U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

Sandia National Laboratories

T23-Verification, Validation, and Uncertainty Quantification of Wind Plant Models Project

Technology RD&T and Resource Characterization – Atmosphere to Electrons
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FY21 Peer Review - Project Overview

Project Summary:

- This project will ensure that the predictive capability of the suite of models being developed across the Atmosphere to electrons (A2e) program is established through formal verification, validation, and uncertainty quantification (V&V/UQ) processes.
  - Quantitatively establish where models are valid and where improvements are necessary.
  - Knowing the uncertainty of a model prediction allows for better planning and reduced risk in its application.
- The result will be established V&V/UQ techniques applied to computational modeling tools spanning a range of fidelities.
  - Multifidelity UQ tools and concepts adopted by A2e projects (ISDA).
  - These tools will be adopted by the wind industry through collaborations planned in future phases of the work.
- Key project partners: NREL, PNNL, University of Wyoming

Project Objective(s) 2019-2020:

- Establish a validation framework with well-defined performance metrics, apply it to benchmark wind-plant simulation cases.
- Coordinate validation activities across A2e, which will maximize the value from a limited number of facility experiments.
- Validation work is focused on wind turbine loads, detailed wake development and control, and turbine-turbine interaction for wind plant wake interaction.

Overall Project Objectives (life of project):

- Develop and apply verification, validation, and uncertainty quantification techniques to wind industry relevant applications, driving innovation through the trusted application of high fidelity models.

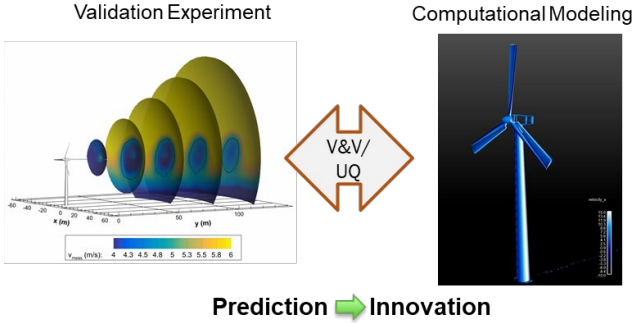
Project Start Year: 2019
Expected Completion Year: FY22
Total expected duration: 3 years

