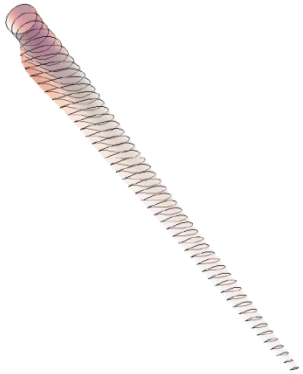
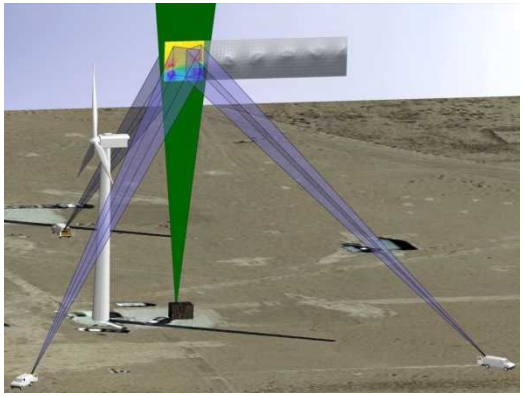
SAND2016-2330C

Exceptional service in the national interest

Sandia National Laboratories





NDI, Analysis, and SHM to Drive Blade Reliability

March 15, 2016

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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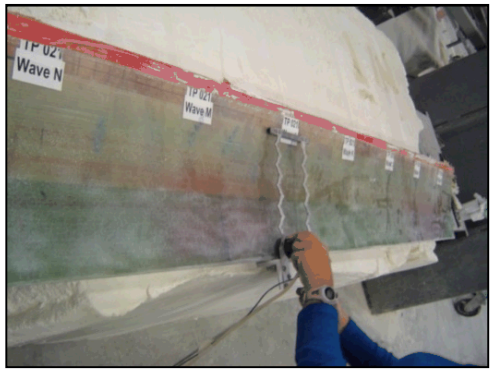
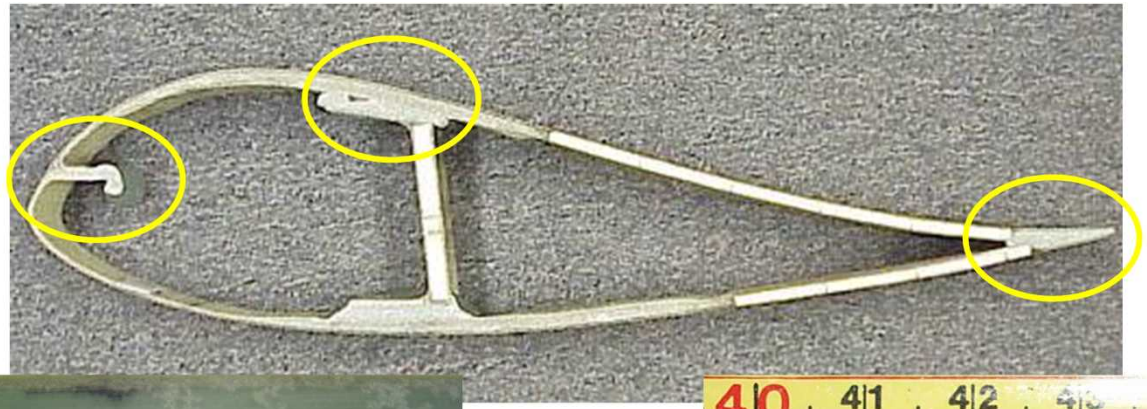
Blade Reliability Collaborative: NDI Objectives

Create the ability for manufacturers to determine the quality of their product before it leaves the factory & to enhance the in-service inspection of blades for wind farm operators

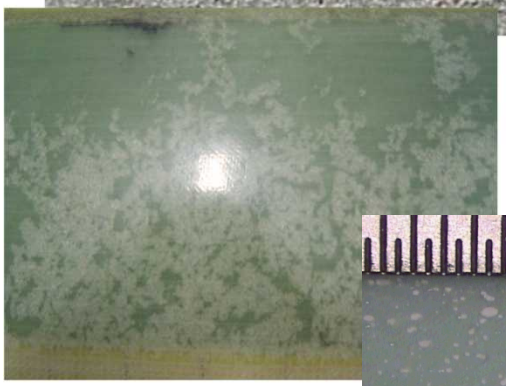
- Develop, evaluate and validate the array of potential nondestructive inspection methods for the detection of flaws in composite wind turbine blades
- Plan and implement a national capability – including a physical presence and methodology - to comprehensively evaluate blade inspection techniques
- Produce optimum deployment of automated or semi-automated NDI to detect undesirable flaws in blades (time, cost, sensitivity)
- Transfer technology to industry through hardware and technology evaluation, inspector training, and procedure development

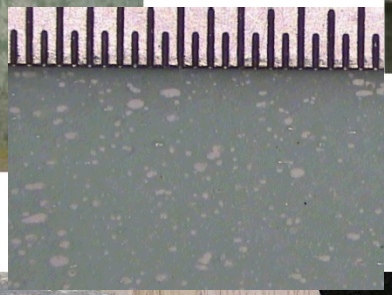


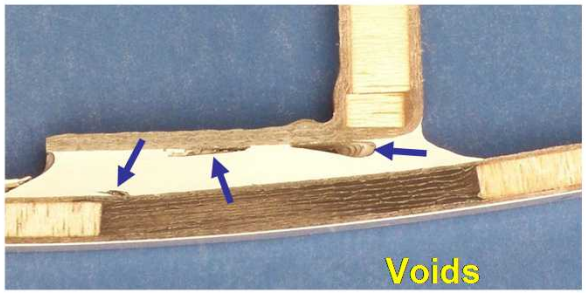
Inspection Areas and Flaw Types of Interest



Flaws include: Ply Waves Delaminations, Adhesive Voids, Joint Disbonds, Snowflaking, Fiber Fracture and Porosity





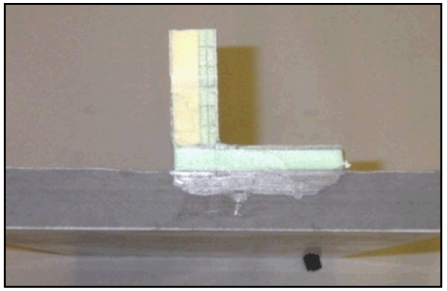


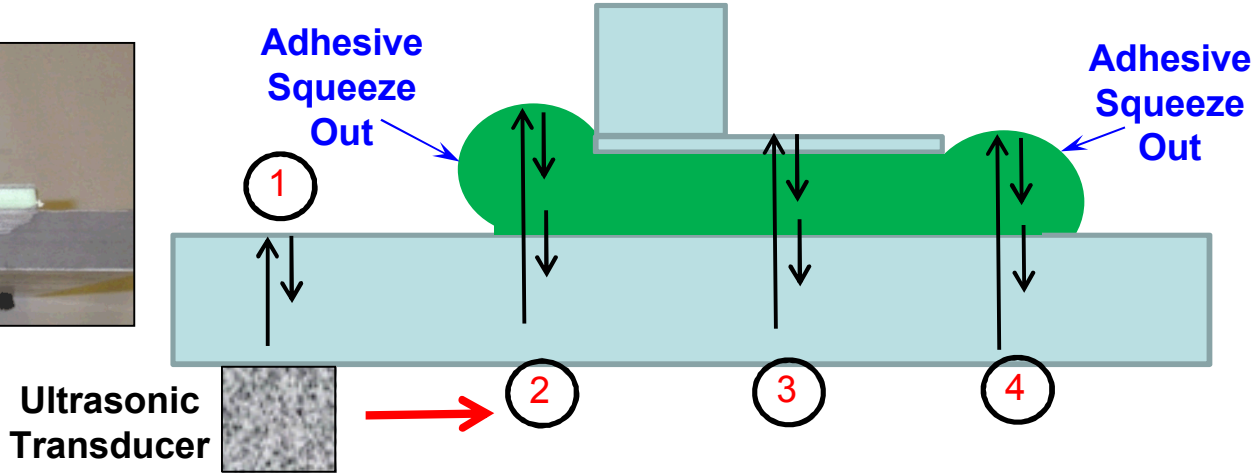
Sandia Labs Wind Turbine Blade Test Specimen Library

