SAND2014-1719P

Blade Reliability Collaborative (BRC)

Josh Paquette
Wind Energy Technology Dept.
Sandia National Laboratories
Joshua.Paquette@sandia.gov
(505) 844-7766

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

BRC Mission

Problem:

- **Blade reliability issues related to manufacturing, transportation, installation, and operation can have large effects on COE as blade failures can cause extensive down time and lead to expensive repairs.**

Project Goal:

- **The BRC aims to better understand:**
  - Primary causes of premature blade failure
  - Ability of inspection methods to detect flaws and damage
  - Effects of prominent manufacturing defects on blade materials
  - Adequacy of design tools and certification testing to replicate operational life

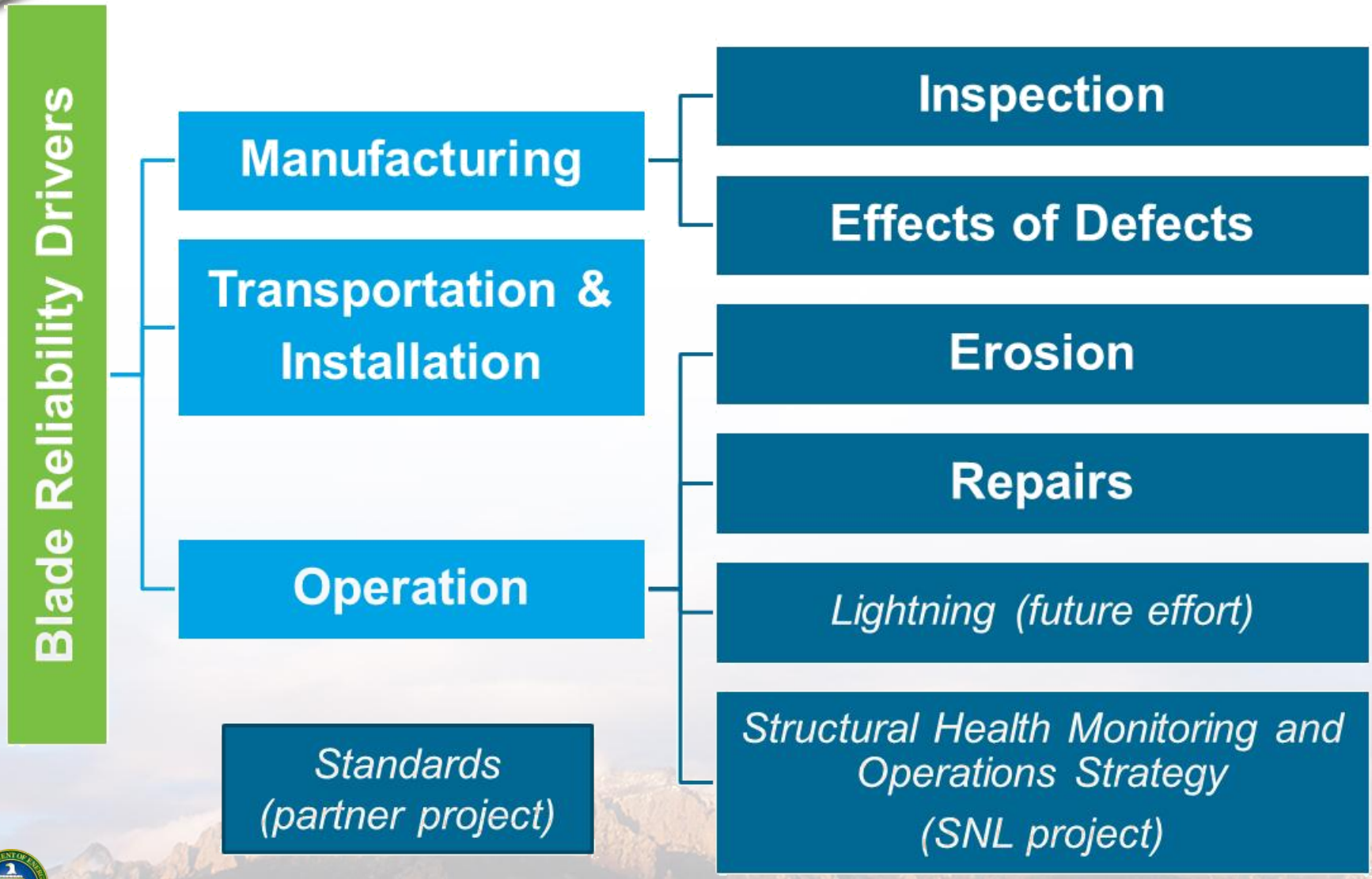
  and

  - Interface with a wide spectrum of industry, lab, and academic partners throughout the project.

