U.S. DEPARTMENT OF ENERGY

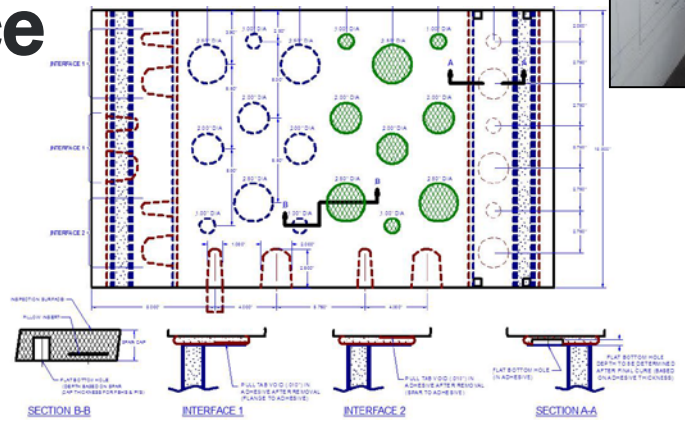
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Wind Blade Durability and Damage Tolerance

Project ID #T14

Josh Paquette

Sandia National Laboratories



Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY | NNSA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

FY17-FY18 Wind Office Project Organization

"Enabling Wind Energy Options Nationwide"

Technology Development	Market Acceleration & Deployment
Atmosphere to Electrons	Stakeholder Engagement, Workforce Development, and Human Use Considerations
Offshore Wind	Environmental Research
Distributed Wind	Grid Integration
Testing Infrastructure	Regulatory and Siting
Standards Support and International Engagement	
Advanced Components, Reliability, and Manufacturing	

Analysis and Modeling (cross-cutting)

Project Overview

T14: Wind Blade Durability and Damage Tolerance

Project Summary

- Development and transfer of knowledge to industry on state-of-the-art inspection and defect/damage modeling methods.
- Project-led workshops, with industry specified formats, will enable immediate utility of the project outcomes.
- Lower the uncertainty in blade lifetimes and reduce the cost of building and maintaining a blade in operation.
- Enable the larger, higher-energy capture rotors of the future, which will be main driver of LCOE reduction and thus deployment.

Project Objective & Impact

- Reduce cost-uncertainty in the manufacturing and operation of wind turbine blades by transitioning from a safe-life methodology to a durability-and-damage-tolerance design methodology.
- Understand the effect of manufacturing defects and lightning damage on blade structures, the ability of non-destructive inspection (NDI) technologies to determine the extent of these issues, and the most cost-effective damage repair methods.
- Impact: lower levelized cost of energy (LCOE), increase reliability, and further develop and improve the wind turbine operations and maintenance (O&M) sector. The results of this project will be broadly applicable to the industry, ranging from OEM's and blade manufacturers to owner/operators and service companies.

Project Attributes

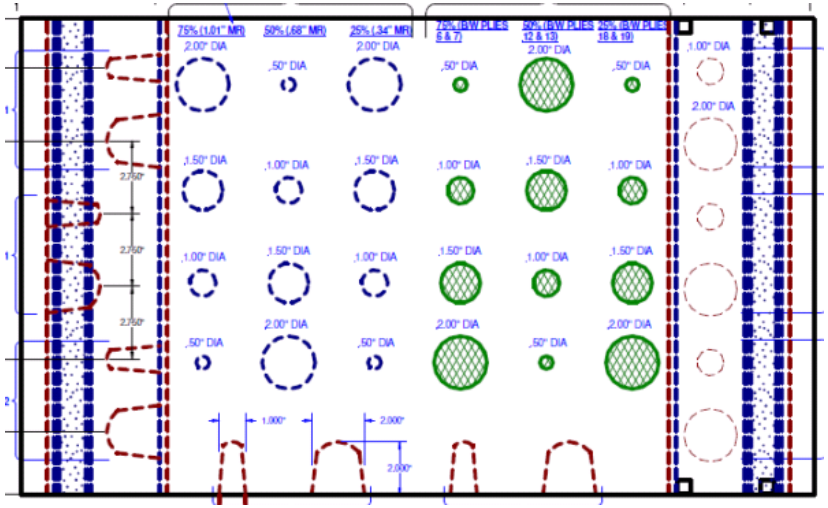
Project Principal Investigator(s)
Josh Paquette
DOE Lead
Bradley Ring
Project Partners/Subs
Doug Cairns – Montana State University
Project Duration
October 2015–September 2018

