U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

NREL Transforming ENERGY

T22 – Multi-Physics Model Validation and Uncertainty Quantification (UQ)

Technology RD&T and Resource Characterization – Atmosphere to Electrons (A2e)

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FY21 Peer Review – Project Overview

Project Summary:

- ***Challenge:*** Lower wind cost of energy requires technology advancement through improved engineering capability founded on physics
- ***Approach:*** Use the knowledge, data, and high-fidelity modeling (HFM) results from the broader A2e initiative and collaboratively with the wind community to validate and improve physics-based engineering design competence and tools, focusing on rotor aeroelasticity and farm aerodynamics for loads analysis
- ***Key Partners:*** International Energy Agency (IEA) Wind Task 29 (Aerodynamics), IEA Wind Task 31 (WakeBench)

Project Objective(s) 2019-2020:

- ***Verify and Validate (V&V) Models:*** V&V of OpenFAST and FAST.Farm in Task 29 and 31 and related V&V against HFM and data
- ***Improve Model Accuracy and Applicability:*** Minimize FAST.Farm computational expense and improve the wake model robustness
- ***Understand Design Drivers:*** Identify uncertain wind inflow, wind turbine, and wake parameters that are most influential to structural loads

Overall Project Objectives (life of project):

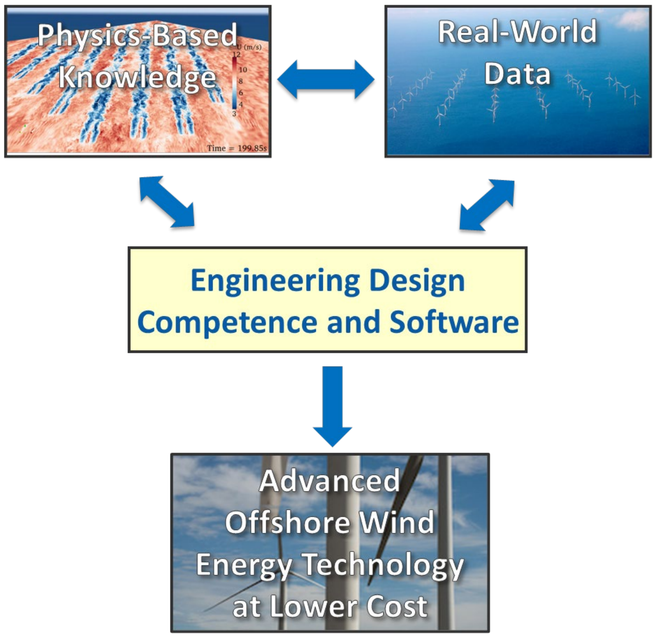
- ***Verify and Validate Models:*** Quantitively understand the accuracy, applicability, limitations, and uncertainty in engineering tools
- ***Improve Model Accuracy and Applicability:*** Improve the physics of engineering tools based on V&V outcomes and industry needs
- ***Understand Design Drivers:*** Assess sensitivity to understand conditions or features that are design driving

Project Start Year: FY 2016
Expected Completion Year: FY 2023
Total expected duration: 8 years

FY19 - FY20 Budget: $1,004,740

Key Project Personnel: Emmanuel Branlard (NREL), Paula Doubrawa (NREL), Jason Jonkman (PI – NREL), Tony Martinez (NREL), Kelsey Shaler (NREL), Amy Robertson (NREL)