In summary:

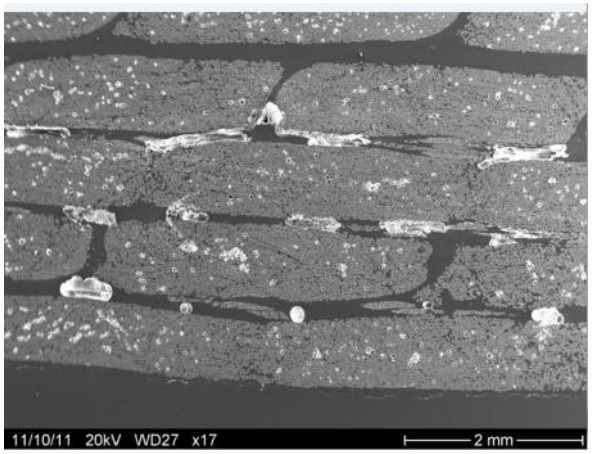
- Improve the reliability of blades delivered to the field so that remediation work before operation can be reduced and the service lifetimes can achieve the 20 year targets that are expected by wind plant operators and financiers.

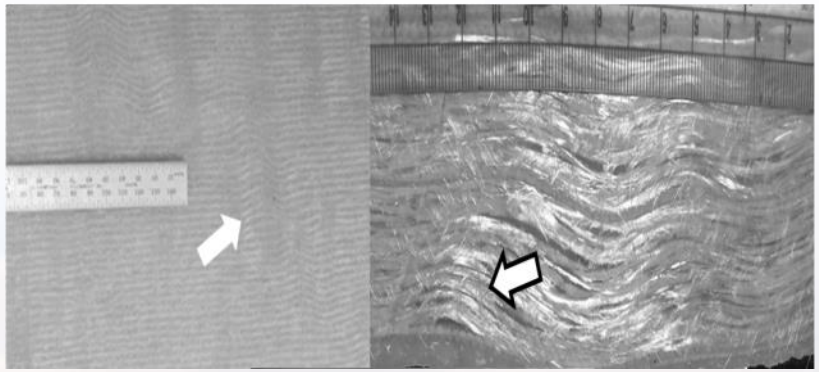
BRC Research Areas

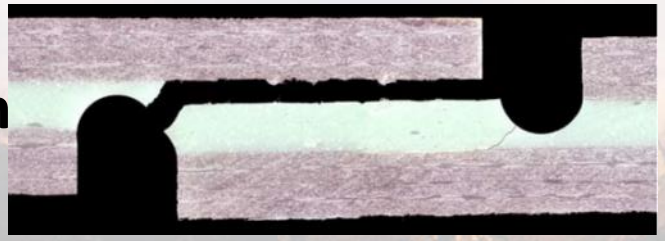


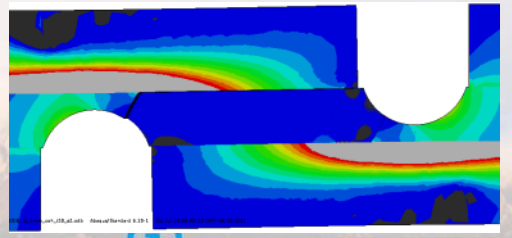
Effects of Defects

- Tested coupon samples containing prominent types of blade flaws
- Developed probabilistic flaw and damage model for blade design
- Created/validated new cohesive zone modeling procedure to analyze fiber waviness and adhesive crack growth