Technical Merit and Relevance

- **Large uncertainty in the lifetime cost of maintaining and operating wind turbine rotor blades.**
- **Blade replacements are costly, growing with larger rotors**
- **Cost of blade failure is shared by:**
  - OEMs
  - Owner-operators
  - Insurance companies
  - Affects all components of LCOE
- **Multiple causes:**
  - Design and manufacturing errors
  - Transportation and installation
  - Operations.
- **The cost of these failures can be only be alleviated by prevention or repair**
- **Current repairs are non-standardized, possibly non-optimized**
- **Several annual conferences now dedicated to the topic**
  - Including Sandia Blade Reliability Collaborative Meetings

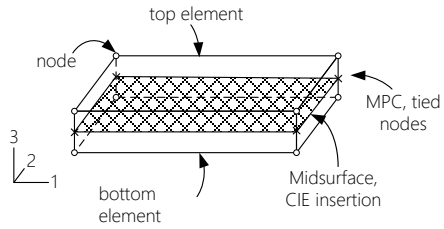
Approach and Methodology: Inspection

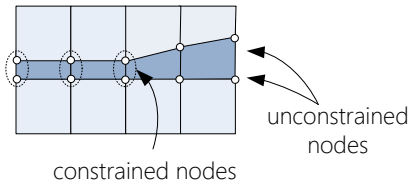
- Quantify wind blade plant inspection technology
- Develop autonomous inspection technology

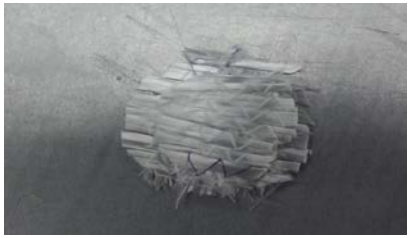


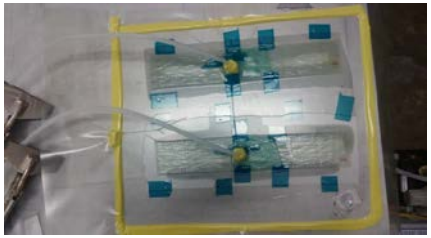
Approach and Methodology: Defects and Repairs

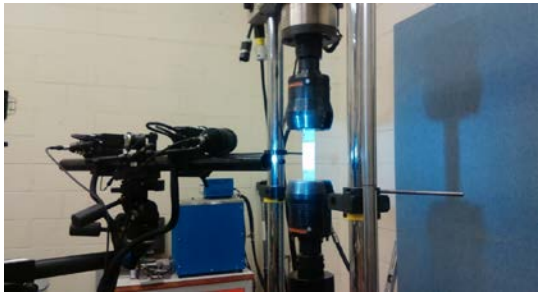
- Develop and validate state-of-the-art progressive damage modeling method
- Manufacture and test repair specimens at coupon and sub-structure scale