Key DOE Personnel: Alana Duerr, Nathan McKenzie



Project Impact

Issues

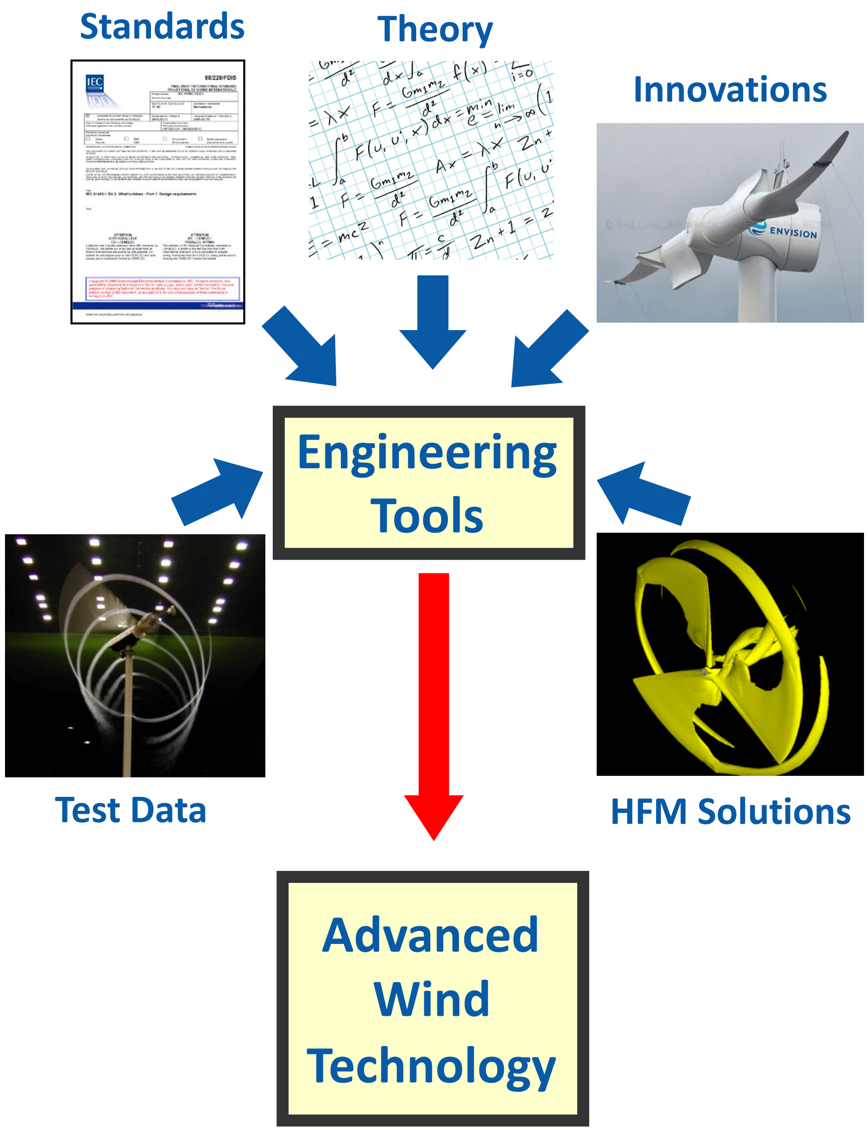
- Larger rotors experience inflow nonheterogeneity and structural flexibility
- Improvements needed in wind farm performance and reliability to achieve cost targets
- Design process is iterative and probabilistic

