

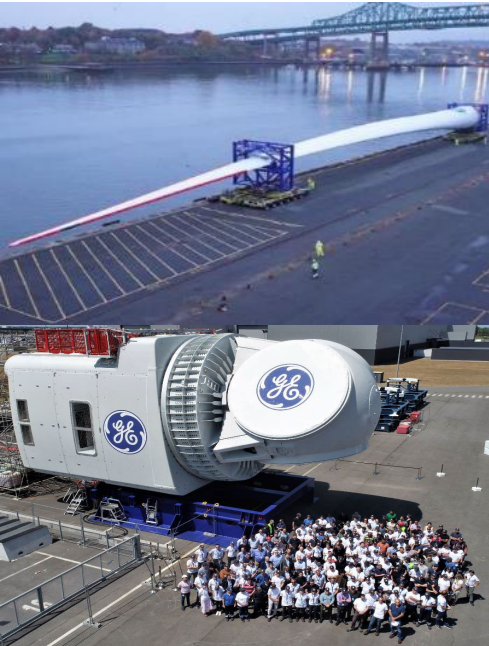
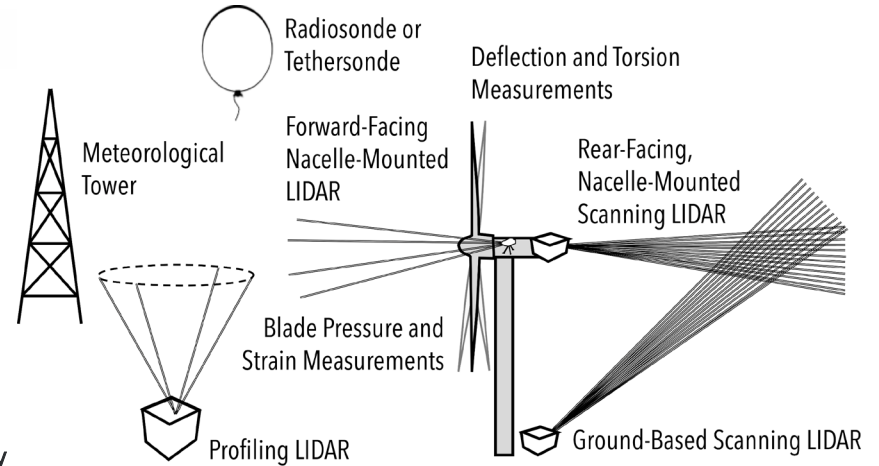
Rotor Wake Measurements and Predictions for Validation

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

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University of Wyoming

Patrick Moriarty
National Renewable Energy Laboratory

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FY21 Peer Review - Project Overview

Project Summary:

- Challenges: (1) significant gaps in the understanding of the unsteady aerodynamics of large, flexible blades interacting with a turbulent inflow and the resulting wake; (2) a lack of data for validating the performance of large, flexible blades and predicting the resulting wake
- Approach: targeted data acquisition and analysis to address pressing validation needs and to answer crosscutting science questions to address the physical phenomena associated with with modern large, flexible and slender blades
- Key project partners
 - Industry: NextEra, General Electric, Wetzell Engineering
 - Academia: U. Colorado, Mich. Tech. U., Texas Tech., Danish Tech. U.
 - Gov't Lab: Other WETO efforts
 - IEA Tasks: 29 (Aerodynamics) and 31 (Wakebench)

Project Start Year: FY 17
Expected Completion Year: FY 23
Total expected duration: 7 years

FY19 - FY20 Budget: \$5,922,041

Key Project Personnel:
Jonathan Naughton, U. Wyoming, Patrick Moriarty, NREL, Paula Doubrawa, NREL, Christopher Kelley, SNL

Key DOE Personnel: Michael Derby, Michael Robinson, Benjamin Hallissy

Project Objective(s) 2019-2020:

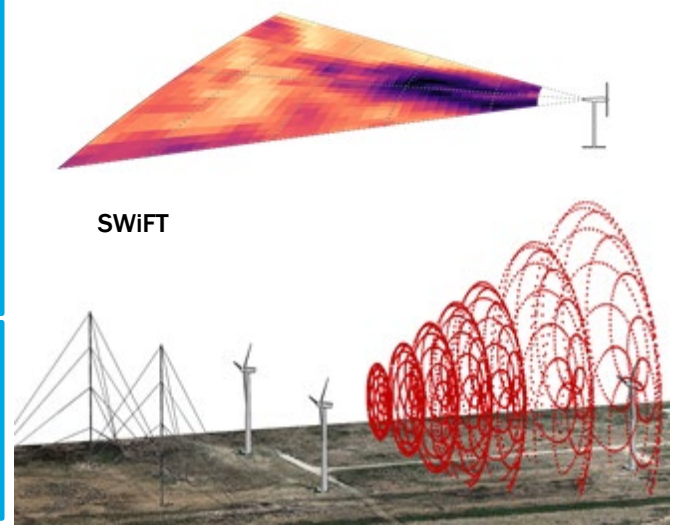
- Perform high-quality validation experiments relevant to modern wind turbine rotors under different atmospheric and operating conditions
- Develop data analysis methods to facilitate model validation
- Further wind turbine flow physics understanding under different operating and atmospheric conditions
- Release model validation benchmarks to the international community

Overall Project Objectives (life of project):

- Enable the validation of cross-application simulation tools for wind-turbine and wind-plant modeling, and to further our understanding of modern wind turbine flow physics

Wake Steering Efforts

Utility-Scale



Project Impact

Develop New Experiments

- **Utility-Scale Wake Steering**
 - The first successful public demonstration of wake steering at a utility-scale wind plant in the US
- **National Research Testbed (NRT) Rotor**
 - Deploy a scaled rotor that produces a wake similar to that of a modern utility-scale turbine
 - Perform experiments to confirm utility-scale wake appearance
- **Rotor Aerodynamics, Aeroelastics and Wake (RAAW)**
 - Perform experiments on the flexible large blades of a modern multi-megawatt turbine

Analyze and Release Data

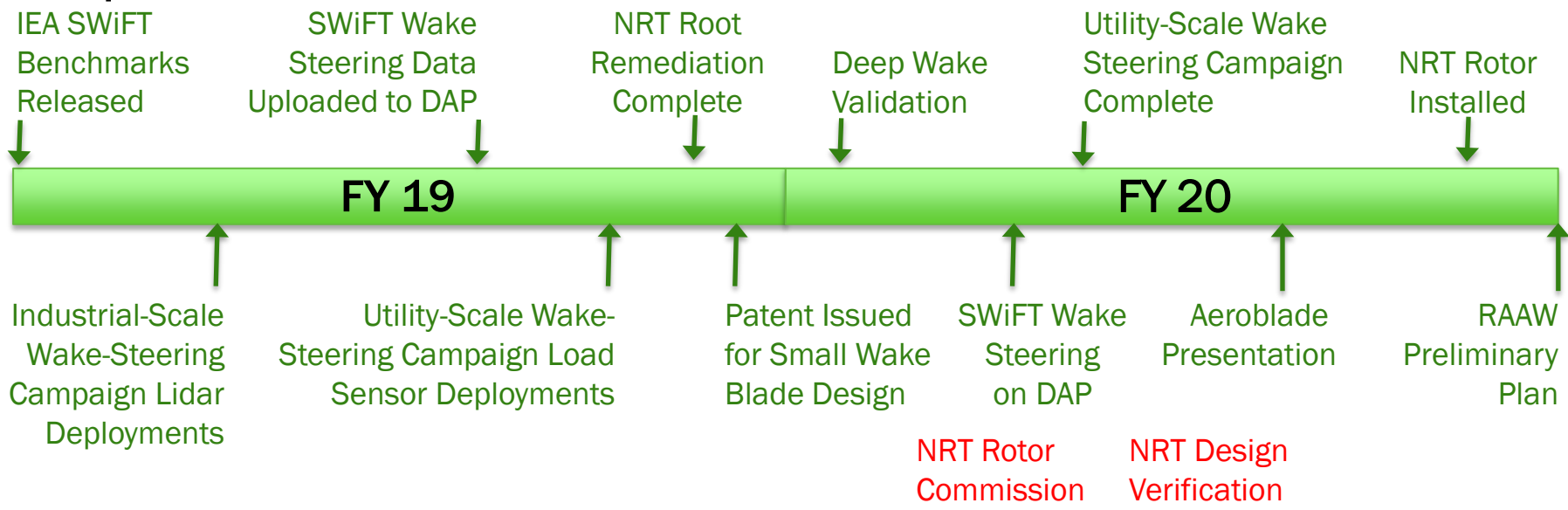
- **SWiFT Wake Steering Benchmark**
- **NRT Blade Description**
- **Publications**
 - Patents (1), Reports (2), Conference (14), Journal (5)