FY19 - FY20 Budget: $1,452,209

Key Project Personnel: David Maniaci (PI), Jonathan Naughton, Gianluca Geraci

Key DOE Personnel: Michael Derby (Lead), Ben Hallissy, Michael Robinson

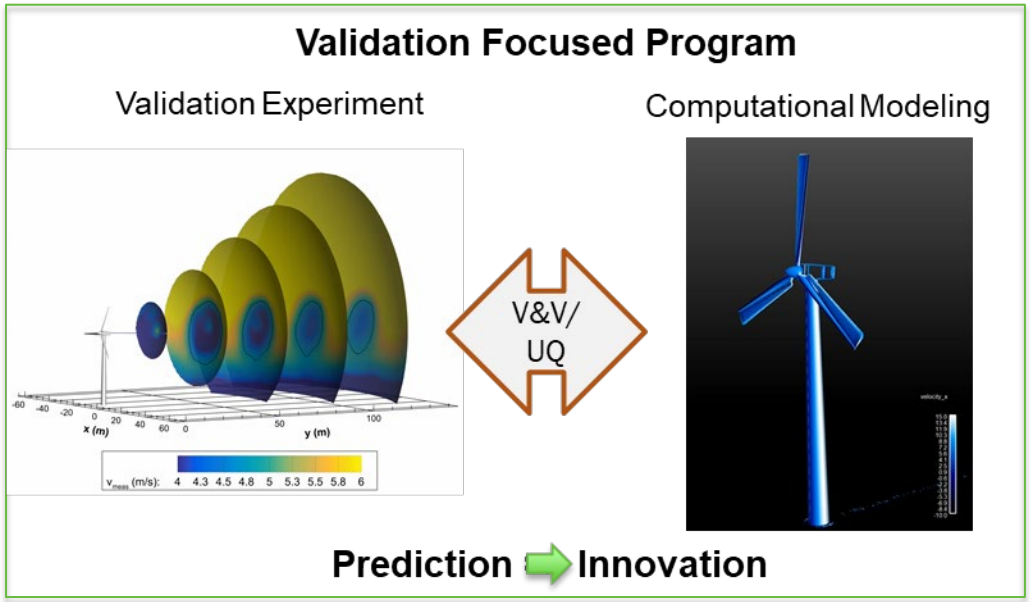
Validation Focused Program



Project Impact

The A2e V&V/UQ focus has changed wind program culture

- Validation is now a part of every A2e effort.
- Validation efforts are based on common validation framework and terminology.
- Developed algorithms to link models and data across program areas.
- Influenced the R&D community to be validation focused.



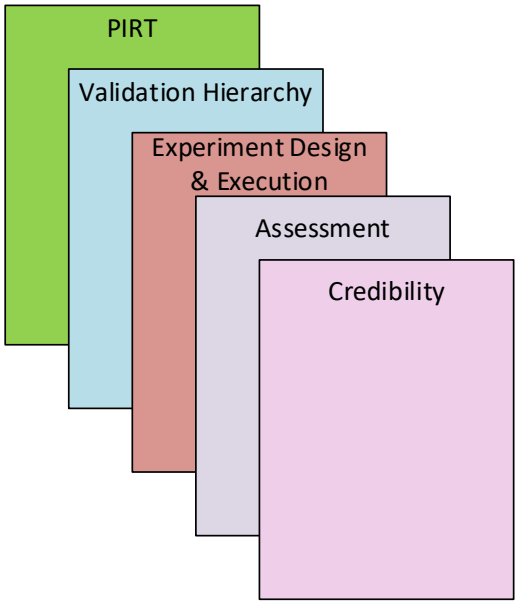
Adoption of V&V in Wind Energy Community

- V&V programs now part of:
  - IEA Task 30, Offshore Code Comparison
  - IEA task 31, Wakebench
  - IEA Wind Task 36: Forecasting for Wind Energy
- Standards engagement and support:
  - AWEA TR-1: Wind Plant Uncertainty
  - IEC/IECRE V&V JWF

Program Performance – Scope, Schedule, Execution

Key Program Goals & Objectives By Completion

- Establish a validation framework with well-defined performance metrics.
  - Apply it to benchmark wind-plant simulation cases.
- Coordinate validation activities across A2e.
- Develop and demonstrate wind turbine and wind plant V&V/UQ techniques.
- Develop tools to define the most informative physical and high-fidelity computational experiments that best inform our predictive capability.
- Disseminate methods and study results with stakeholders.



Validation Program Steps

Primary Tasks:

