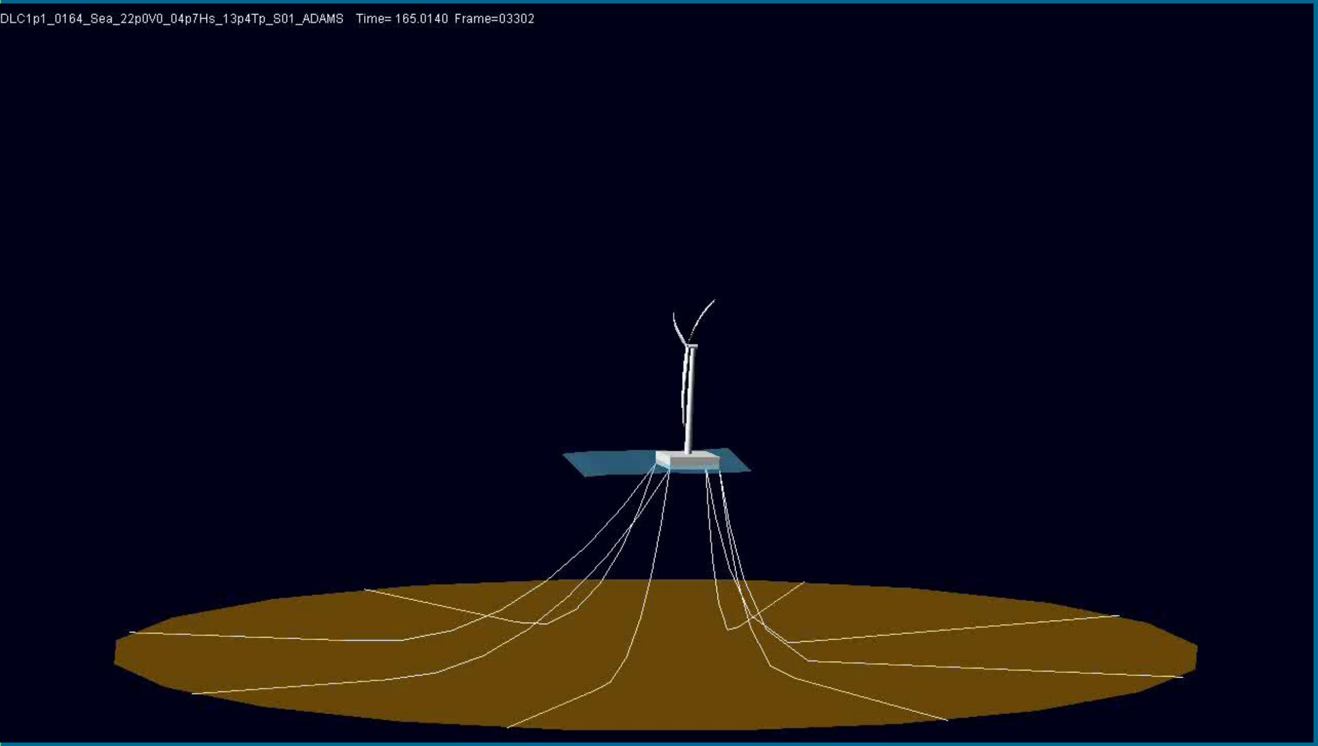
Advanced Coupled Aero-elastic Hydrodynamics Model of an Offshore Floating Wind Turbine



Jason Jonkman; 2007

- **NREL 5 MW Turbine Used as Baseline**
  - **Adopted as an international standard for comparison**
- **Concatenation of Reduced-Order Models:**
  - **Linear modal blade & tower**
  - **Linear wave dynamics**
  - **Homogeneous turbulence**
  - **Linear aerodynamics (BEM)**
  - **Platform treated as rigid body**
  - **Quasi-static mooring**
  - **Integrated state space and PID control modeling**
- **Existing Capability**
  - **Lacks Fully Coupled Inflow, Wake and Wind/Wave Physics for Multi-Array Modeling**
  - **Not Well Suited for Highly Flexible Blades, Examination of Failure Modes, Non-Linear Coupled Response**

Wind Energy Fundamental Science Issues Requiring HPC

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HPC Code Development for Predictive, Rational Design and Operation Supporting High Penetration Wind Energy

- **Wind & Solar Resource Assessment as a Strategic National Energy Resource**
  - ➢ Guide the Strategic Development & Deployment of Future Infrastructure – Generation & Transmission
- **Weather Driven Energy Forecast Models - Coupled Wind & Solar**
  - ➢ Integrated Monitoring, Forecast, Generation, Load Flow & Operational Dispatch
- **Quantify Potential Effects of High Penetration Scenarios**
  - ➢ Climate change Sensitivities
  - ➢ Macro & Micro Climatology Impacts
  - ➢ Insure against trading carbon alleviation for unknown consequences
- **Characterize Inflow and Outflow Resource**
  - ➢ Boundary Layer Processes, Stability, Marine & Nocturnal Formation
  - ➢ Atmospheric turbulence
  - ➢ Flow separation in complex terrain
  - ➢ Air/Sea Boundary Conditions & Wave Interaction
  - ➢ Inter & Intra Array Wake Effects
- **Coupled Physics Models Inflow / Wind Plant Interaction / Grid Response**
  - ➢ Energy production optimization and grid integration
  - ➢ Wind Plant Operation & Control Strategy Development
- **Establish the Design Criteria for Future Turbine & Plant Innovation -**
  - ➢ Individual blades and gearboxes, materials.
  - ➢ Multi-turbine arrays.
  - ➢ Mesoscale atmospheric models.
  - ➢ Wind/Wave models.
  - ➢ Inter/intra plant dynamics

Classic Coupled Multi-Scale, Multi-Physics Problems

Repower 5MW Demonstration at Beatrice Four-pile jacket