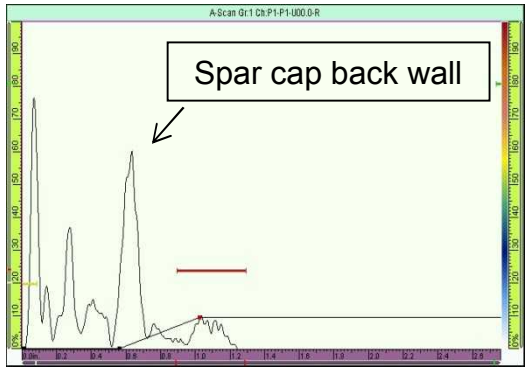
Engineered Test Specimens

Wind Blade Specimens

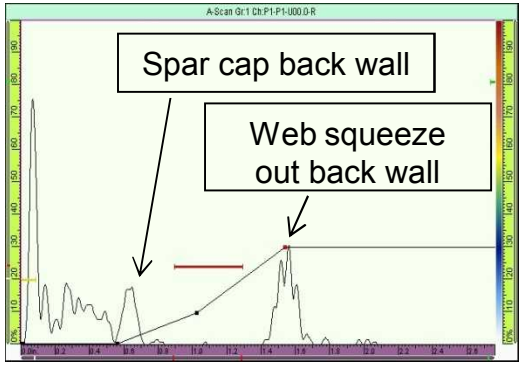
Pulse-Echo Inspection of Bond Joint



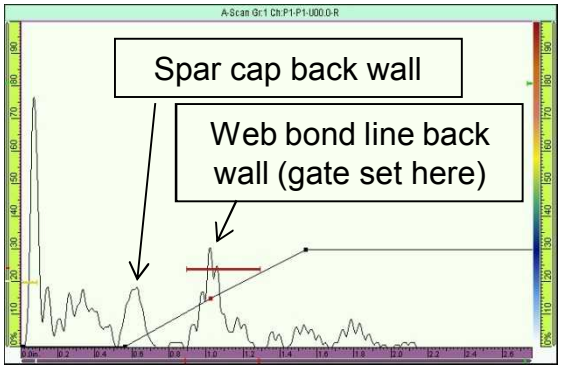




Spar Cap - 1

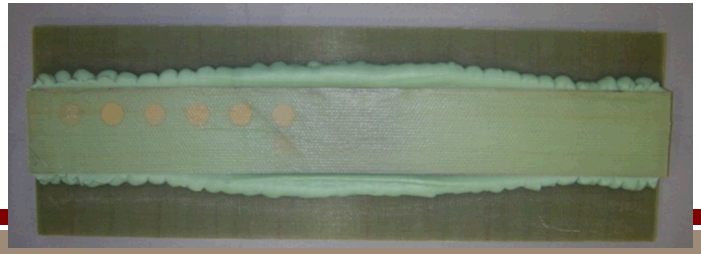


Web Squeeze Out- 2 & 4

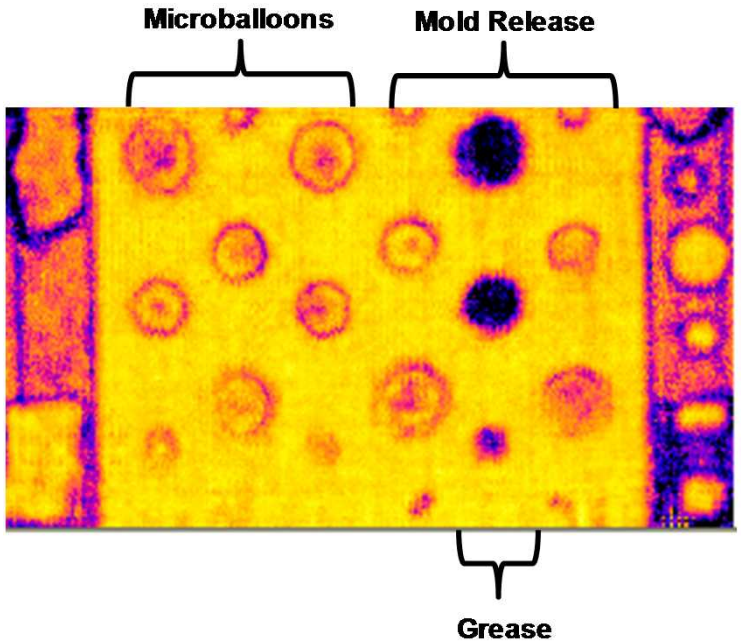


Web Bond Line- 3

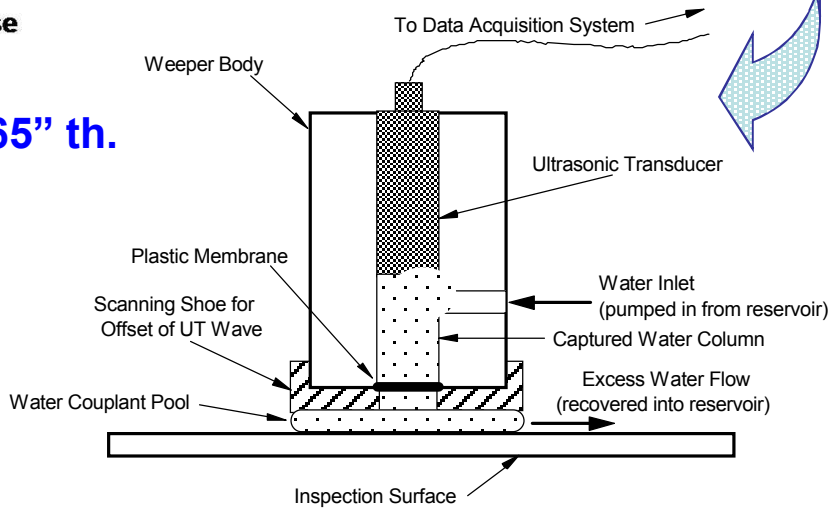
A-Scan Signals



Scanning UT - Focused Probe and Adjustable Water Path

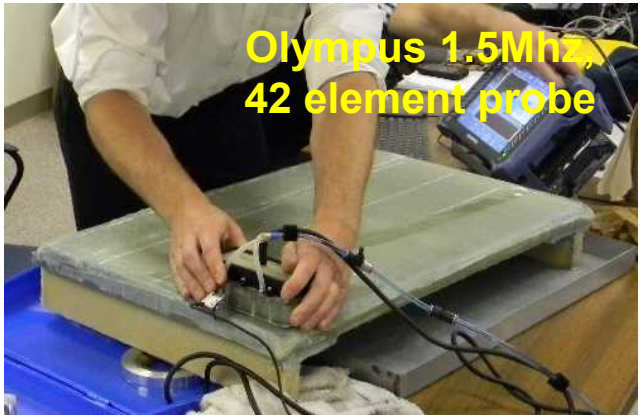


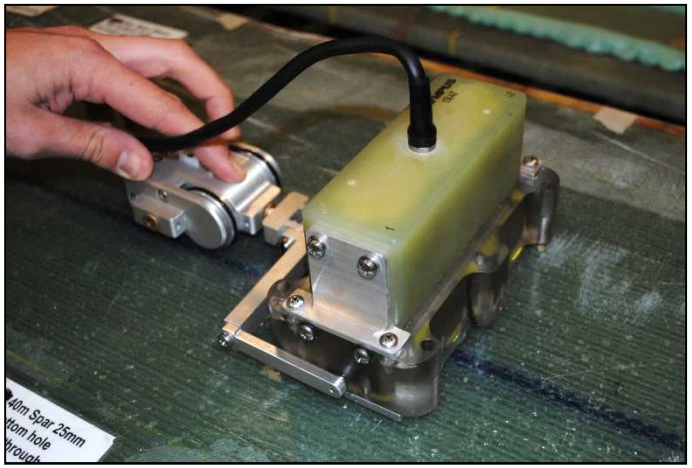
Spar Cap = 2.14" th
Adhesive Bond Line = 2.65" th.

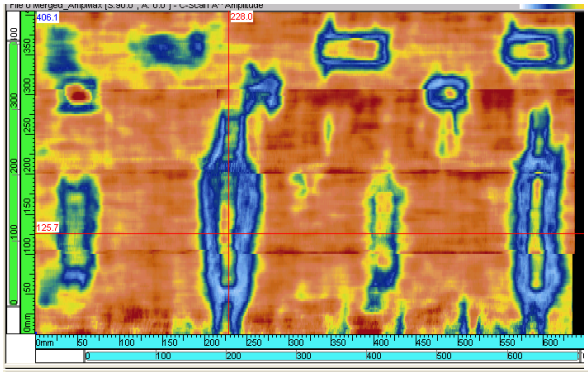


New "Immersion" Probe Holder Allows for Adjustable Water Path

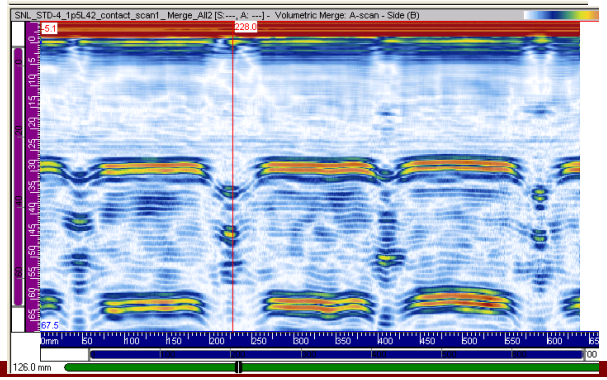
Phased Array Ultrasonics – 3-D Display and Ease of Deployment



