Industry Modeling/Simulation Gaps

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Turbine Modeling Challenges

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

- 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

Jason Jonkman; 2007
Wind Energy Fundamental Science Issues Requiring HPC

**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**