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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

T13 - Wind Turbine Blade Durability and Damage Tolerance

Technology RD&T and Resource Characterization - Materials, Manufacturing, and Design Innovation

Josh Paquette
SNL

August 3rd, 2021

FY21 Peer Review - Project Overview

Project Summary:
- Reduce cost-uncertainty of wind blade O&M
- Develop data, methods, and technology to enable the transition from a safe-life methodology to durability and damage tolerance

Partners
- Montana State University and Cornell University
- 3M, EDF, ICM, Dolphitech
- IEA Wind Tasks 43 and 46

Project Objectives 2019-2020:
- Develop inspection crawler robot prototype
- Test new repair methods
- Review damage tolerant materials and structures for blades
- Test lightning strikes on wind blade carbon materials
- Organize erosion experts group

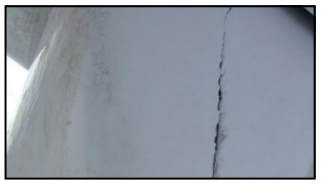
Overall Project Objectives (life of project):
- Deploy fast, inexpensive, and high-fidelity inspection techniques.
- Design and test composite repair methods
- Identify new material forms which are resistance to damage Growth.
- Create a lifecycle economic model of wind blades
- Quantify the effects of lightning strikes on carbon materials
- Organize experts to develop knowledge base on leading edge erosion
- Develop a blade load accumulation monitoring system

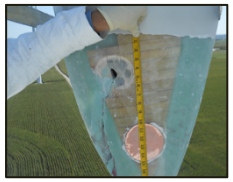
Project Start Year: [2019]
Expected Completion Year: FY [2021]
Total expected duration: [3] years

FY19 - FY20 Budget: $1,241,842

Key Project Personnel: Josh Paquette (PI), Michelle Williams, David Maniaci, Ryan Clarke

Key DOE Personnel: Tyler Christoffel, Benjamin Hallissy, (formerly Lillie Ghobrial, Brad Ring)




Project Impact

Background

- Operation and maintenance (O&M) is a large component of levelized cost of energy (LCOE)
- Blades are a major source of these expenses
- Blades continue to grow
- Continued growth requires better structural efficiency

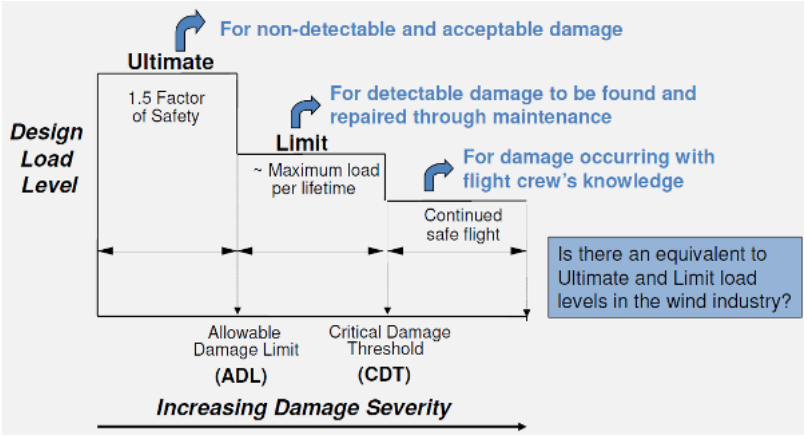
Problems:

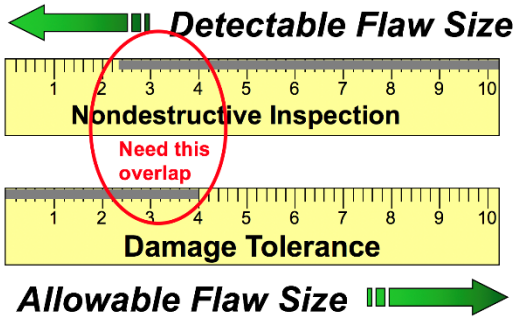
- Repair methodologies may not be well optimized
- Structural and material defects are difficult to access
- Cost for inspections and repairs increase with size and location
- Life extension is challenging without operational history

Approach

- Develop methods, data-sets, and technology to reduce cost and cost uncertainty in blade O&M
- Enable durability and damage tolerant design