Approach

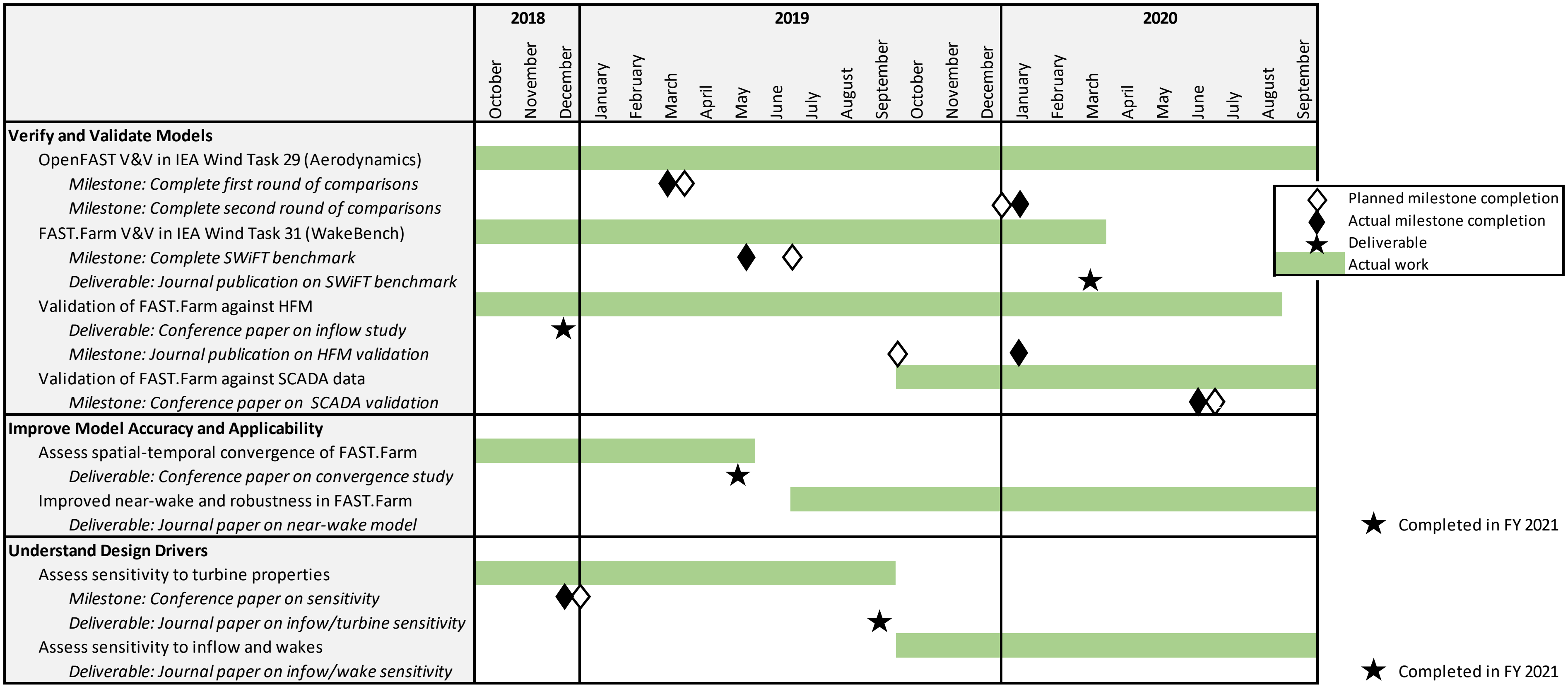
- Verify, validate, and improve physics-based engineering tools applicable to loads analysis
- Assess sensitivity to understand factors driving design

Results

- Quantified level of tool uncertainty
- Improved accuracy and applicability of tools
- Understood design drivers
- Increase tool acceptance within the wind industry and research communities, who will apply the tools to advance wind technology



Project Performance – Scope, Schedule, Execution



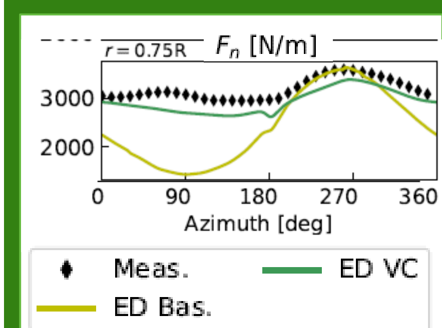
SWiFT = Scaled Wind Farm Technology | SCADA = Supervisory Control And Data

- All but one milestone completed on time or ahead of schedule:
  - FY 2019 Q4 milestone one-quarter late due to overcommitment of key staff on other projects
- FY 2016 project concluded in FY 2019
- Project tasks migrated to the *Modeling and Validation for Offshore Wind* (T24) project in FY 2020, continuing through FY 2023