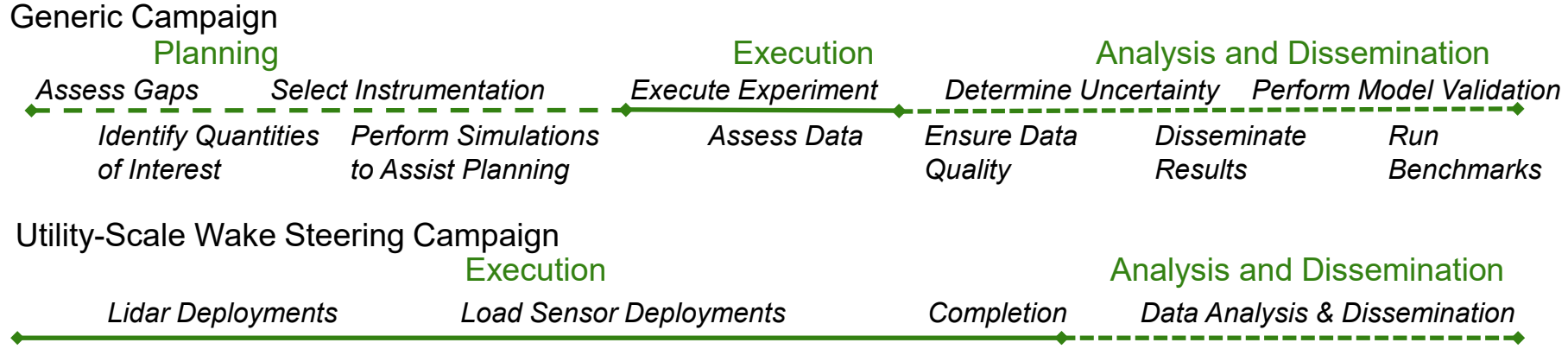
NRT Rotor Installation

Program Performance – Scope, Schedule, Execution

Scope and Schedule

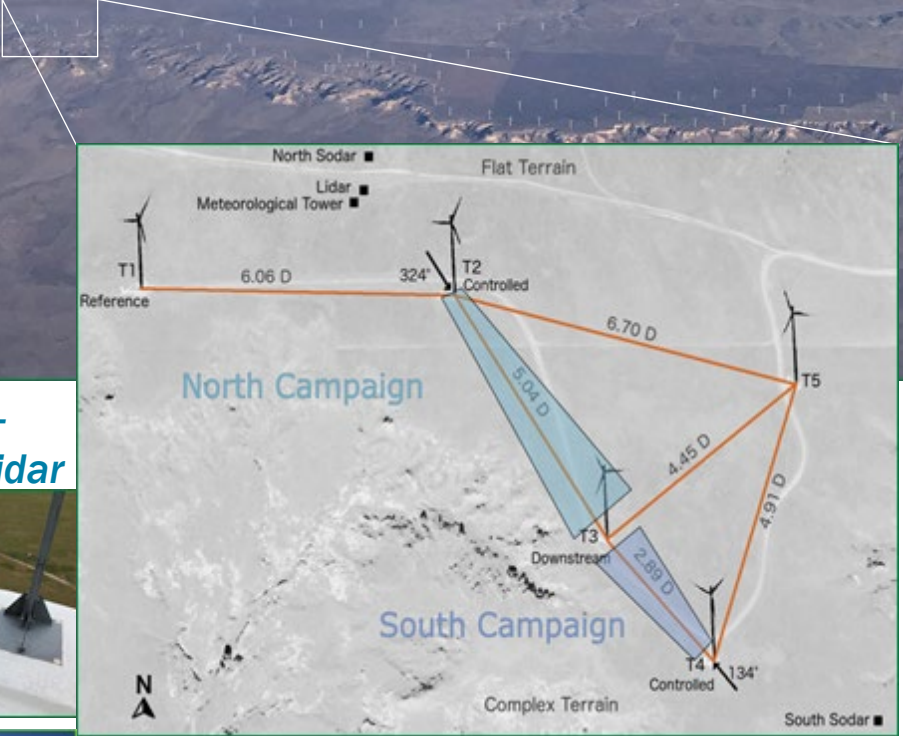


Execution



Program Performance – Accomplishments & Progress

Utility-Scale Wake-Steering Experiment Summary *Birds-Eye View of Wind Plant*



Nacelle-Mounted Lidar



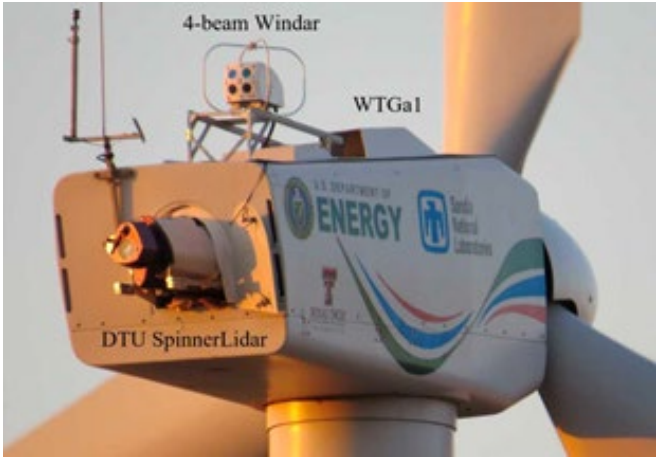
- Two turbines controlled at different times to measure the response of a downstream turbine
- Ongoing research, to be completed in FY21

- ✓ Successful demonstration of wake steering at utility scale
- ✓ Long-term record of detailed, quality-controlled measurements
- ✓ Improvements to wake steering controller
- ✓ Improvements to controls-oriented model FLORIS