Damage Tolerant Design





Program Performance – Scope, Schedule, Execution

Autonomous Inspection

Repairs and Damage Tolerant Materials

Lifetime Value Modeling

Lightning Effects

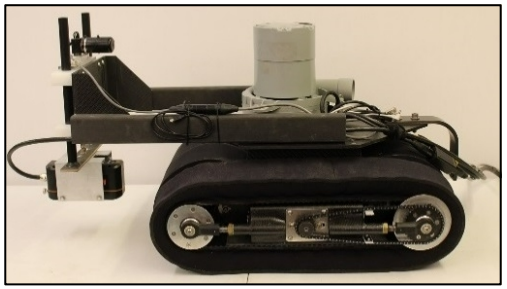
Erosion

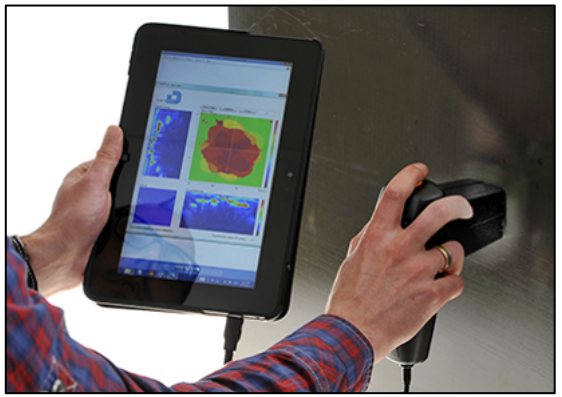
Damage Accumulation

Program Performance – Accomplishments & Progress

Autonomous Inspection

- Assessment Robot for Resilient Optimized Wind Energy (ARROW)
- Bring advanced inspection technology to blades in the field
- Use in coordination with visual inspection or known flaws
- Phased Array Ultrasonics for full-penetration damage detection and close-up visual inspection
- Inspections can be reviewed remotely or through AI
- Reduce failures, extensive repairs, and replacements





Robot with On-Board NDI System and Camera(s) for Real-Time Assessments

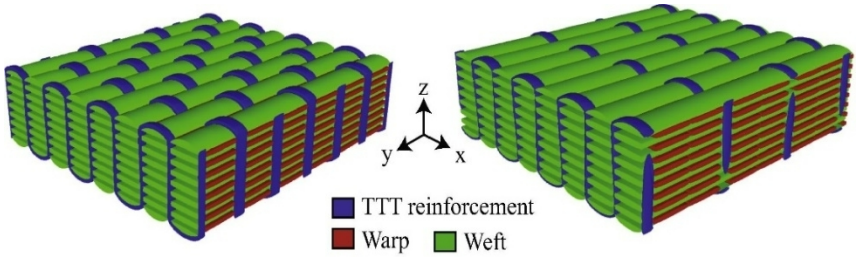
Program Performance – Accomplishments & Progress

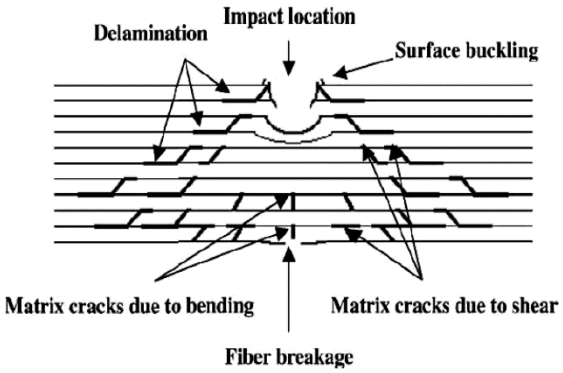
Damage Tolerant Materials

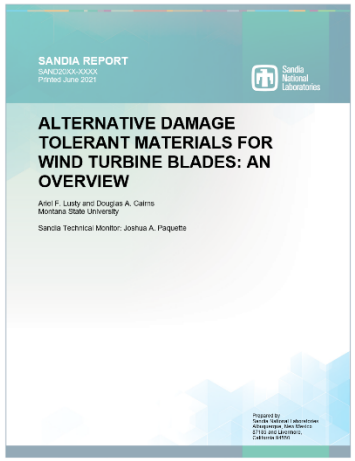
- New standards allow for progressive damage analysis
- Not limited by initiation
- Review of damage tolerant materials and structures for wind blades
- Identified alternative methods of designing and manufacturing wind blades
- Potential for lighter ***and*** more reliable blades in future designs