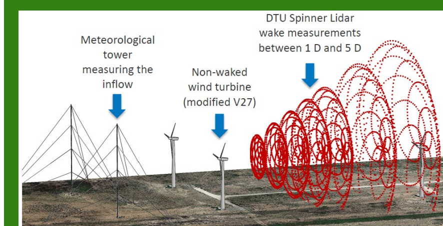
Project Performance – Accomplishments and Progress

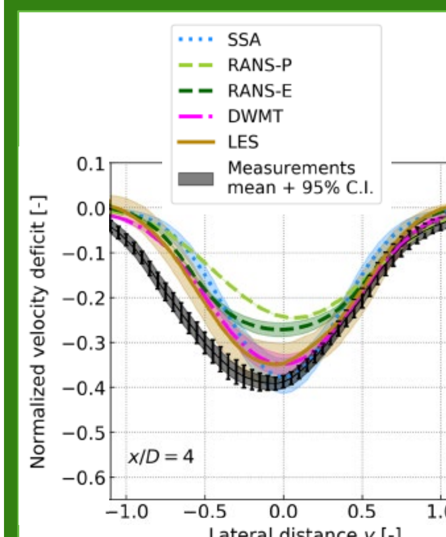
Performed three-way V&V of engineering tools against HFM and measured data to assess accuracy and identify needed improvements in OpenFAST and FAST.Farm

V&V of OpenFAST rotor aeroelastics using DanAero data within IEA Task 29

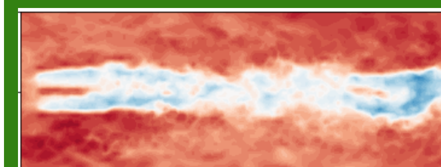


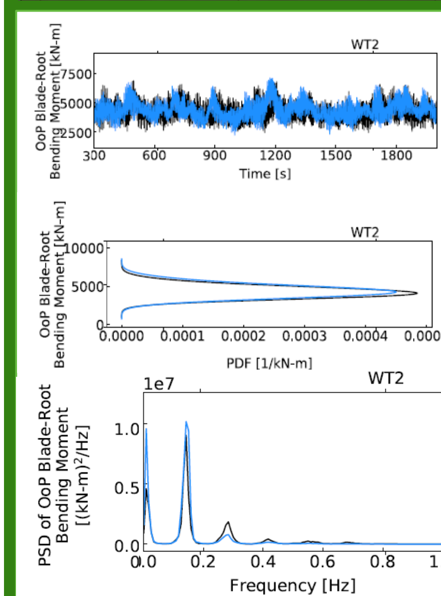
V&V of FAST.Farm wake dynamics using SWiFT data within IEA Task 31



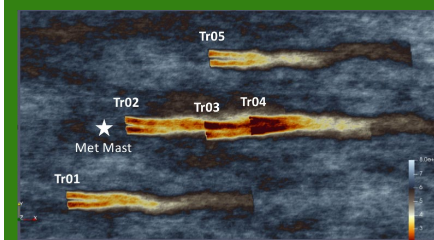


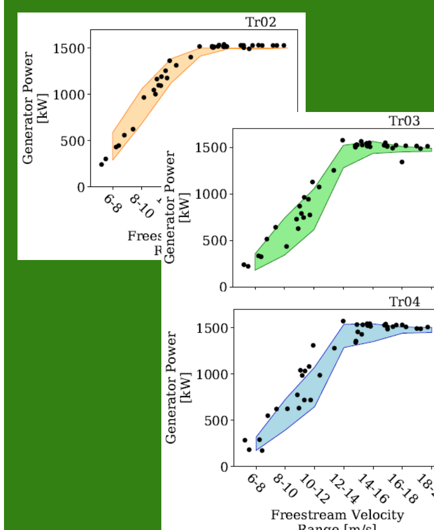
Assessed synthetic inflow and validated FAST.Farm structural loads against HFM