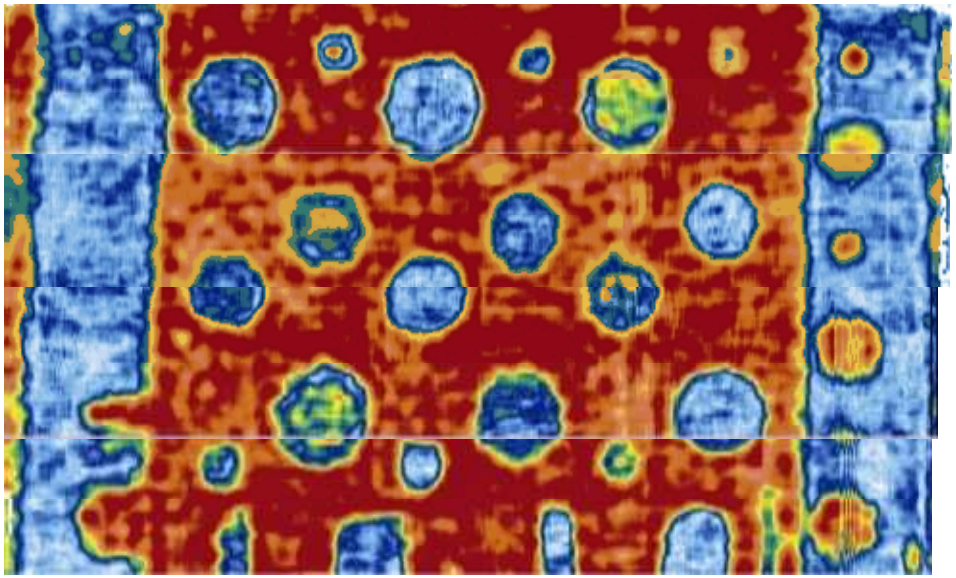




C-Scan Display



B-Scan Display



An Experiment to Assess Flaw Detection Performance in Wind Turbine Blades (POD)

Sandia National Laboratories

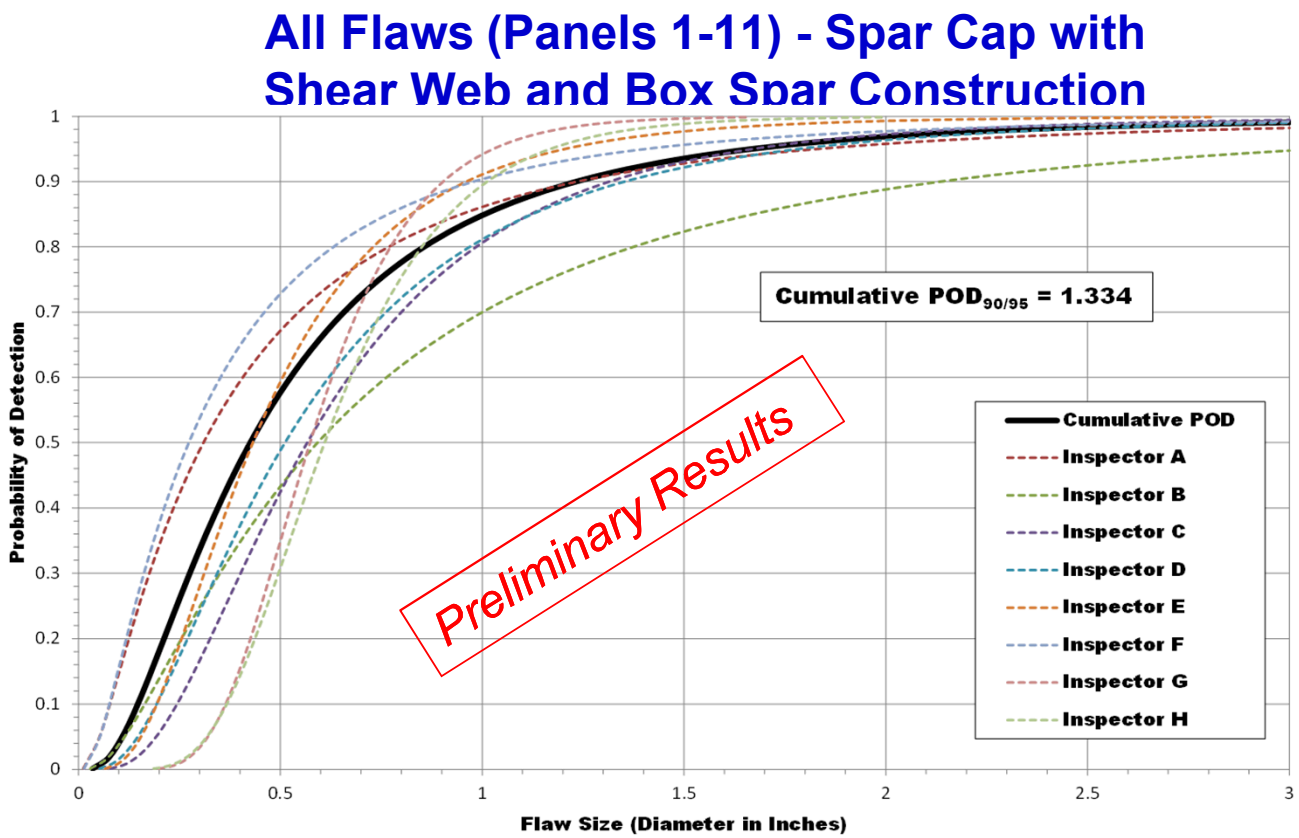
Purpose

- Generate industry-wide performance curves to quantify:
  - how well current inspection techniques are able to reliably find flaws in wind turbine blades (industry baseline)
  - the degree of improvements possible through integrating more advanced NDI techniques and procedures.

Expected Results - evaluate performance attributes

1) accuracy & sensitivity (hits, misses, false calls, sizing)
2) versatility, portability, complexity, inspection time (human factors)
3) produce guideline documents to improve inspections
4) introduce advanced NDI where warranted

Wind Blade Flaw Detection Experiment – Probability of Detection Comparison



All Panels, All Flaw Types – Conventional NDI

$POD_{90/95} = 1.334$

All Panels, All Flaw Types – Advanced NDI (preliminary only)

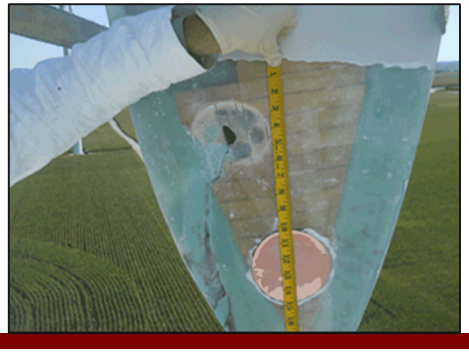
$POD_{90/95} = 1.105$

In-Service Inspection of Wind Turbine Blades

Damage Sources - Installation, Lightning Strike, Impact, Erosion, Overstress, Fatigue, Fabrication-Seeded, Environmental

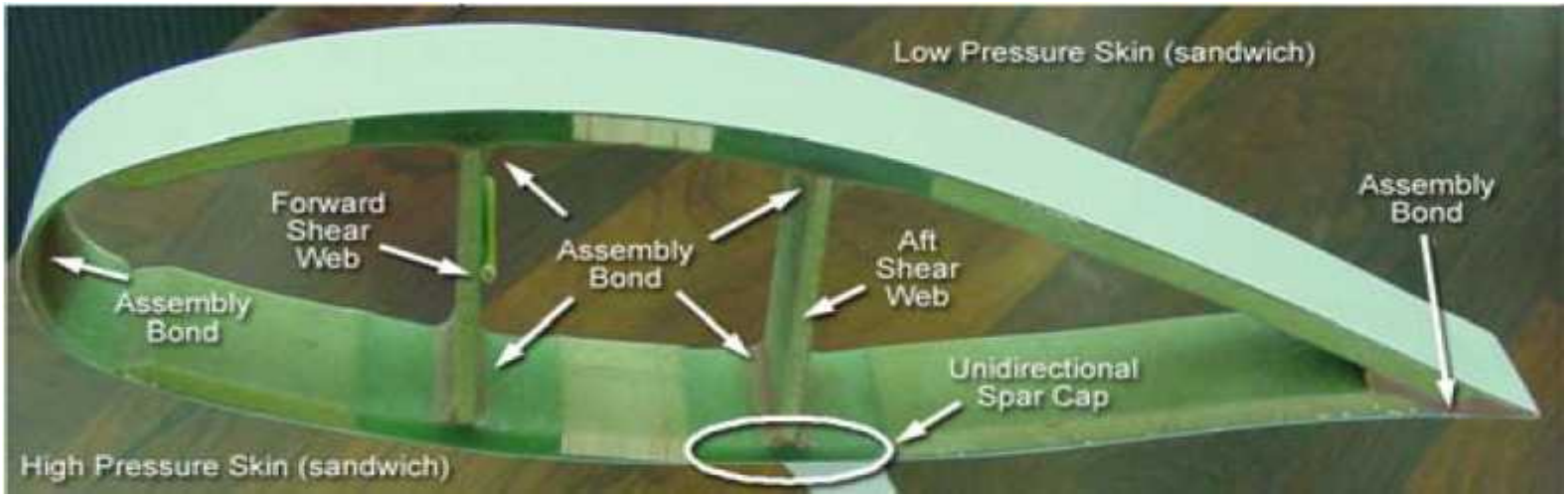
Skin Laminate Fracture

- In-service NDI can improve blade reliability, minimize blade downtime & extend blade life
- Additional access & deployment challenges
- Post-repair inspections
- Where to apply NDI?