1.0 Validation Coordination

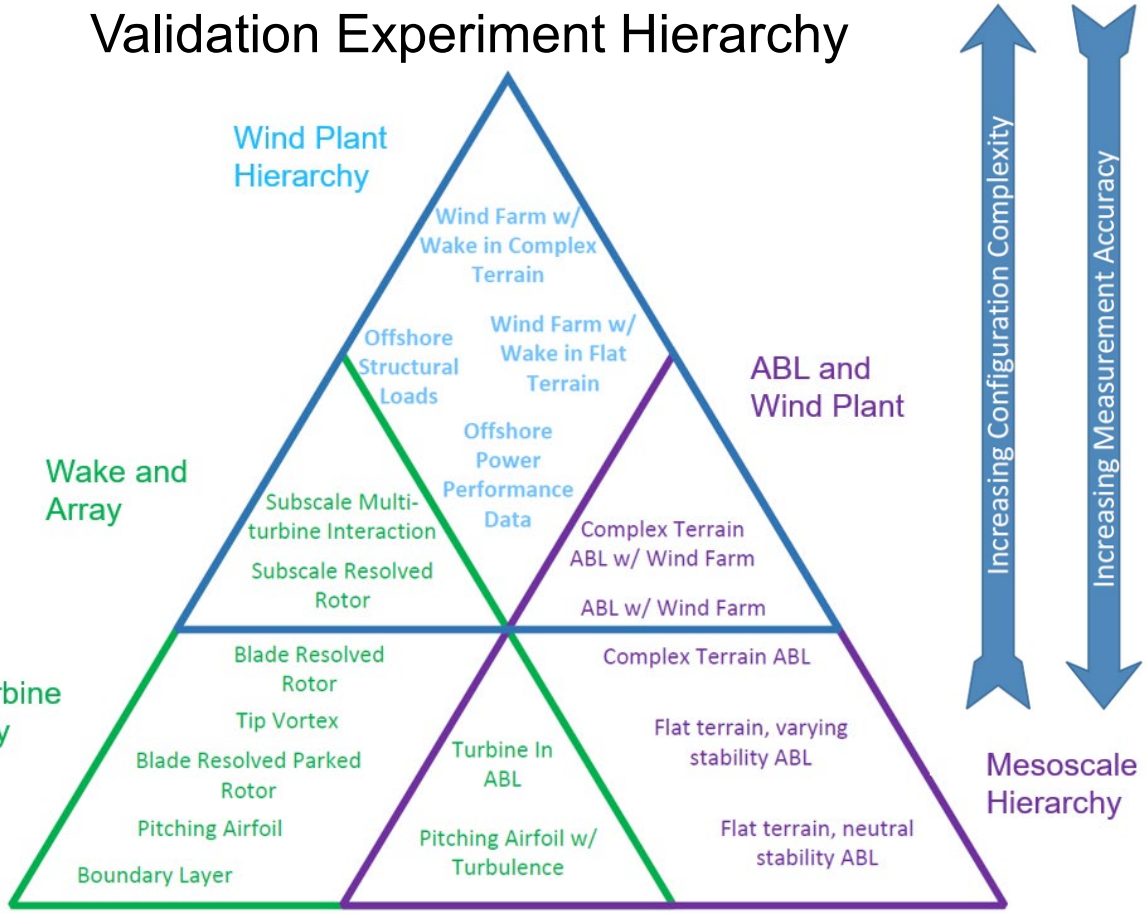
2.0 Uncertainty Quantification Development

3.0 Validation and Uncertainty Quantification Application

Program Performance – Scope, Schedule, Execution

1.0 Validation Coordination

- V&V/UQ plays an integrating role across A2e projects.
- Validation Experiment Hierarchy captures how coordinated experiments of varying complexity are needed to validate high-fidelity models.



FY20

-Released *Wind Energy High Fidelity Model Verification and Validation Plan.*

-Held A2e V&V engagement meeting.

-Developed validation experiment roadmap framework.

Program Performance – Scope, Schedule, Execution

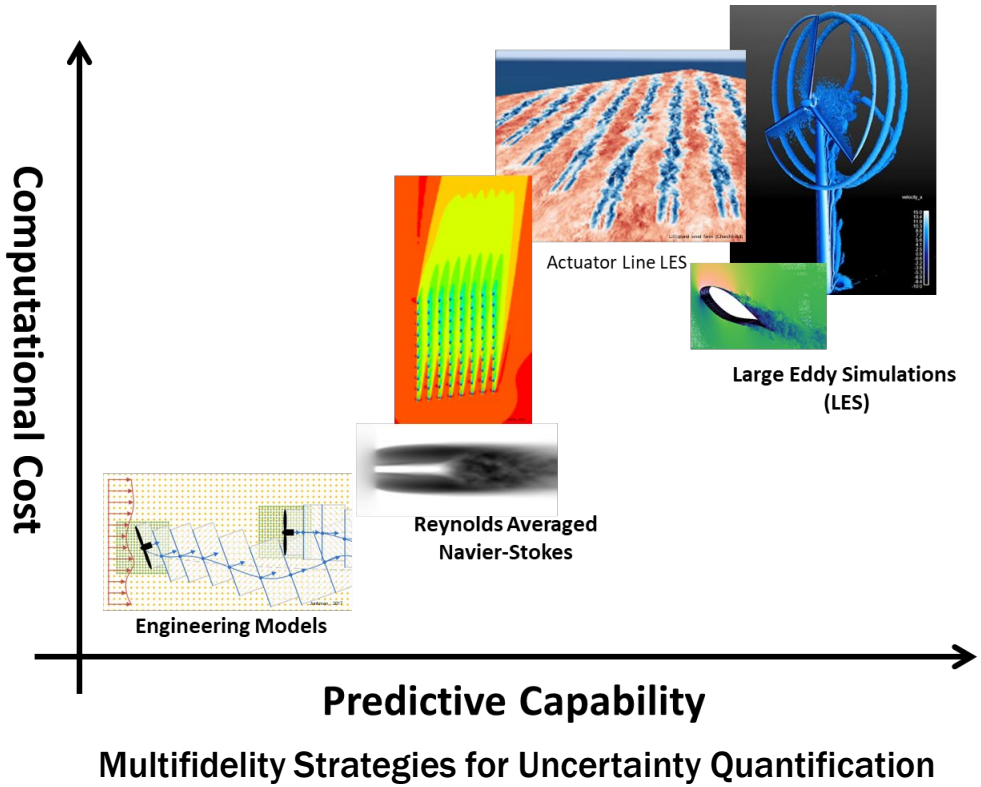
2.0 Uncertainty Quantification Development