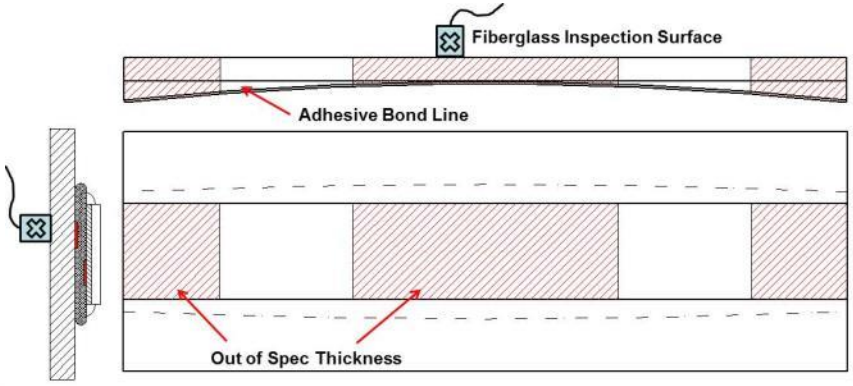


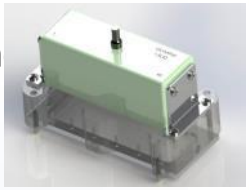


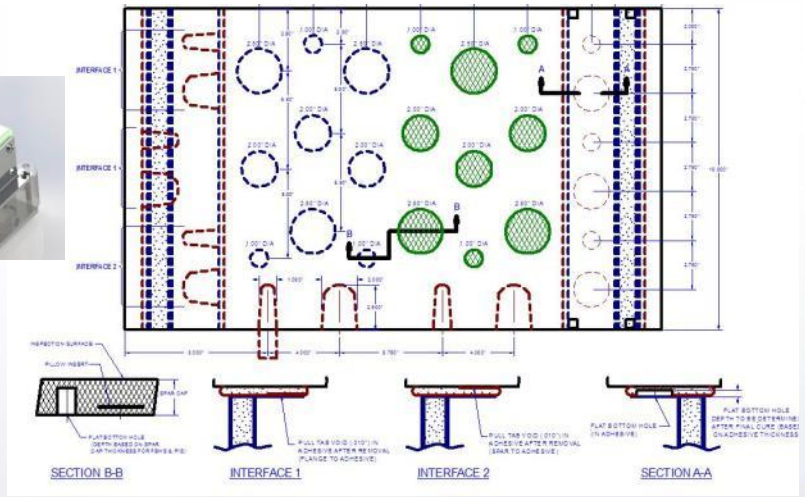


Inspection

- Developed initial set of wind-blade-specific panels with flaws and tested with over 20 equipment developers
- Completed inspection of sub-scale validation blade with 5 equipment manufacturers
- Developed improved hardware for ultrasonic inspection, allowing for sensitive inspection of thick composites
- Developed methods to detect flaws in both th spar cap and bond line and methods to quantify bond line thickness
- Designed/fabricated fiberglass and carbon NDI Reference Standards for setting up and verifying the proper function of inspection equipment
- Completed manufacturing plant visits to assess applicability of lab-based inspection methods







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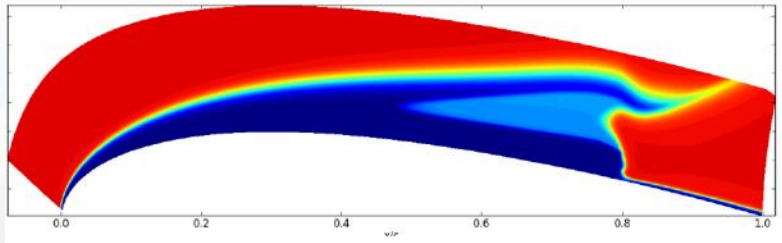
Leading Edge Erosion: Characterization, Measurement, and Modeling

Heavy blade erosion[2]

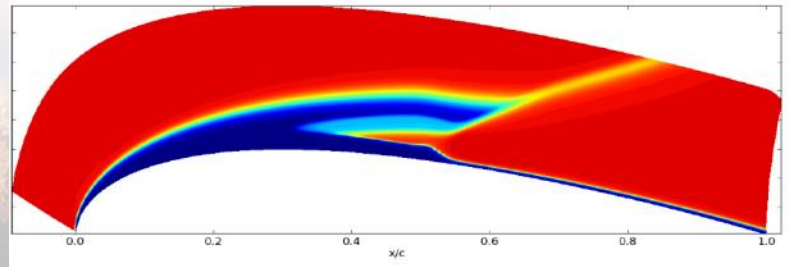
Insect roughness[3]

Leading edge blade erosion[4]