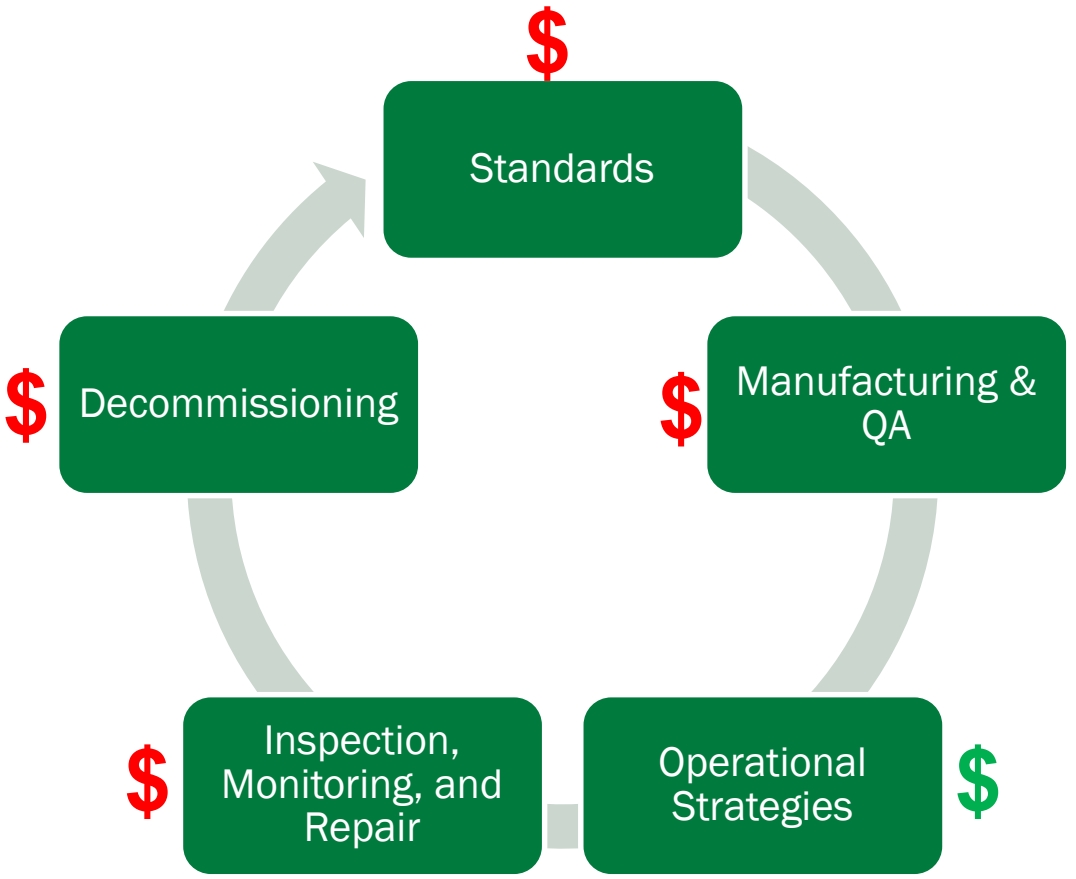






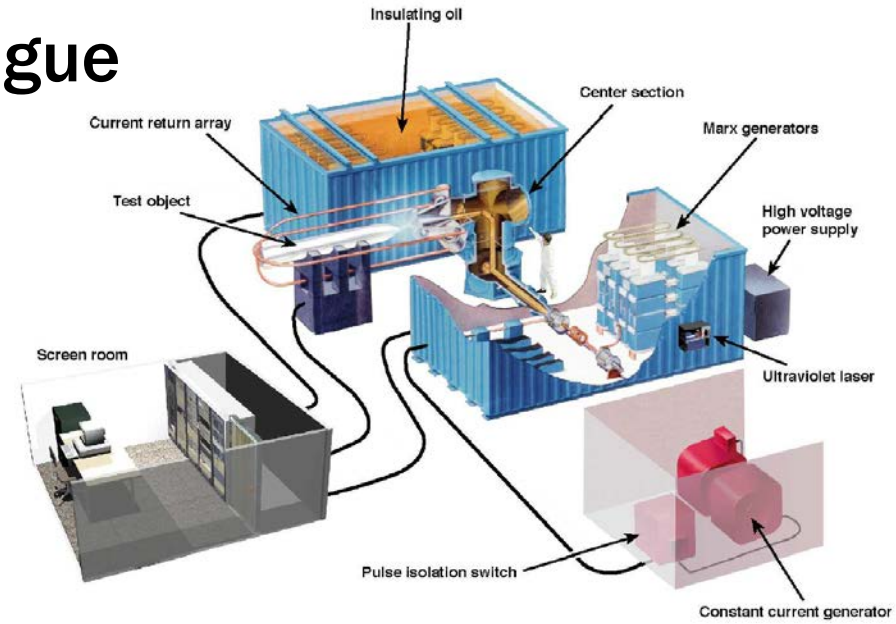
Approach and Methodology: Blade Lifetime Value Model

- **Develop a techno-economic model of a wind turbine blade that incorporates the full life-cycle**
  - Design
  - Manufacturing
  - Operation
  - Retirement
- **Enable analysis of how proposed innovations affect the total lifetime cost of a blade vs. the total lifetime revenue generated.**