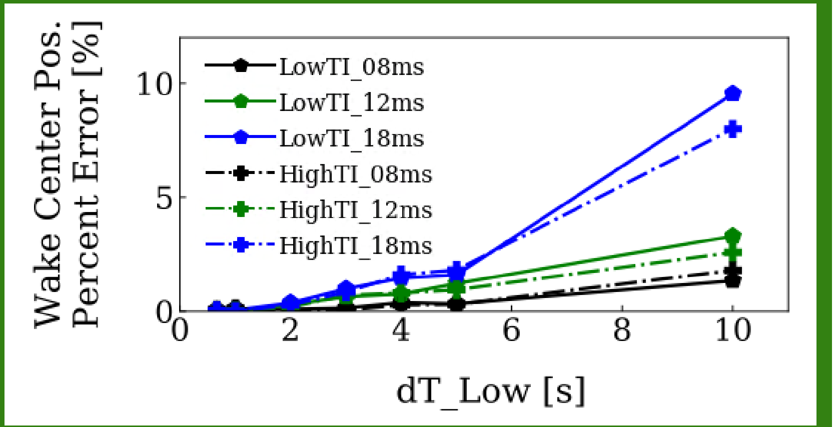
Validated FAST.Farm turbine response against SCADA data from five GE 1.5 MW





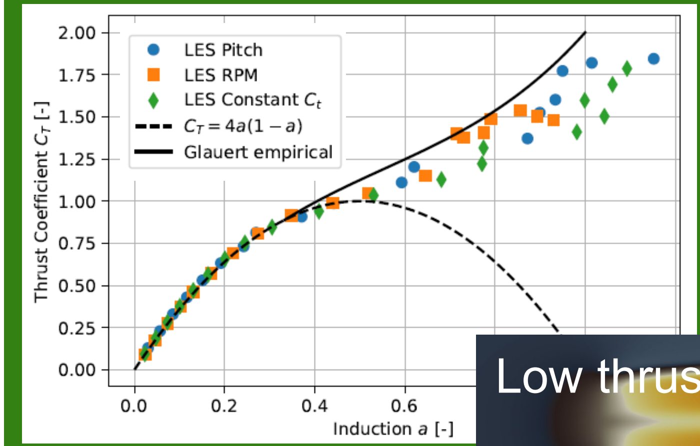
Project Performance – Accomplishments and Progress

Assessed the convergence of spatial-temporal discretization in FAST.Farm to ensure accuracy while minimizing computational expense



Percent error of lateral wake center position standard deviation associated with low-resolution time step

Derived a new near-wake correction model valid at high thrust by fitting to large-eddy simulation, making FAST.Farm more robust

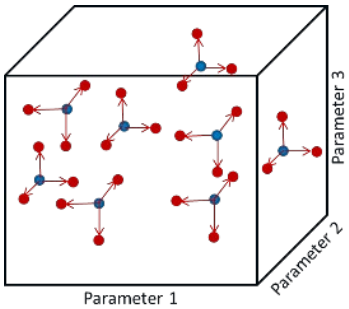


Wakes behave differently at high thrust, with increased turbulence and faster recovery; new wake deficit from FAST.Farm matches HFM well

Project Performance – Accomplishments and Progress

Identified input parameters most influencing turbine loads through a sensitivity assessment