Repairs

- Quantified effects of solvent cleaning on repair quality



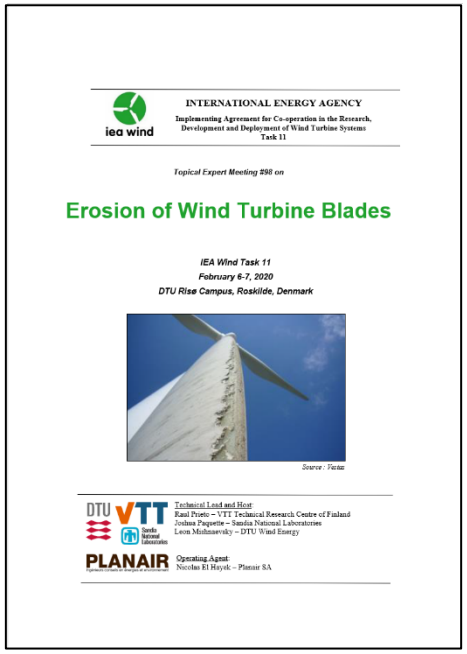




Program Performance – Accomplishments & Progress

Erosion

- Co-organized IEA TEM 98 on Erosion
- Co-developed (with DTU & VTT) IEA Task 46: Erosion
- Developed probabilistic model of erosion
- Formed partnership with material supplier and owner/operator
- Developed code and analyzed wind plant performance data of erosion and repairs
- Showed performance restoration


INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems Task 11

Topical Expert Meeting #98 on

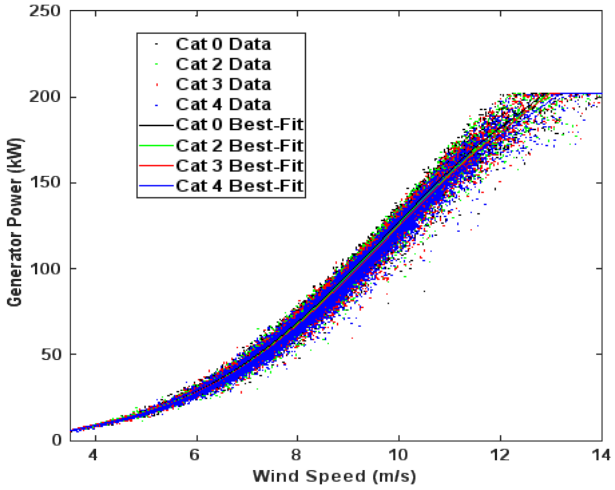
Erosion of Wind Turbine Blades

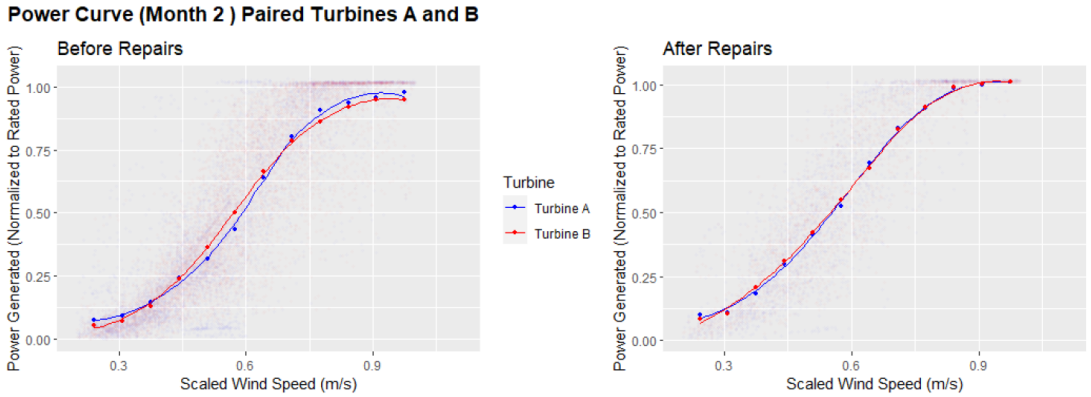
IEA Wind Task 11
February 6-7, 2020
DTU Risø Campus, Roskilde, Denmark