Wind plant challenges for uncertainty quantification (UQ):

- **High-fidelity** state-of-the-art modeling and simulations with high performance computing.
- **Severe** simulations **budget constraints.**
- **Significant dimensionality** driven by model complexity.

Objectives of the work:

1. **Efficient forward UQ**: Uncertainty's impact on wind plant performance.
2. **Efficient inverse UQ**: Uncertainty characterization.
3. **Optimization Under Uncertainty**: Wind plant performance augmentation under uncertainty.



Multifidelity Strategies for Uncertainty Quantification

FY20

-Developed and demonstrated multifidelity strategies for forward and inverse UQ on wind energy applications, including high fidelity wind turbine models.

-Organized non-deterministic approaches wind session at the AIAA SciTech 2020 conference.

-Presented multiple papers on techniques for wind energy uncertainty quantification.

Program Performance – Scope, Schedule, Execution

3.0 Validation and Uncertainty Quantification Application

FY20

-Investigated the effect of mesh resolution on a wide range of atmospheric, turbine, and wake quantities.

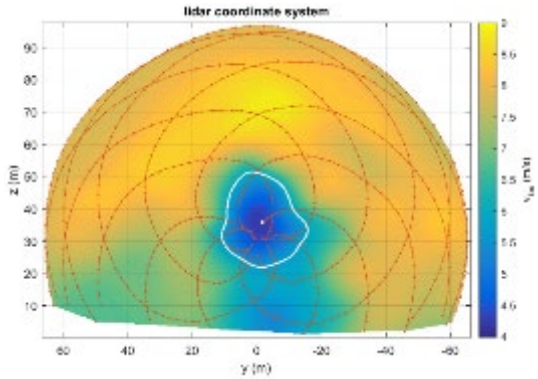
-Characterized experimental and simulation uncertainty in experimental validation comparisons.

-Demonstrated the effectiveness of Nalu-Wind's simulated lidar model in capturing higher-order experimental wake profiles.

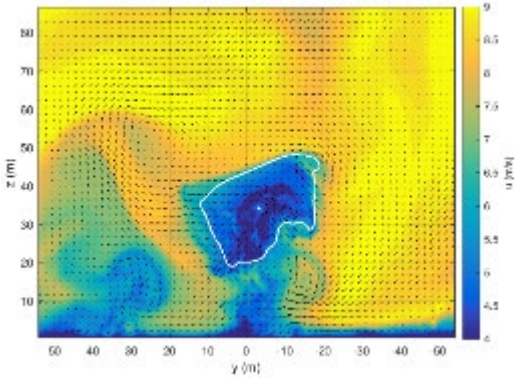
-Journal paper, "High-Fidelity Wind Farm Simulation Methodology with Experimental Validation," submitted for review.