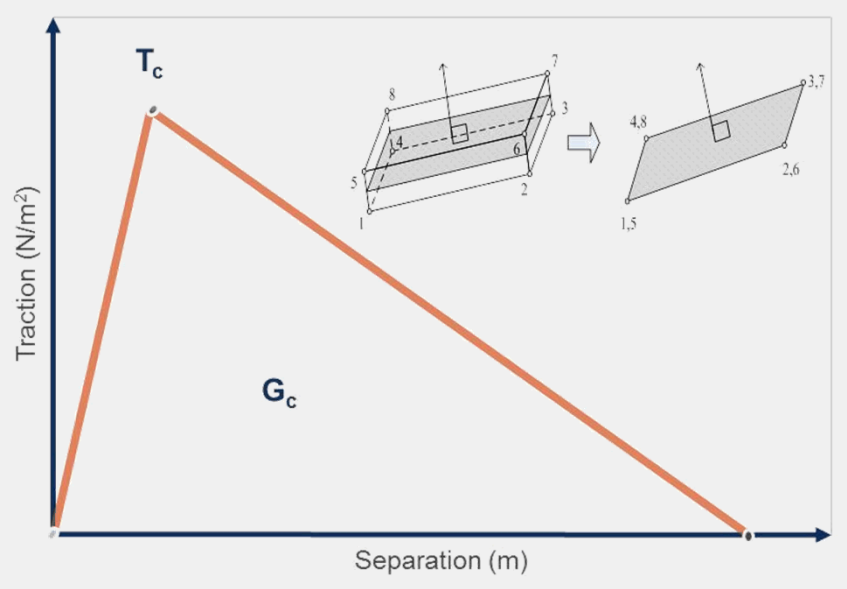
Bonding Quality

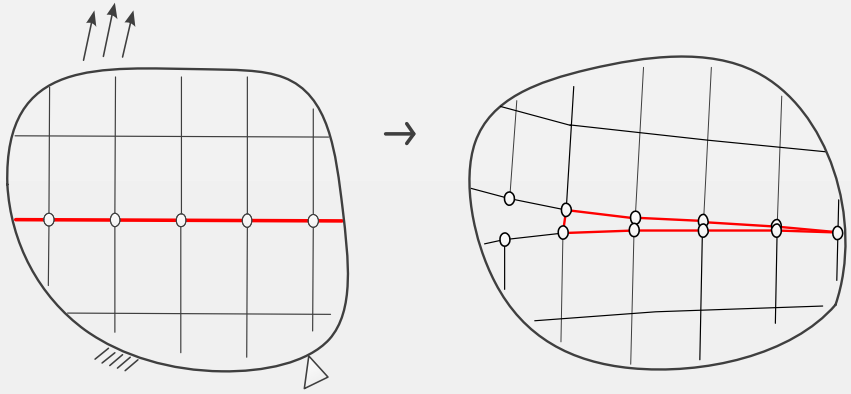
- Typical Blade Bond Lines
  - Difficult to control
  - Blind bonds
  - Scaling effects
- Voids and poor bonding can occur
- Geometrically complex crack growth, without a priori knowledge of where it might occur
- Modeling must include crack initiation, potential crack branching, and flaw interaction



Cohesive Zone Modeling

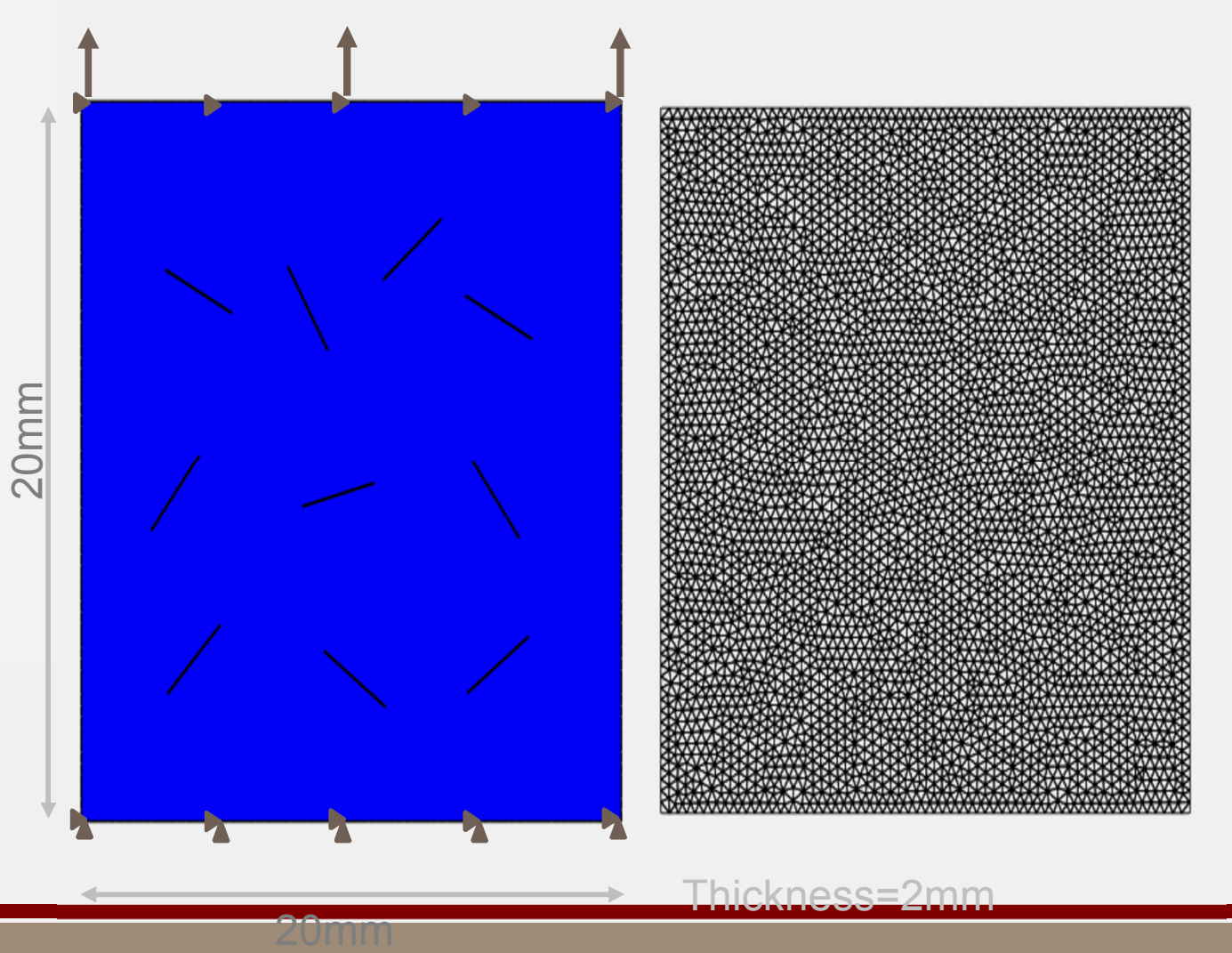
- Material separation & fracture is resisted by internal "cohesive" forces over extended process zone.
- Implemented in the FEM using cohesive interface elements (CIEs) placed at inter-element boundaries.
- The CZM is a versatile tool for modeling crack growth under complex load and boundary conditions, but suffers from some drawbacks.
- Selective Activation of cohesive elements appears to be a natural improvement.
  - Removes or minimizes artificial compliance
  - Reduces the number of active DOF
  - Reactivates CIEs as needed "on-the-fly"





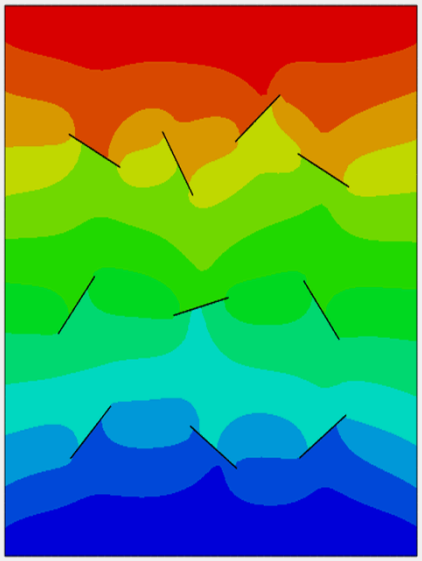
Multicrack Model

Geometry, BC, Mesh

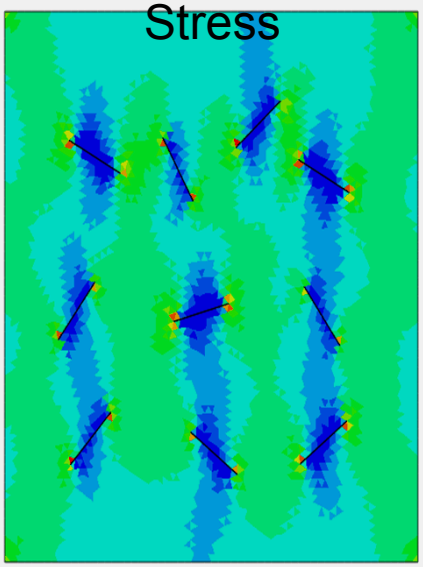


Multicrack Growth (Pt 1)