$$\text{EE} = \frac{\partial Y}{\partial U} \Delta U$$



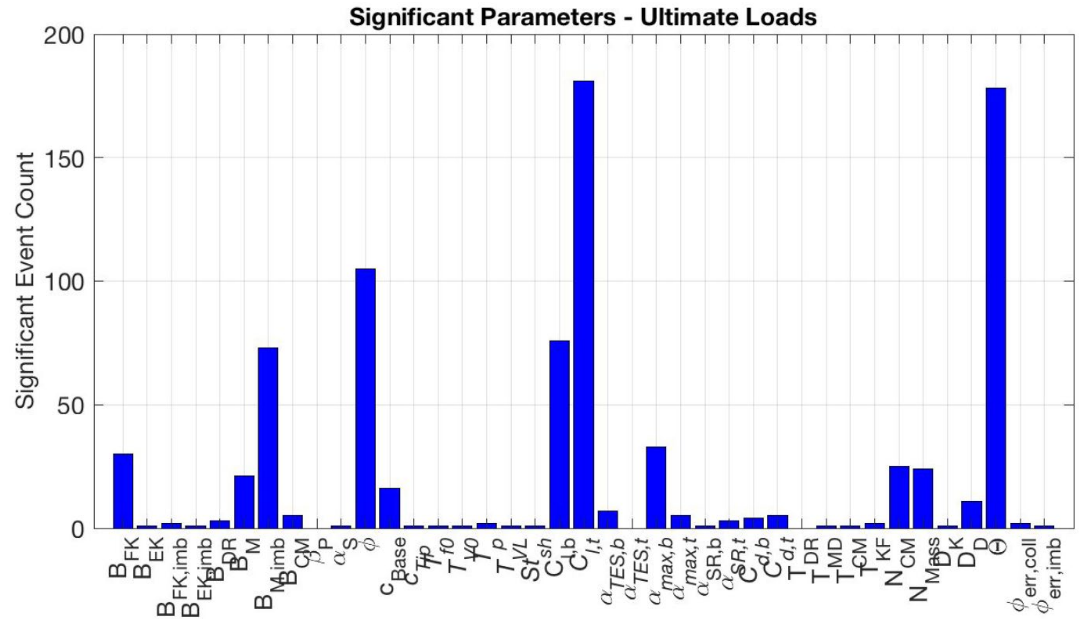
An Elementary Effects approach is used, requiring 100K+ OpenFAST or FAST.Farm sims

Which simulation input parameters…

- Inflow
  - Profile
  - Turbulence spectra
  - Spatial coherence
  - Reynold's stresses
  - Wind direction
- Turbine properties
  - Structural
  - Aerodynamic
  - Control
- Wake
  - Yaw misalignment
  - Eddy viscosity

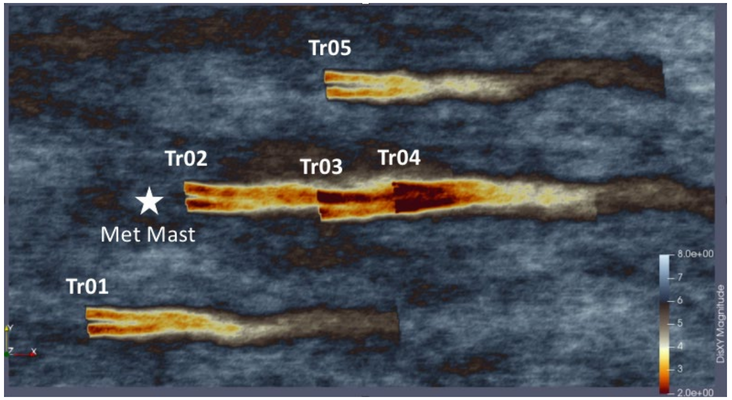
…most influence turbine ultimate and fatigue loads?

- Blades
- Drivetrain
- Tower



For turbine properties, outboard lift and mass imbalance are most sensitive, followed by twist, inboard lift, and blade frequencies

Project Performance – Upcoming Activities

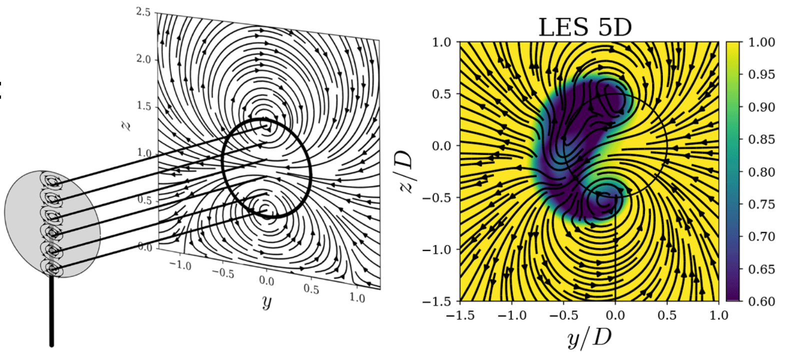


Verify and Validate Models

- Complete IEA Wind Task 29 and successor, Task 47
- Complete V&V of OpenFAST against RAAW data
- Complete V&V of FAST.Farm against alpha ventus and small farm data
- Complete initial validation of FAST.Farm against AWAKEN data
- Assess the IEC effective turbulence model