Source : Vestas

Technical Lead and Host:
Raul Prieto – VTT Technical Research Centre of Finland
Joshua Paquette – Sandia National Laboratories
Leon Mishnaevsky – DTU Wind Energy

Operating Agent:
Nicolas El Hayek – Planair SA





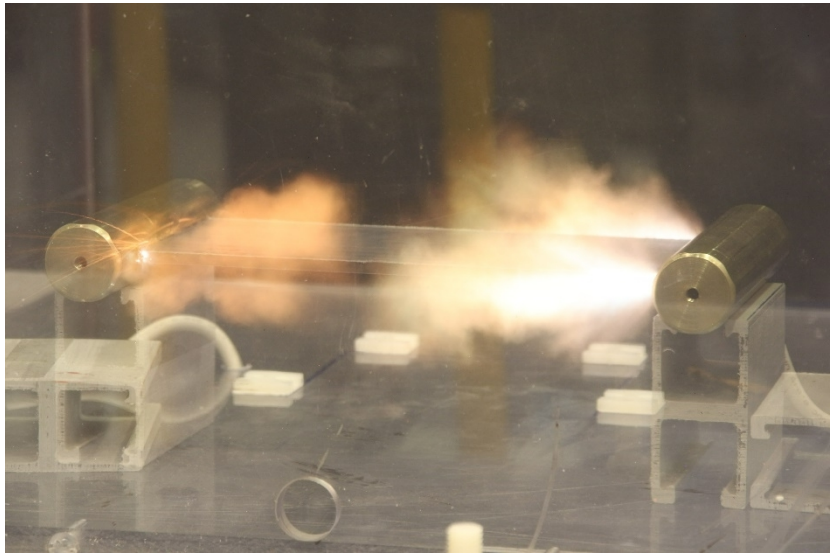
Project Performance - Upcoming Activities

FY21

- Go/No-Go Milestone: Continue development of damage accumulation monitoring system
- Technology Commercialization Fund (TCF) proposal to commercialize NDI robot
- Lightning strike testing, inspection, and testing of protruded carbon fiber specimens
  - → Lighting impact on carbon
- Implement load accumulation monitoring system for Sandia SWiFT turbines
  - → Inform inspections and operations

Future Research

- Novel robotic inspection technologies
- Repair inspections
- Aging of materials and repairs
- Wind blade lightning measurement



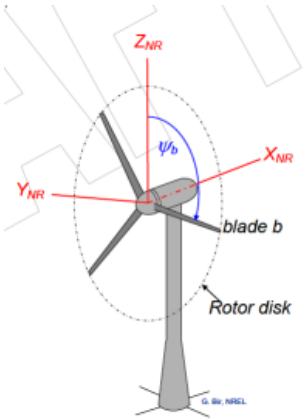
Basic state space model

$$\dot{x}(t) = A(t)x(t)$$
$$y(t) = C(t)x(t)$$

$x = vector\ of\ states\ and\ their\ derivatives$
$y = vector\ of\ sensor\ measurements$
$A = state\ matrix$
$C = Output\ matrix$

$$A = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix}$$

M = mass matrix
K = Stiffness matrix
C = damping/gyroscopic matrix



Stakeholder Engagement & Information Sharing

Project is driven by the most pressing concerns that owner operators and blade service companies have

Regular interaction with these stakeholders at conferences and workshops

Conference Presentations and Industry Engagement

- IEA TEM 93 Wind Plant Lifetime Extension
- IEA TEM 94 Testing of Ultra-Long Blades
- 2018 Wind Blade Manufacture Conference
- Blade O&M USA Conference
- Blades USA conference
- IEA TEM 98: Erosion of Blades
- DTU Erosion Symposium
- DTU Materials Symposium
- On-site meeting with NextEra Energy

Key Takeaways and Closing Remarks

Project Impact:

- Reduce cost-uncertainty of wind blade O&M
- Developed data, methods, and technology to enable the transition from a safe-life methodology to a DADT methodology

Project Performance:

- Project covers a wide set of blade reliability topics for the given budget
- Project has met or exceeded most objectives

Stakeholder Engagement:

- Project is directly driven by industry input
- Focus on immediate and future issues facing wind plant owners and service companies