Displacement



Max Principal Stress



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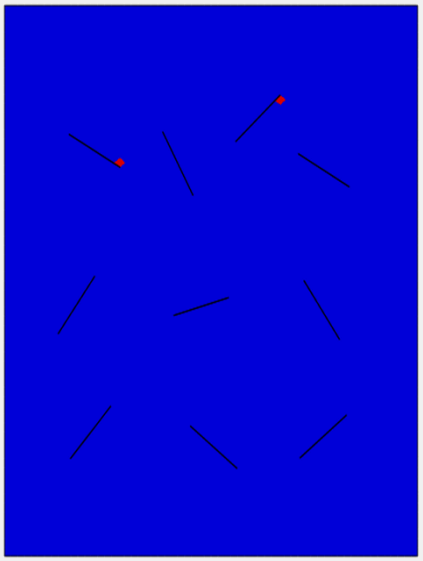
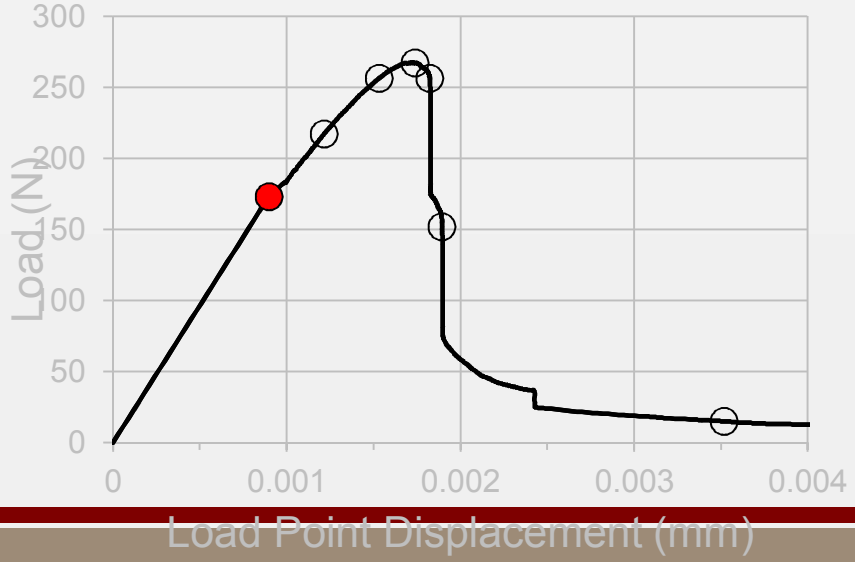
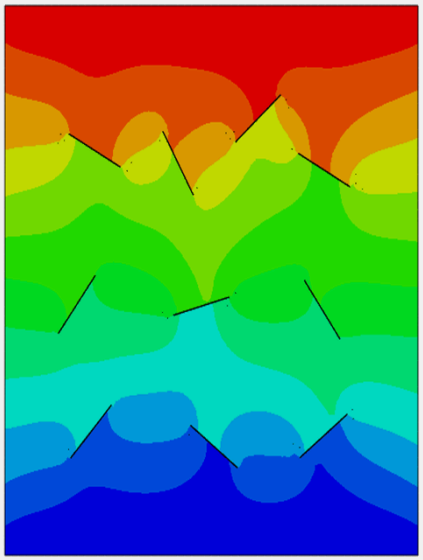


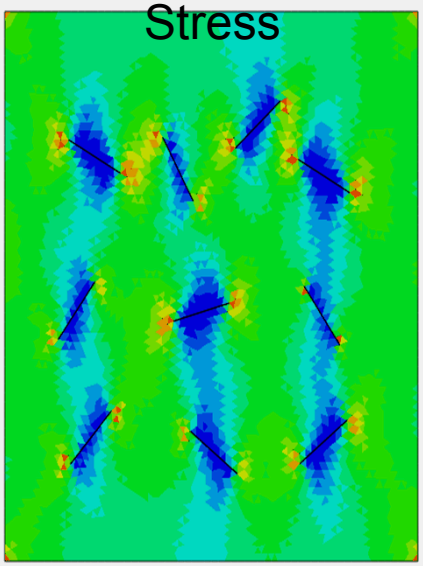


Multicrack Growth (Pt 2)

Displacement



Max Principal Stress



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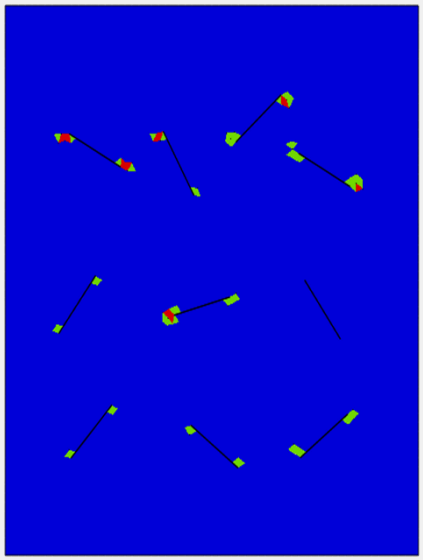
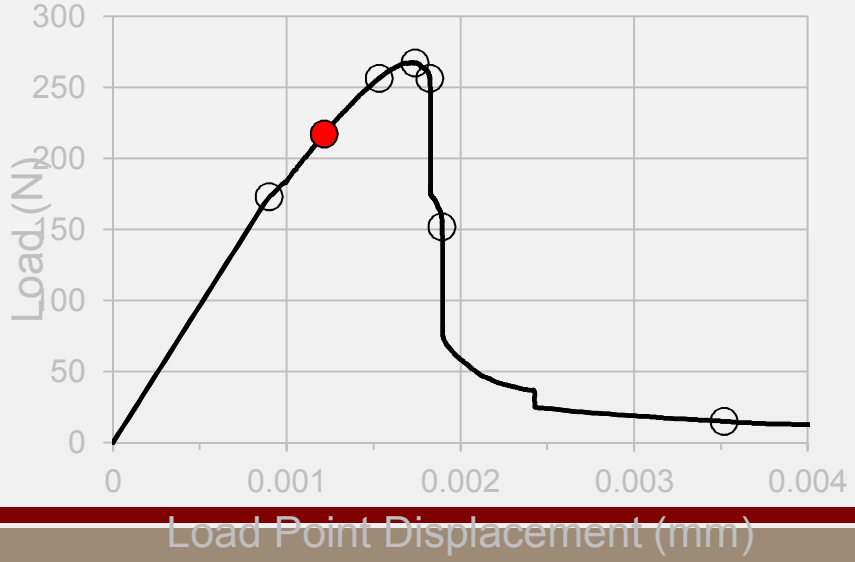
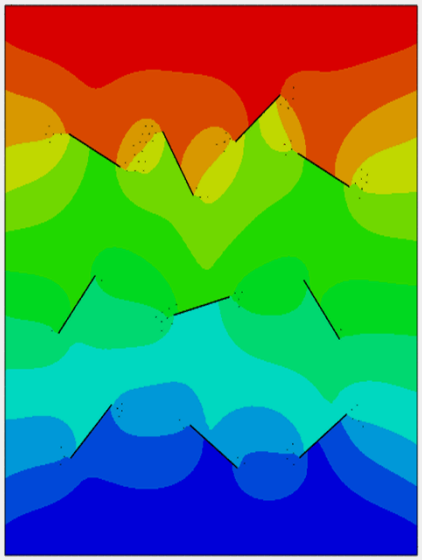


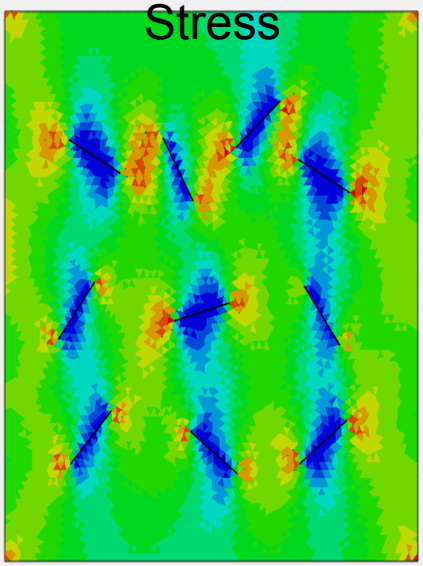


Multicrack Growth (Pt 3)