- ✓ Successful collaboration with industry (NextEra, Ystrategies) and academia (EPFL)
- ✓ Valuable lessons learned that will inform larger experiments, e.g. RAAW and AWAKEN
- ✓ 10 journal and conference publications to date

Program Performance – Accomplishments & Progress

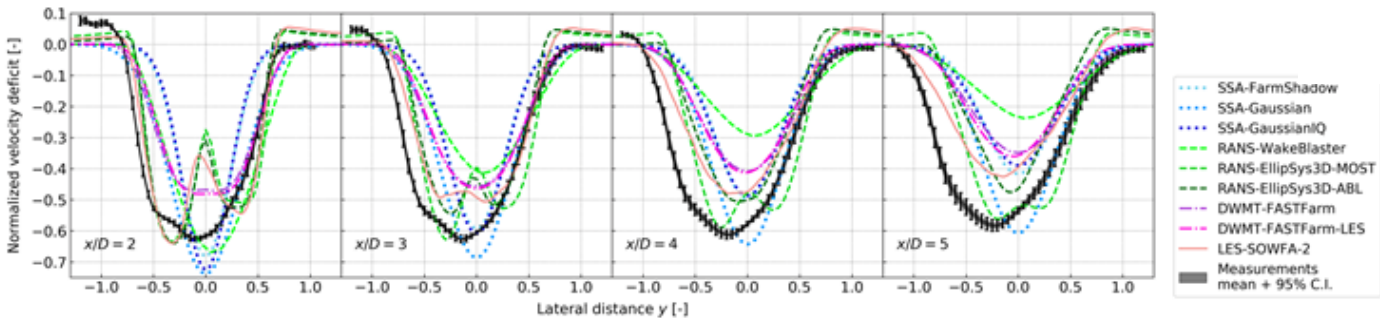
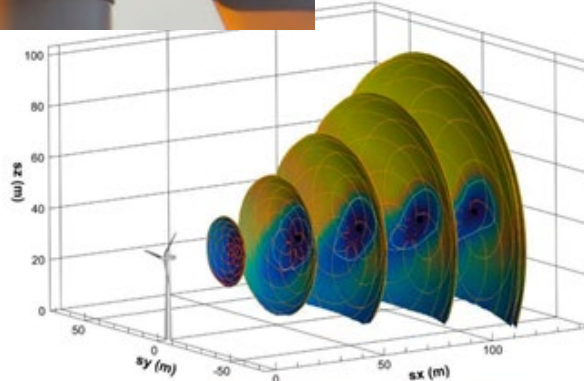
SWiFT Activities Summary

- SWiFT Wake Steering data used in Benchmark IEA Task 31
- NRT Rotor installed and modal tested
- NRT design documentation shared publicly
- Patent issued for small wake blade design
- Aeroblade instrumentation selected
- Delays for NRT experiment occurred
 - Manufacturing defect /outstanding safety issues
 - Back on planned schedule in FY 22