High Fidelity Wake Model Validation

Instantaneous Wake Snap-shots

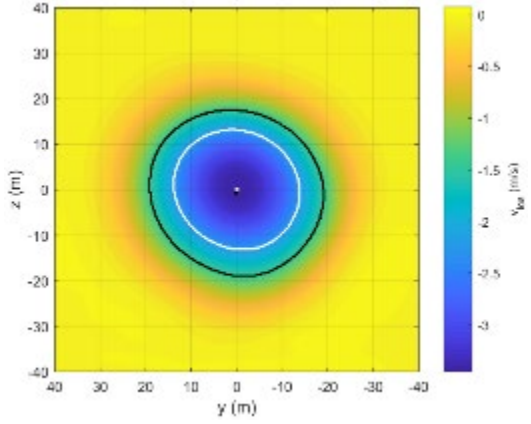


Sample of the wake date from the measured Spinnerlidar at the SWiFT facility.

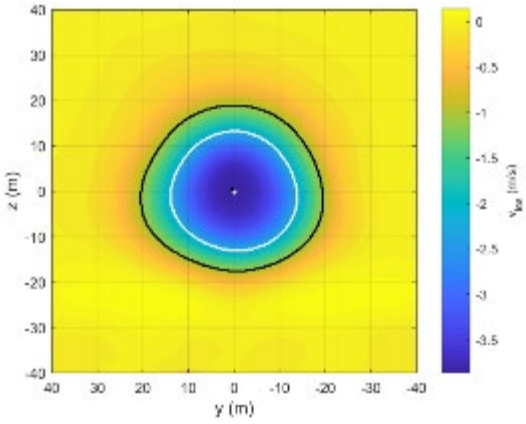


Nalu-Wind Simulated wake data 5D downwind.

Time-averaged Wake Data



Average over 10 minutes of the wake data from the measured Spinnerlidar.

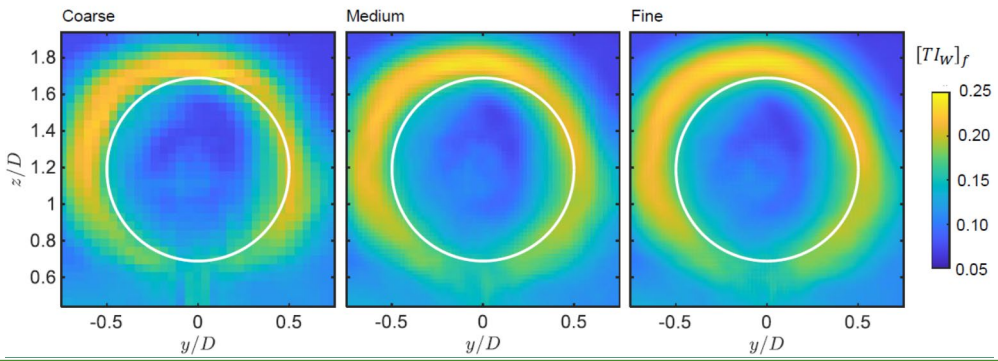


Average over 10 minutes for the simulated wake data 5D downwind, sampled to match the experimental lidar data.

Program Performance – Accomplishments & Progress

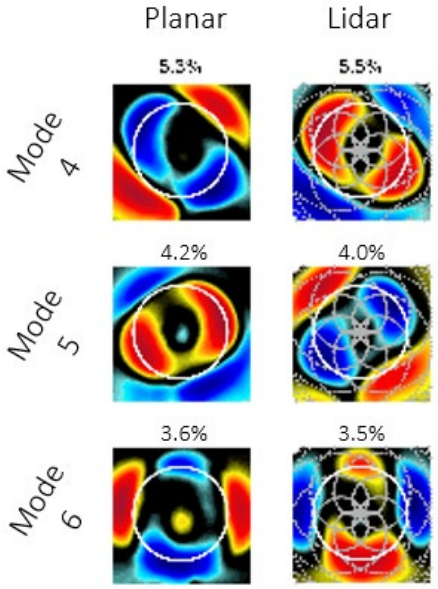
- Publication of High Fidelity Modeling Validation Roadmap, a basis for validation experiment planning across A2e.
- Developed and demonstrated novel uncertainty quantification techniques for wind energy analyses.
  - Worked closely with High-Fidelity Modeling, Systems Engineering & Optimization, and Multi Physics Model Validation projects to deploy multifidelity UQ methods using a range of models (WindSE, OpenFAST/TurbSim, Nalu-Wind).
- Initial validation of Nalu-Wind, part of the ExaWind code suite, for wake strength and deflection.
- Developed Validation Experiment Roadmap framework: bridge between long term validation objectives and experiment development.