Displacement



Max Principal Stress



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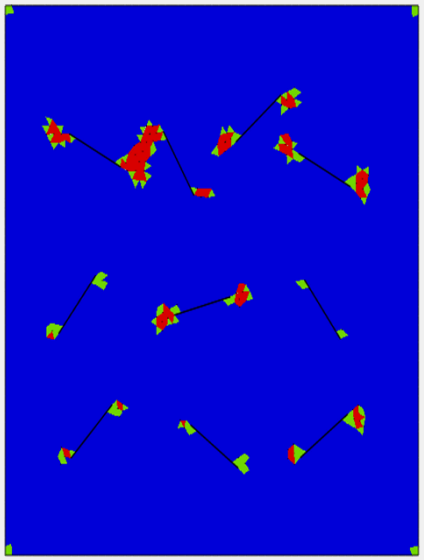
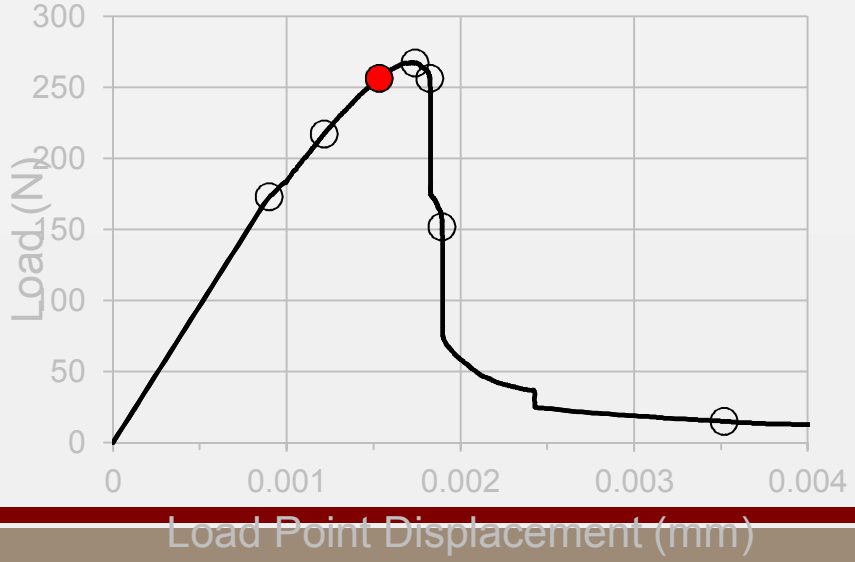
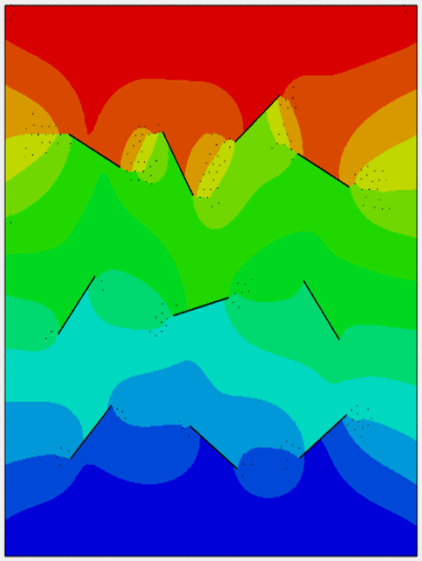




Multicrack Growth (Pt 4)

Displacement



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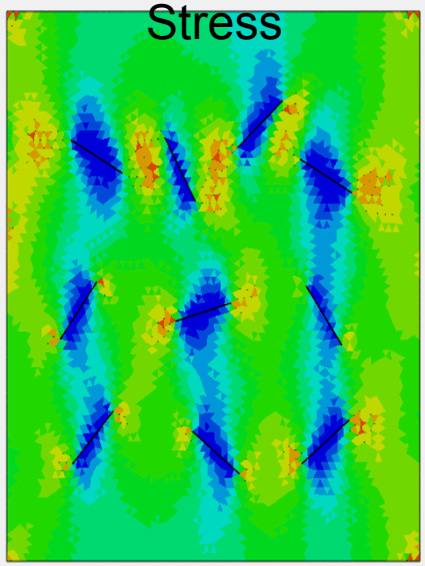

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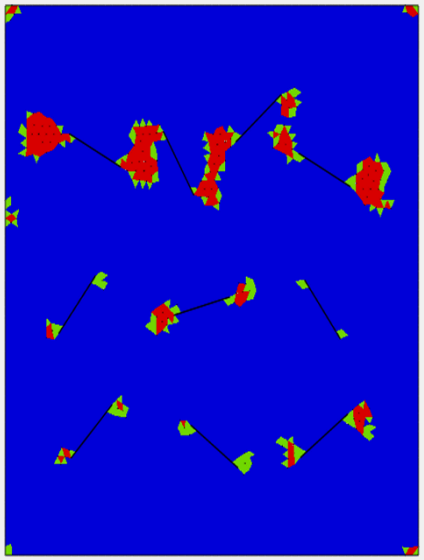
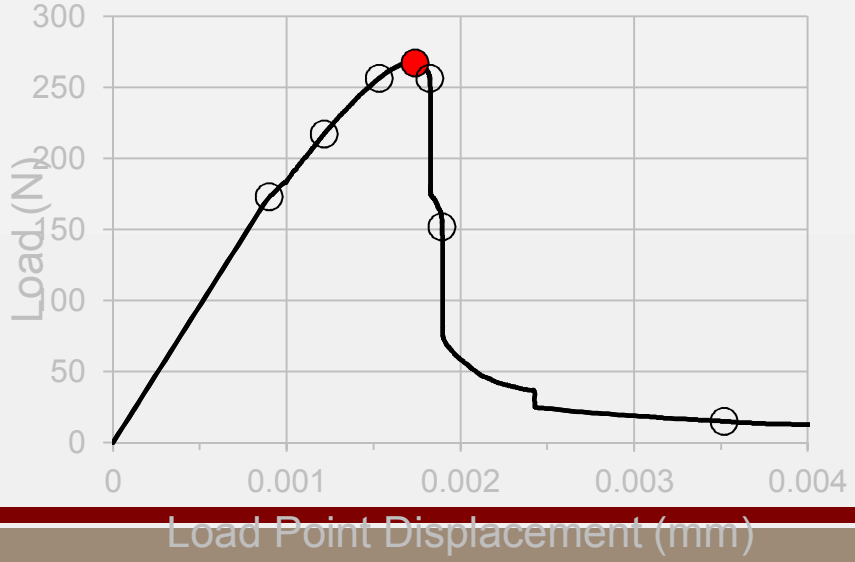
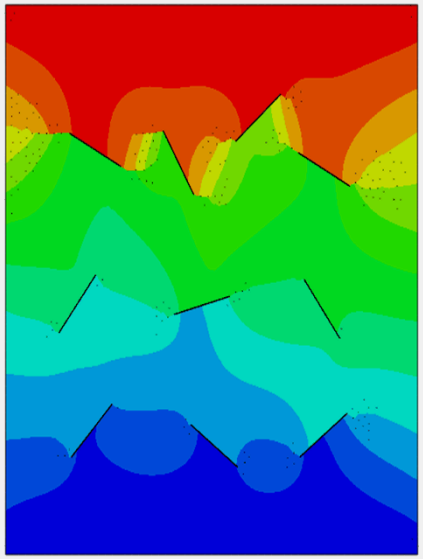


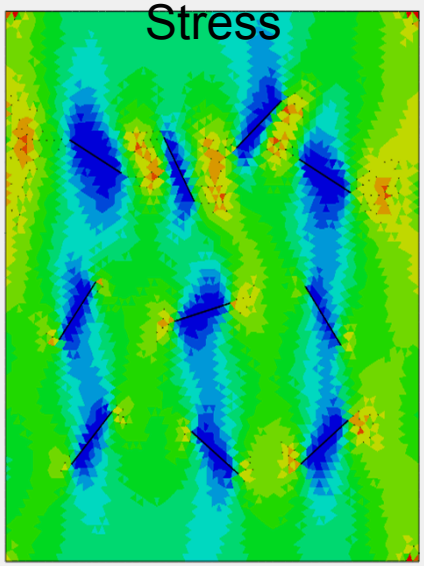


Multicrack Growth (Pt 5)