SWiFT Turbine Nacelle with Lidars

Spinner Lidar Wake Measurements



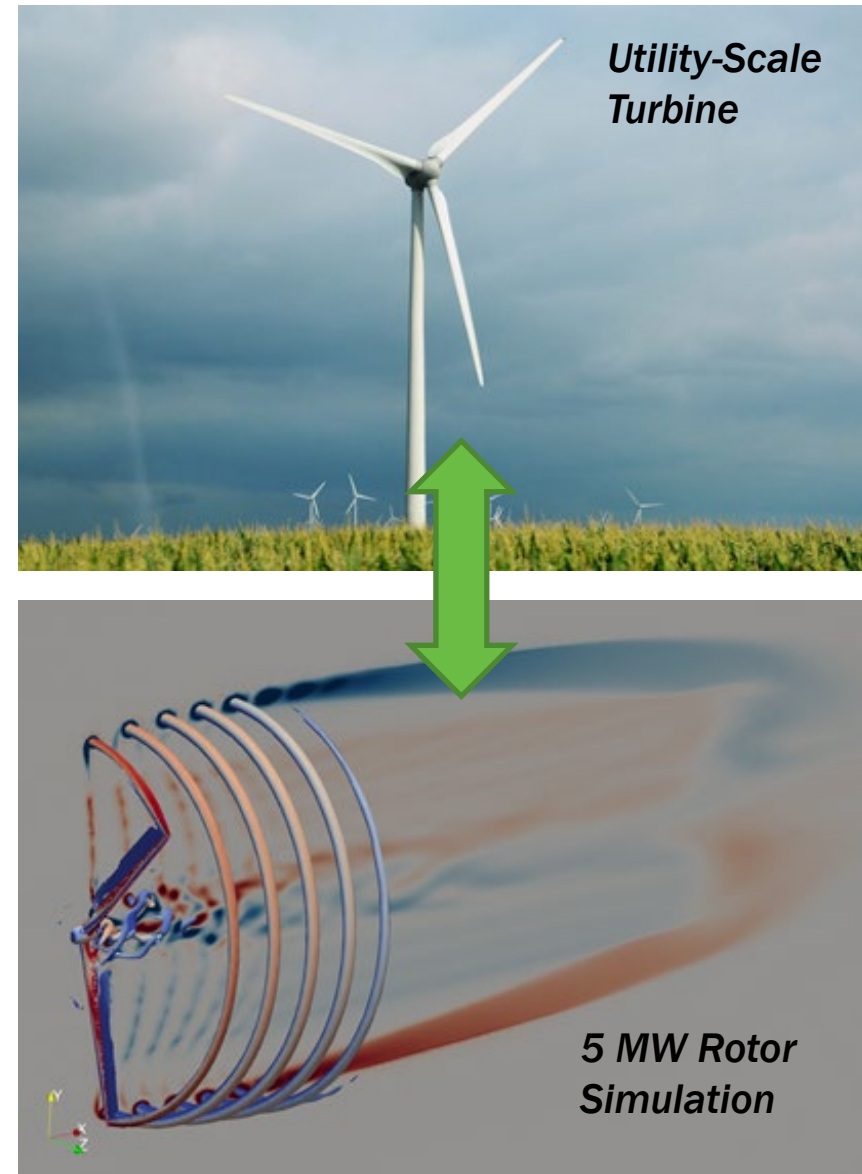
SWiFT Wake Steering Benchmark Results

Doubrawa et al. "Multimodel validation of single wakes in neutral and stratified atmospheric conditions," Wind Energy 23 (11), 2027-2055, 2020