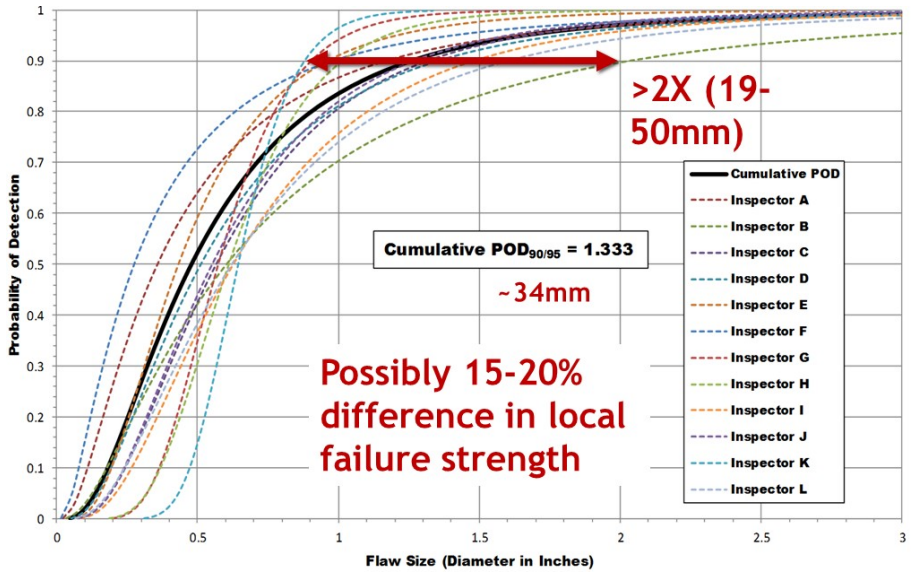


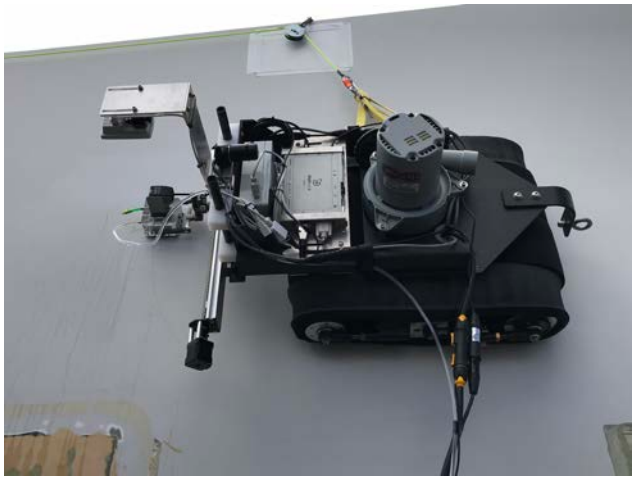
Approach and Methodology: Lightning Damage

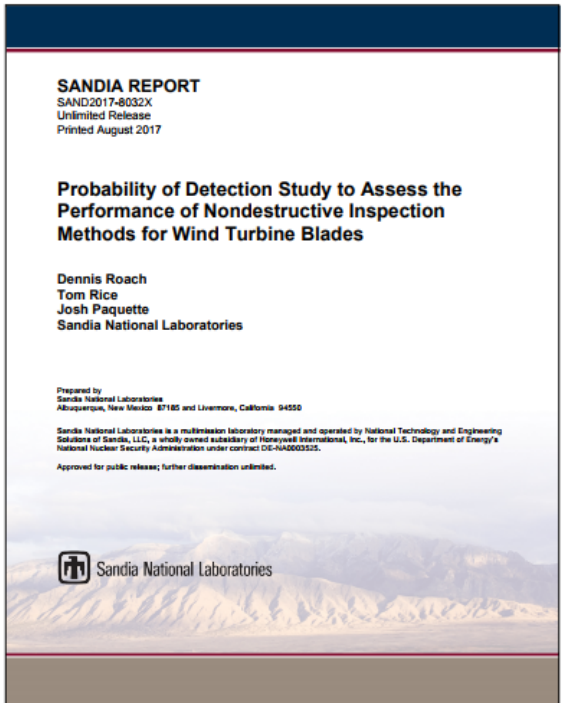
- Develop wind blade carbon fiber lightning specimens
- Test in specialized lightning chamber
- Perform pre/post inspections
- Conduct ultimate and fatigue testing