Displacement



Max Principal Stress



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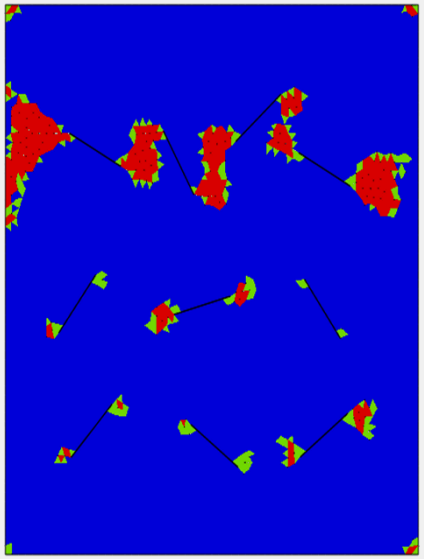
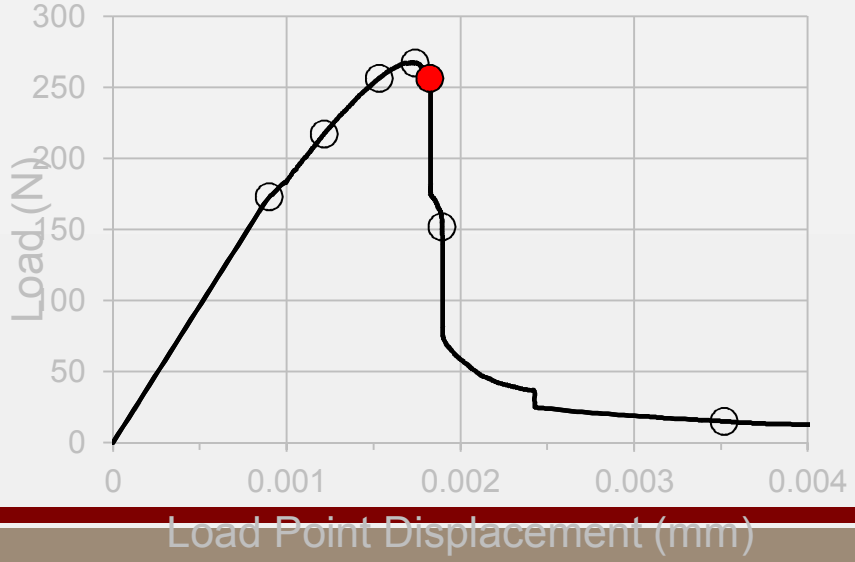
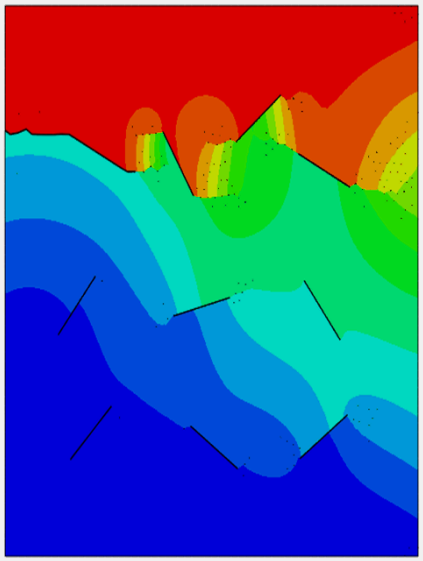




Multicrack Growth (Pt 6)

Displacement



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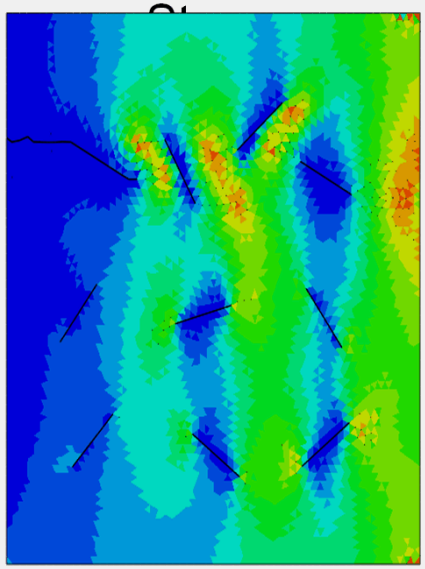

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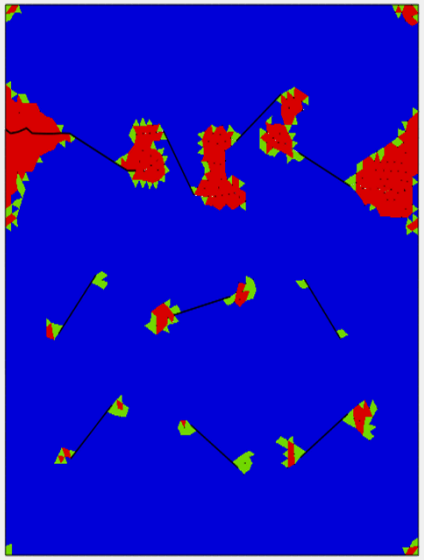
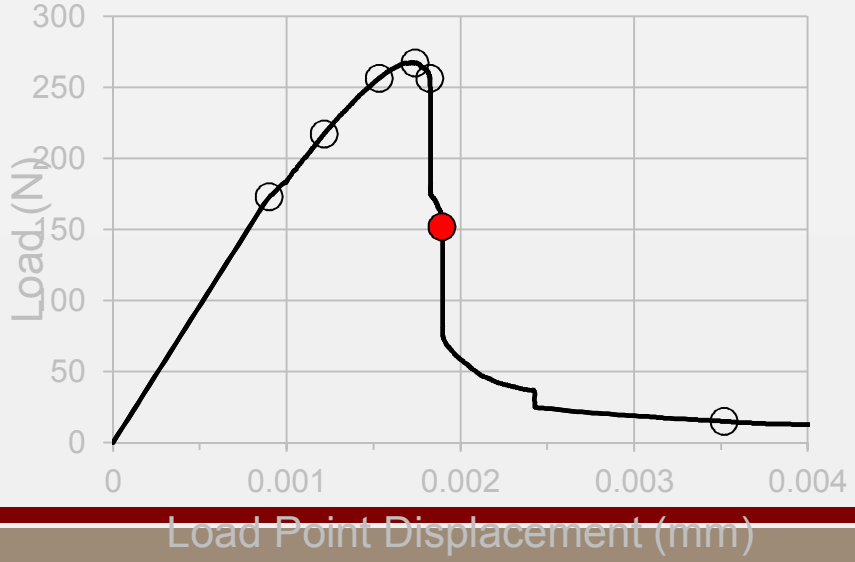
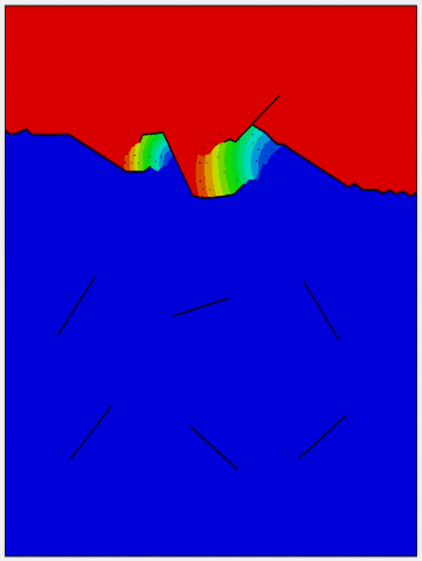


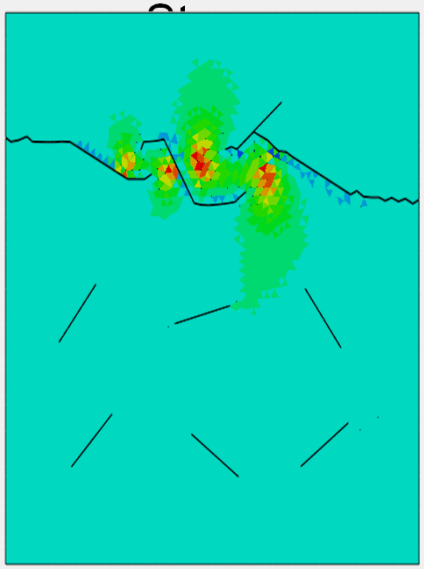


Multicrack Growth (Pt 7)