Oran W. Nicks
Low Speed Wind Tunnel



No Roughness



k_s = 350 μm

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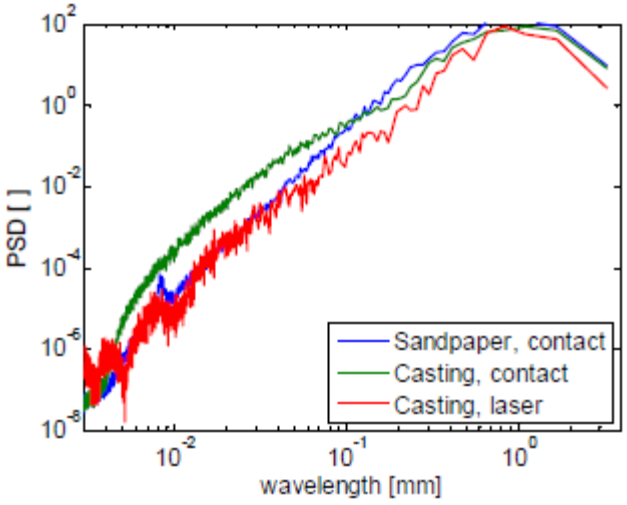
Types of Surface Roughness

Heavy blade erosion[2]



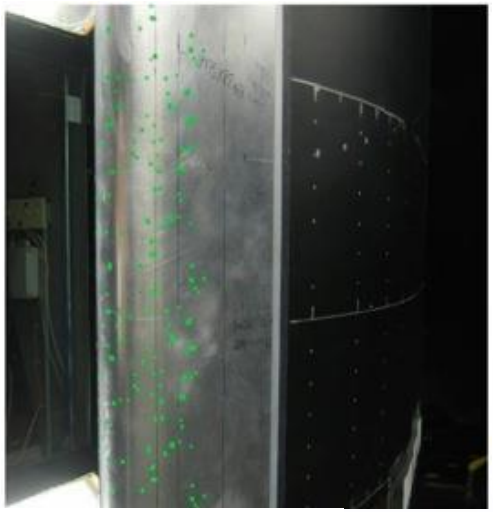
Insect roughness[3]

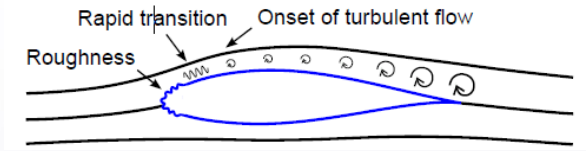
Leading edge blade erosion[4]

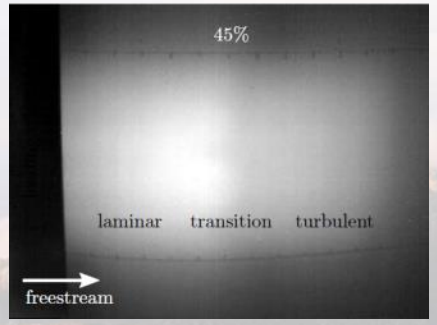
- **Gathered detailed LE erosion measurements from utility scale wind farm**

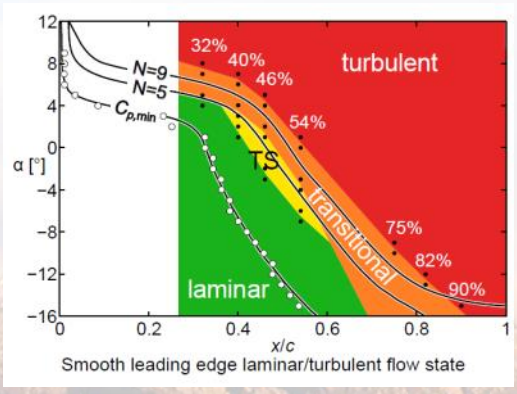
Wind Tunnel Testing

- Measurements from the field used to parameterize roughness
- LE erosion wind tunnel models based on parameterized roughness elements
- Large database of airfoil boundary layer characteristics

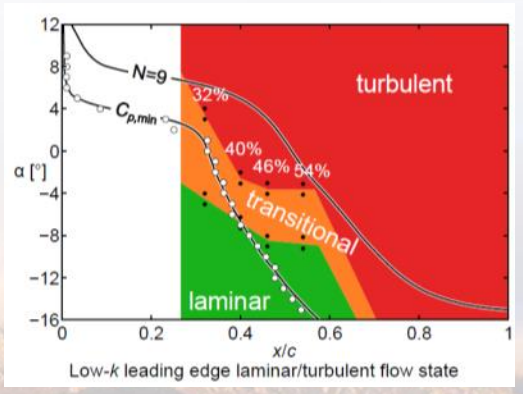








Smooth leading edge laminar/turbulent flow state



Low-*k* leading edge laminar/turbulent flow state

Wind Tunnel Testing



Smooth (left), low-*k* (middle), and high-*k* (right) leading edges.