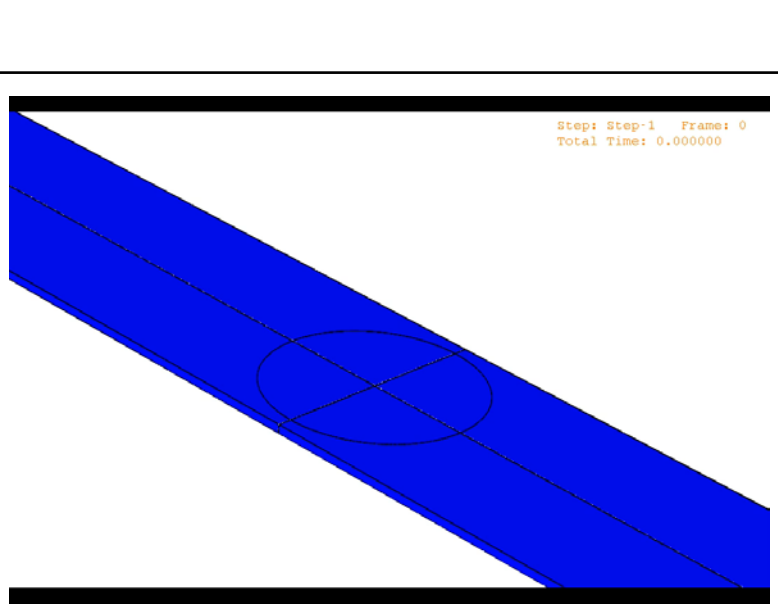
Accomplishments and Progress: Inspection