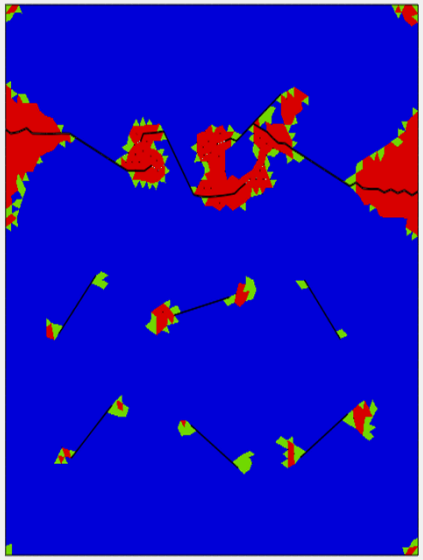
Displacement

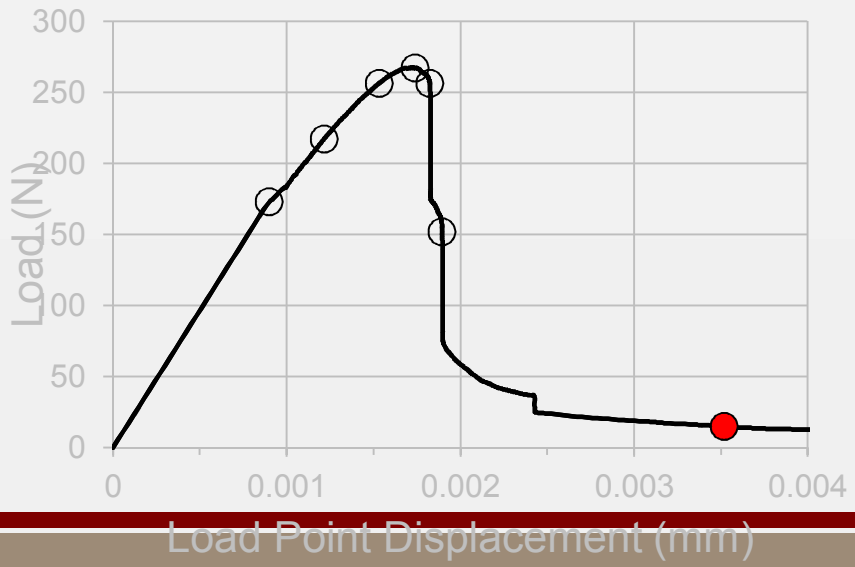


Max Principal



MPC Release



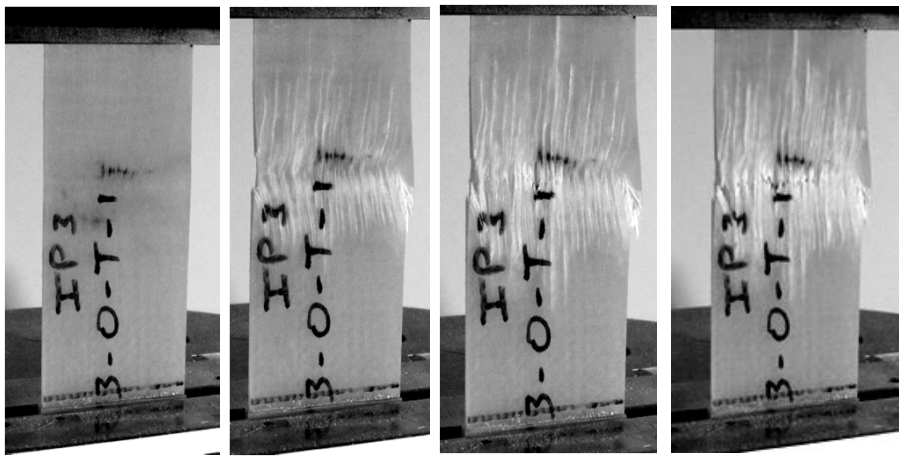


Multi-Scale, Multi-Axis Test Facility (MSU)

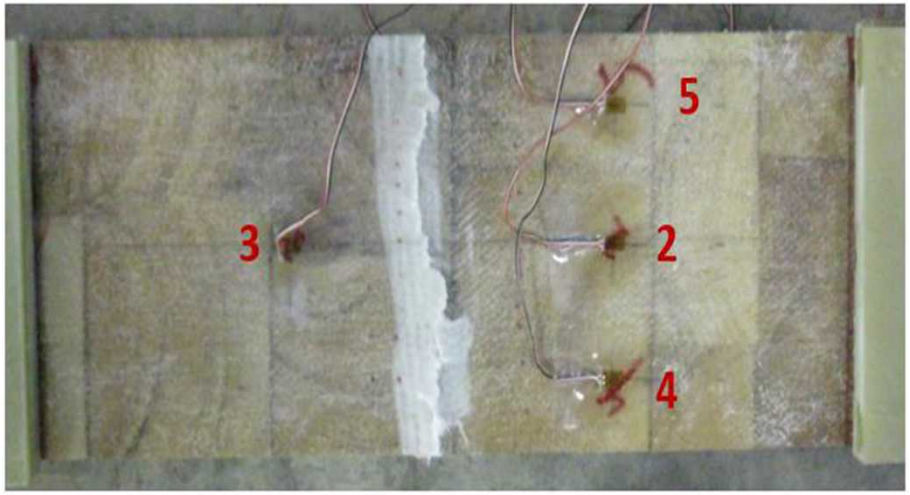
- Substructure test frame with 250 kN linear actuator, capable for structures up to 3m, bending and/or torsion
- Practical intermediate step between coupons and full scale testing
- Can be used for a variety of test configurations
  - Subscale sections
  - Large adhesive joints
  - Combined loading (flexural bending plus torsion)

Coupons and Sub-Structures

- Coupons with in-plane waviness tested
- Beam samples fabricated and tested with varying flaw magnitudes
  - No Flaw: 6.2kN
  - Partial width flaw (wavy fibers in middle, straight fibers on edges): 5.8 kN
  - Full Width Flaw: 3.8-4.4 kN
- Initial beam results consistent with coupons



Beam with Full Width Flaw



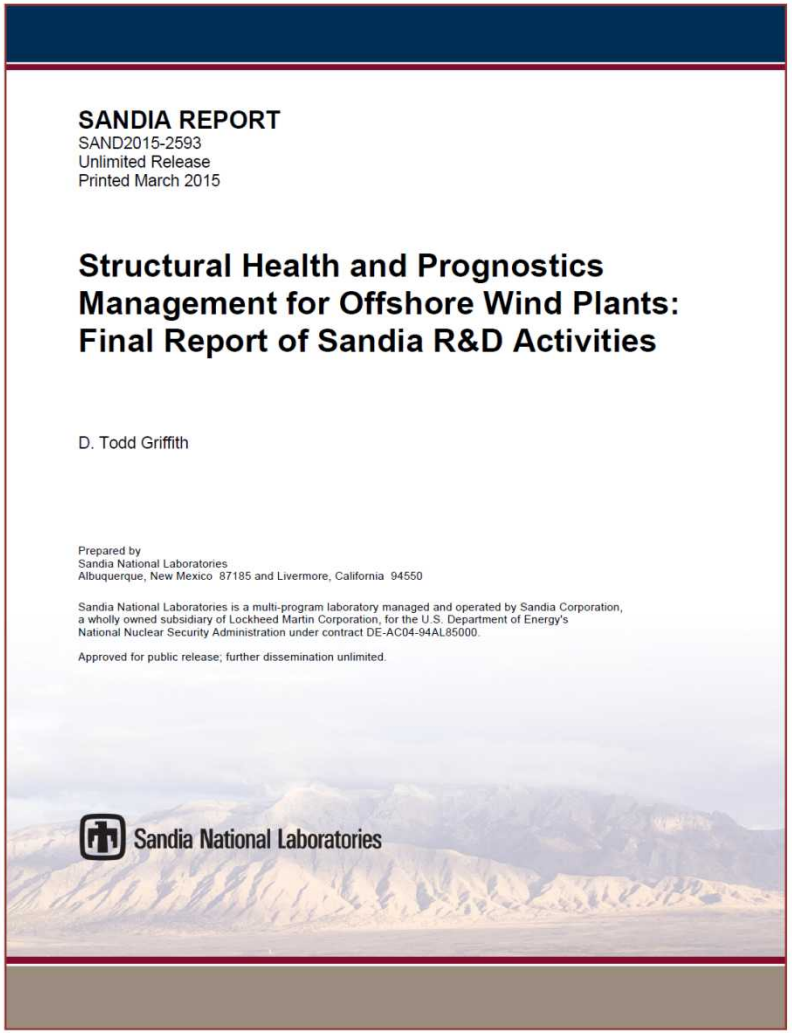
Beam with Full Width Flaw

Structural Health and Prognostics Management

- **Summary/LCOE Impact**
  - **Mitigate rising costs for offshore O&M** (estimated to be 2-5 times of land-based)
  - **Maximize energy capture** by increasing availability
- **Focus Areas**

  Simulation of Damage:
  1. Identify best operating signatures (sensors) : Damage Detection
  2. Analyze effects of damage (state of health and remaining life): Prognostics; Damage Mitigation
- **Key Blade Downtime Issues**
  - Rotor imbalance
  - Trailing edge disbonds
  - Leading edge cracks
  - Edge-wise vibration
  - Erosion
  - Lightning
  - Icing

Final Report: Structural Health and Prognostics Management



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Structural Health and Prognostics Management for Offshore Wind Plants: Final Report of Sandia R&D Activities

D. Todd Griffith

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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"Structural Health and Prognostics Management for Offshore Wind Plants: Final Report of Sandia R&D Activities,"

Sandia National Laboratories Technical Report,

SAND2015-2593, March 2015.

Project website:
http://energy.sandia.gov/energy/renewable-energy/wind-power/materials-reliability-standards/structural-health-monitoring/

Future Work

- Non-Destructive Inspection
  - Complete probability of detection study
  - Field inspections
  - Repairs
  - Lightning damage
- Structural Testing/Modeling
  - Release cohesive zone model user sub-routine
  - Additional beam tests
  - Repairs: How high can a composite laminate repair be compared to undamaged structures in wind blades?
- Rotor Structural Health Monitoring
  - Blade with reconfigurable damage for flight testing at SWiFT