Wind Tunnel Testing

Table summarizing leading edge variation results.
Configurations are referenced to the smooth leading edge.

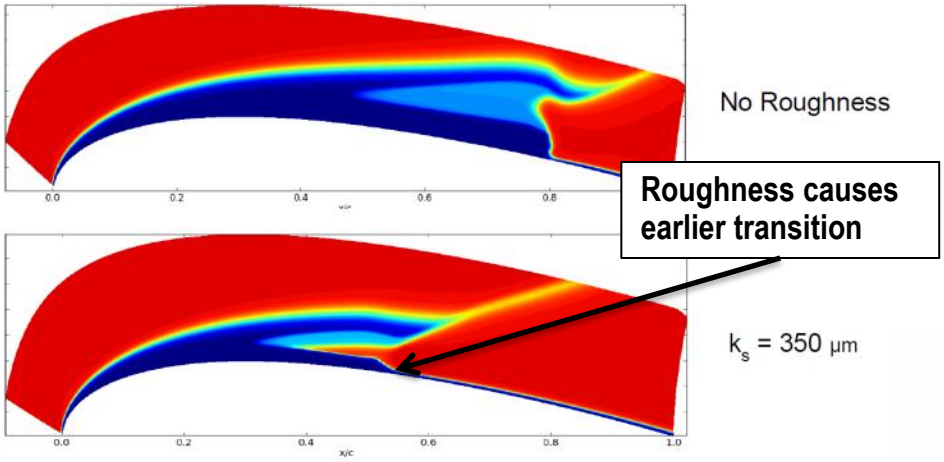
Leading edge	$C_{L,\max}$	C_{D_0}	L/D
Tripped	−6%	+82%	−53%
Low-*k*	−10%	0%	−34%
High-*k*	−23%	+154%	−70%

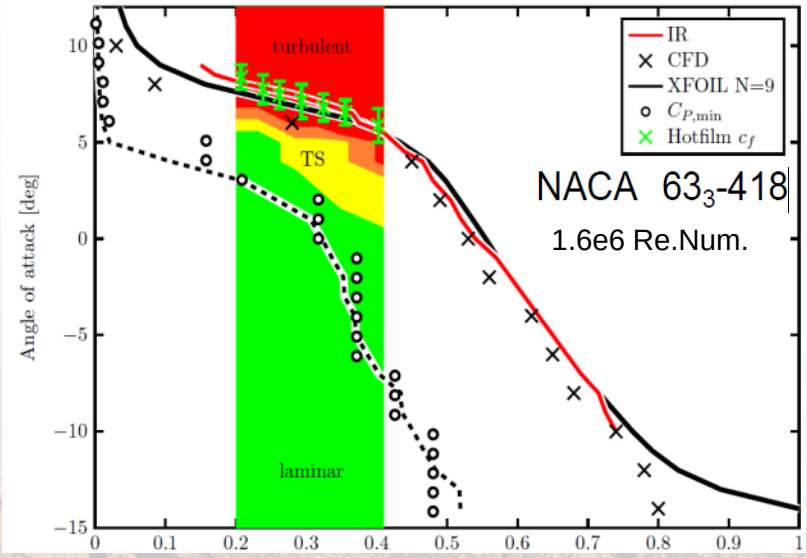
Model Development

- Created CFD model of leading edge erosion
- Tight interaction between modelers and experimentalists
- Detailed calibration and validation of model

Potential Future Work:

- Expand tests to thicker sections
- Modify model to capture stall through addition of pressure gradient terms





Where We're At

- **Completed initial 3-year effort**
  - Collect data on blade reliability drivers from service companies and owner/operators
  - Develop NDI evaluation program and screened over 30 technologies
  - Developed new methods for creating flawed material coupons and conducted significant testing
  - Manufactured glass-spar and carbon-spar sub-scale test pieces
  - Grown participation to over 40 participants from OEM's, labs, academia, blade manufacturers, service companies, inspection equipment suppliers, etc.
  - Interfaced with industry and standards bodies through regular review meetings

Where We're Going

- **Future efforts will focus in the following areas**
  - Continuation of effects of defects testing on fatigue samples
  - Conduct formal probability of detection experiment for NDI technologies and look at how these methods work in factory floor and field settings
  - Develop tools to perform probabilistic analysis of blade flaw criticality/severity using high-performance computing system
  - Test, analyze, and improve blade repair methods
  - Create engineering model of leading edge erosion
  - Develop standardized leading edge erosion test
  - Attempt to tackle the lighting problem