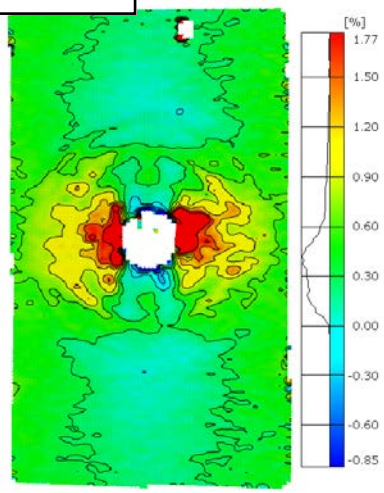




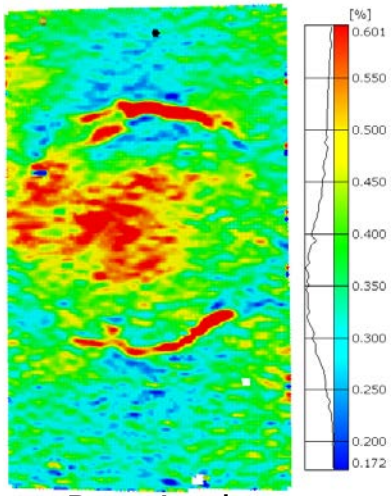


Accomplishments and Progress: Defects and Repairs



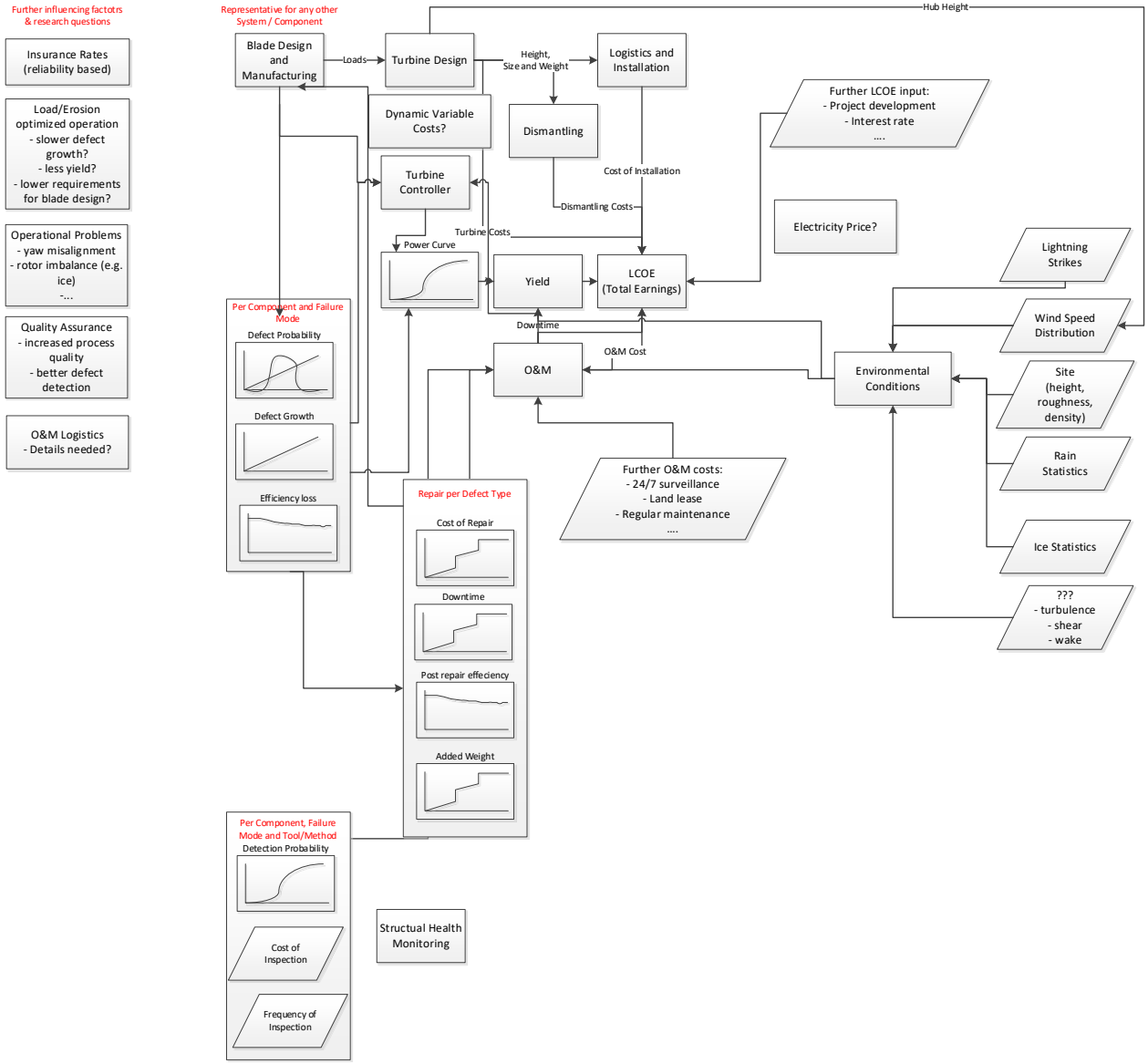


Damaged

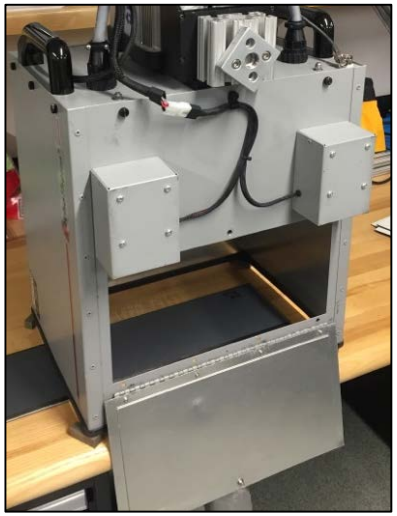


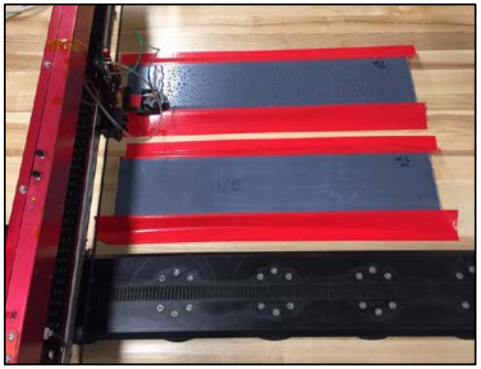
Repaired

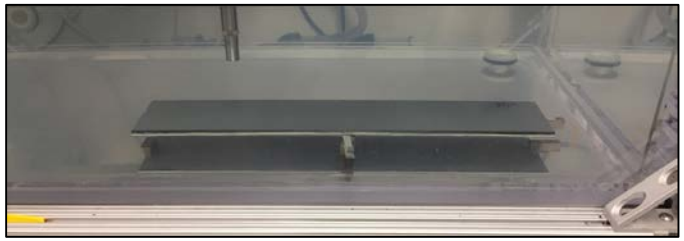
Accomplishments and Progress: Blade Lifetime Value Model