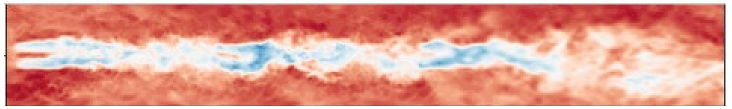
Improve Model Accuracy and Applicability

- Improve the induction model in OpenFAST
- Implement wake curl under skewed flow in FAST.F
- Implement wake-added turbulence in FAST.Farm



Understand Design Drivers

- Identify inflow and wake parameters influencing farm loads
- Identify inflow and wave parameters influencing floating offshore wind turbine loads
- Assess impact of wakes on floating turbine loads



RAAW = Rotor Aerodynamics, Aeroelastics, and Wake | AWAKEN = American Wake Experiment | IEC = International Electrotechnical Commission

Stakeholder Engagement and Information Sharing

Deliverables

- V&V results
- Improved engineering tools (OpenFAST, FAST.Farm)
- Identified design drivers

Audience and Customers

- External wind industry and researchers
- Other DOE projects

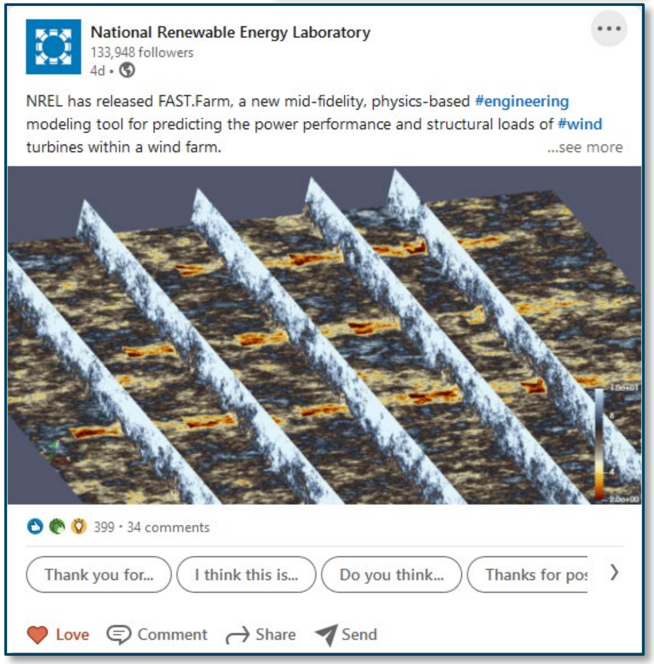
Communication and Outreach Strategy

- Conference presentations and journal publications
- Advertising through social media (e.g., LinkedIn)
- Engagement through IEA Wind V&V collaboratives

Related Externally Funded Industry Projects

- Envision Energy, Google X / Makani, Equinor, Vestas, Shell, IFE

Software Downloads	Journal Articles	Conference Presentations	Technical Reports	External Funding
10,000+ per year	5	6	1	6 projects



Key Takeaways and Closing Remarks

Engineering models required to address design challenges, so that wind turbines are

- Innovative
- Optimized
- Reliable
- Cost-effective

Validated and improved models are needed to address / develop

- Upscaling to larger sizes
- Novel architectures and controls
- Coupling to offshore platforms
- Design at the wind-plant level
- System-wide optimization

George E. P. Box

"Essentially, all models are wrong, but some are useful."

SWT-6.0-154 with Airbus A380

Horns Rev Wind Farm