YZ-contours of turbulence intensity in the wake for different mesh resolutions.

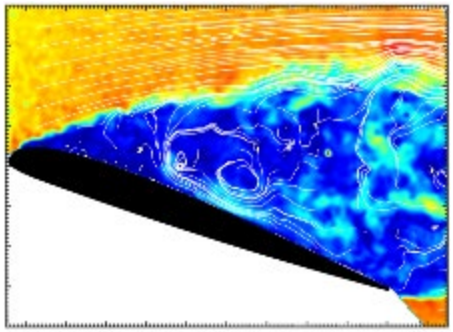


Project Performance - Upcoming Activities

- Wind plant UQ framework and demonstrations.
  - Multilevel-Multifidelity UQ: Forward, Inverse, OUU.
- Enhanced validation techniques: wake assessment through proper orthogonal decomposition (POD) and machine learning.
- Validation of HFM capabilities
  - Validation and parameter optimization for wake simulations in a range of atmospheric boundary layer (ABL) conditions.
  - Identify best practices and quantify the sensitivity to model input parameters for both the ABL and the turbine.
- Support V&V/UQ standards and IEA activities:
  - IEC/IECRE Joint Working Forum on V&V, AWEA TR-1: Wind Plant Uncertainty, IEA-Wind Wakebench and Aerodynamics tasks.
- Short-term unsteady aerodynamics validation experiment: demonstration of complete V&V/UQ process.

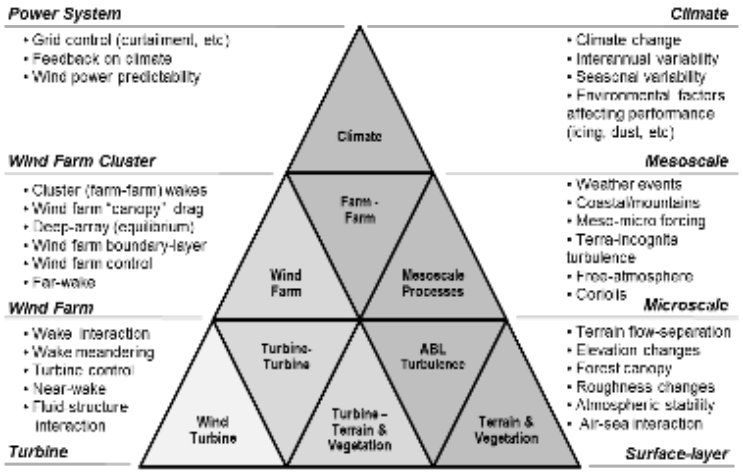


Advanced wake analysis with POD.


Unsteady aerodynamics testing.

Stakeholder Engagement & Information Sharing

- Held engagement meetings with V&V/UQ project stakeholders.
- All project work has resulted in public presentations, papers, or technical reports.
- These reports and publications include quantified uncertainties and details of the experiments and modeling efforts such that the results can be reproduced.
- Public work in 2019-2020 included 2 technical reports, 4 AIAA Scitech conference papers, 4 Torque2020 conference papers, 1 invited presentation, and 1 journal paper in review.
- Organized a session on wind energy UQ research at the 2020 AIAA SciTech conference.
- International Energy Agency (IEA)-Wind Task 31 Wakebench V&V work package leadership.
- IEA-Wind Task 30 engagement.
- IEA-Wind Task 29 input on aerodynamic V&V.
- IEA TEM participation on Multi-Fidelity Modeling.



IEA Task 31 Validation Hierarchy, based on A2e V&V Framework concepts.