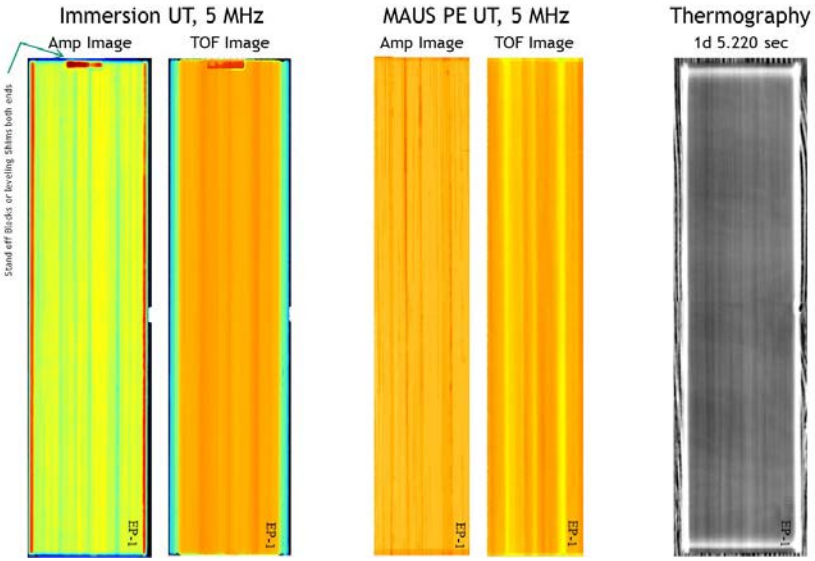


Accomplishments and Progress: Lightning Damage









Accomplishments and Progress

IEA Wind Technical Experts Meeting #91: Durability and Damage Tolerant Design of Wind Blades

- Bring together wind and aerospace communities
- Develop a vision for how durability and damage tolerant design can be implemented for wind blades
- Topics:
  - Aerospace Experience and Wind Standards
  - Manufacturing & Inspection
  - Modeling & Testing
  - Operations

IEA TEM #91 Participants, Bozeman, MT, June, 2018

Communication, Coordination, and Commercialization

Publications:

- Ely, R., Roach, D., Rice, T., Nelson, G., Paquette, J., "Development and Evaluation of a Drone-Deployed Wind Turbine Blade Nondestructive Inspection System," DOE SAND2018-3116, March 2018
- Nelson, J.W., Cairns, D.S, Riddle, W., Effects of defects in composite wind turbine blades – Part 1: Characterization and mechanical testing, Wind Energ. Sci., 2, 641-652, https://doi.org/10.5194/wes-2-641-2017, 2017.
- Nelson, J.W., Cairns, D.S, Riddle, W., Effects of defects in composite wind turbine blades – Part 2: Progressive damage modeling of fiberglass-reinforced epoxy composites with manufacturing-induced waves, Wind Energ. Sci., 2, 653-669, https://doi.org/10.5194/wes-2-653-2017, 2017.
- Riddle, W., Nelson, J.W., Cairns, D.S., Probabilistic Design of Wind Turbine Blades with Treatment of Manufacturing Defects as Uncertainty Variables in a Framework – Part 3, Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2017-14, accepted, January 2018.
- Submitted to Composites: Part B: Combining acoustic emission and guided ultrasonic waves to predict modulus degradation in glass fiber composites, Dr David Miller Listed, Dr Michael Edens, Mr Daniel Samborsky, Mr Michael Voth, Mr Paul Murdy, Professor Douglas CairnsSubmitted to Composite Structures: Selective Activation of Intrinsic Cohesive Elements for Fracture Analysis of Laminated Composites Professor Kyeongsik Woo, Dr. Douglas Cairns
- Meeting summary for IEA Wind Topical Experts Meeting #91 on "Blade Durability and Damage Tolerant Design".

Presentations:

- 2016, 2017, and 2018 Wind Blade Manufacture
- 2018 Sandia Blade Workshop
- 2017 Wind Blade O&M Conference

Blade Reliability Collaborative Meeting, August 2018

Upcoming Activities

- Field testing of robotic crawler ultrasonic testing and drone deployed thermography
- Wind Blade Maintenance Technology Validation Center
- Aero-structural optimized repairs
- Damage arresting materials and laminates
- Initial version of Blade Life Value Model
- Complete coupon tests of lightning samples
- Leading edge erosion standards language
- Damage accumulation monitoring system