Project Performance - Upcoming Activities

- **RAAW Experiment**

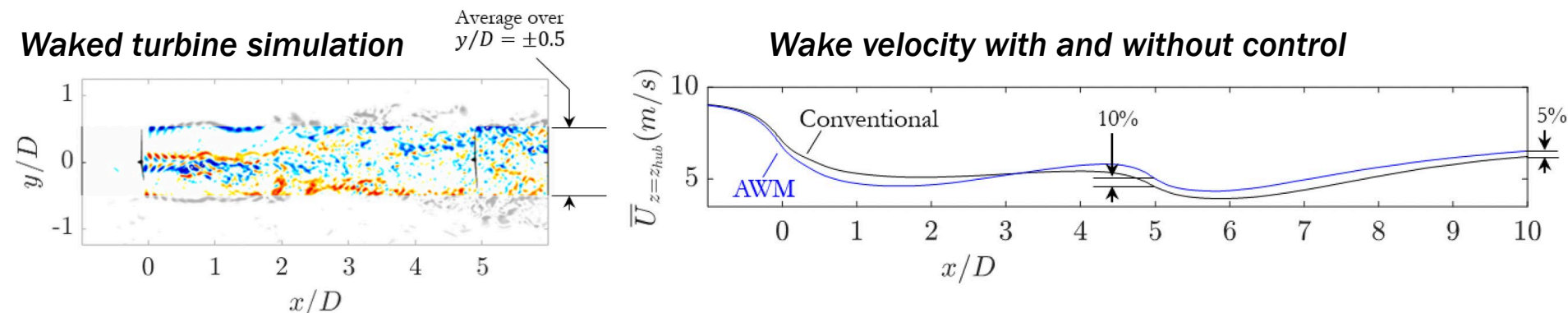
- Finalize the turbine/site to study (FY21)
- Perform simulations to assist with experiment design (FY21-FY22)
- Select and purchase instrumentation (FY21-FY22)
- Collect data and verify its quality (FY22-23)
- Analyze data to provide results for validation and to increase understanding of flexible rotor behavior (FY 23)
- Perform initial model validation activities (FY23)



Project Performance - Upcoming Activities

- **SWiFT-NRT**

- Complete NRT Commissioning and NRT Design Verification Experiment (FY21)
- Update NRT aeroelastic model on GitHub following pitch and torque tuning (FY21)
- Utilize SWiFT with NRT to perform initial demonstration of wake management strategies (FY22-23 subject to approval/funding)
 - NALU CFD simulations showing potential for 5.4% increases in two-turbine power using active wake mixing
 - Objective: Energy, blade lifetime, and ancillary services
 - Approach: Active wake mixing, wake stabilization, induction control, wake steering



Brown et al. "Towards Active Wake Mixing for Lowered Cost of Energy," WESC 2021.

Stakeholder Engagement & Information Sharing

- **Hold RAAW Technical Expert Meetings**
 - Industry, government laboratory, and academic participation including international groups
 - Web-based meeting in June 21
 - Follow up meetings at future conferences
 - Sandia Blade Workshop, Others
- **Participate in IEA Wind Tasks 31 and 47**
 - RAAW and NRT efforts are of interest to both the aerodynamics community (47) and wake community (31)
- **Publish results of experimental and modeling efforts**
 - Conference presentation and papers (14)
 - Journal articles (5)
- **Post results in archive portals as possible**
 - DOE Data Archive Portal, Github, Wakebench

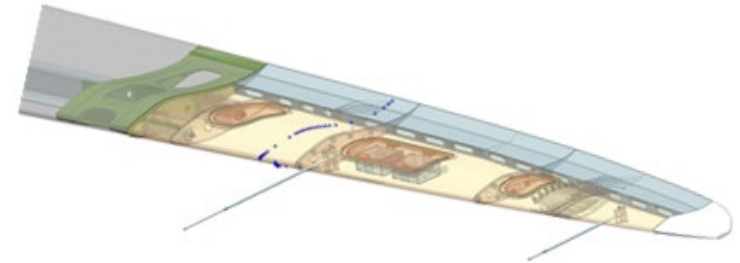
*SWiFT Turbine with
NRT Rotor Installed*



Key Takeaways and Closing Remarks

Develop Wind-Turbine Focused Experiments to Provide Data that Increases Understanding and Provides Model Validation Data

- **Project Impact:**
 - Develop new experiments
 - Aeroblade
 - Rotor Aerodynamics Aeroelastics & Wake
 - Analyze and release data
 - SWiFT Wake Steering Results
 - Utility-Scale Wake Steering Results
- **Project Performance:**
 - Met all but two milestones and deliverables
 - Mitigate delays to allow for all tasks to be on schedule in FY22
- **Stakeholder Engagement:**
 - Involve stakeholders in all phases
 - development/execution/analysis
 - Widely disseminate results
 - Publications, benchmarks, data availability



Aeroblade Removable Tip Concept



*Rotor Aerodynamics
Aeroelastics and Wake*



*SWiFT Wake
Management*