2009 Wind Turbine Reliability Workshop
"Digging Down for Reliability"

Condition Monitoring and Wind Turbine Blades

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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.

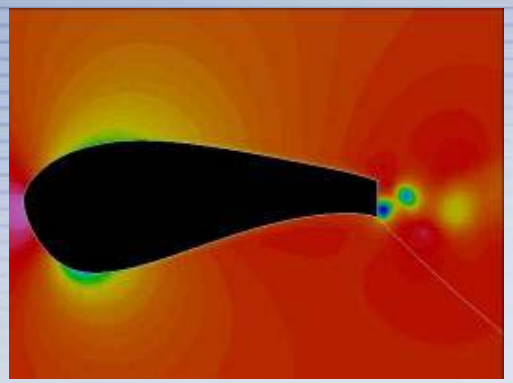
Sandia National Laboratories

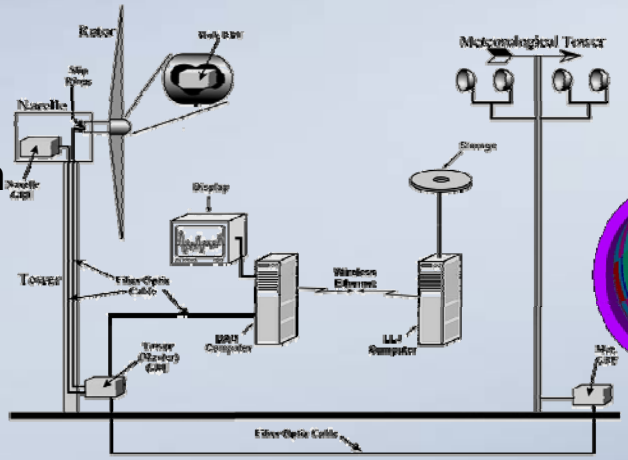
Presentation Outline

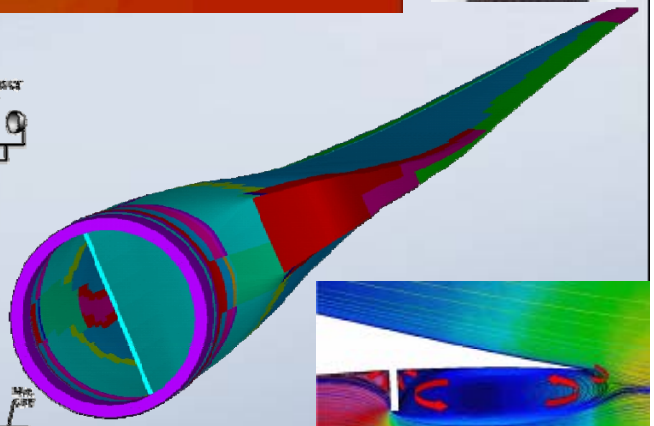
- Sandia Labs – Who we are
- Reliability Refresher
- Condition Monitoring Challenges
- Condition Monitoring at the Labs

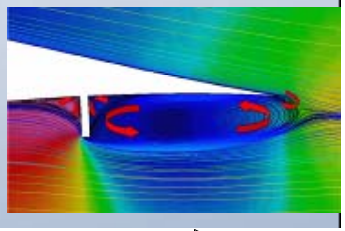
Sandia Wind Energy Technology Focus

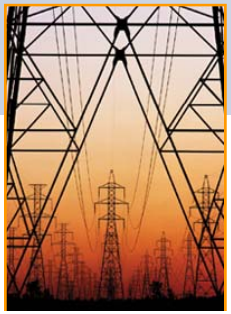
- **Blade Technology**
  - Materials and Manufacturing
  - Structural, Aerodynamic, and Full System Modeling
  - Sensors and Structural Health Monitoring
  - Advanced Blade Concepts
  - Lab - Field Testing and Data Acquisition
- **System Reliability**
  - Industry Data Collection
  - Improve reliability of the existing technology and future designs
- **System Integration & Outreach**
  - DOE/Wind M&O

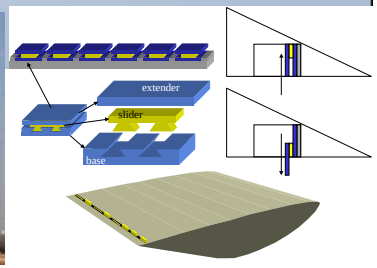




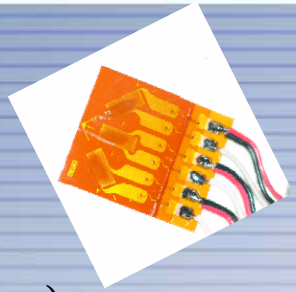


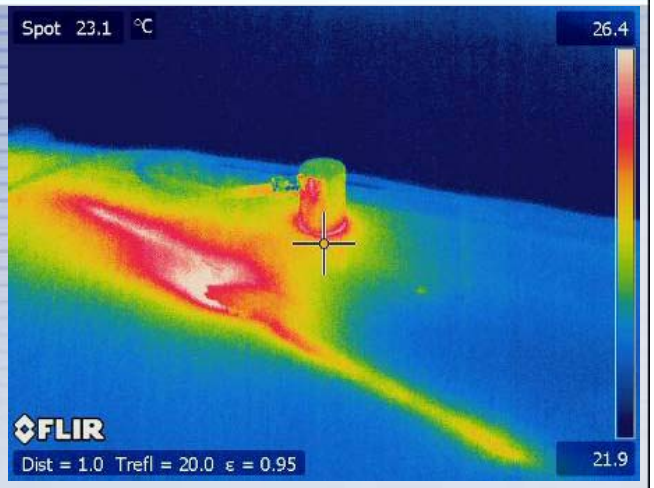






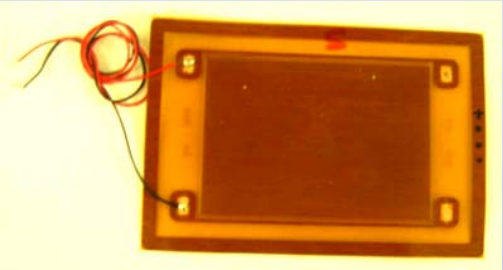
Sensor Tasks at Sandia Labs





- **Laboratory and field diagnostics**

- **Smart blades**
  - **Active-aero Project** (Lead: Dale Berg)
  - **Sensor Blade Project** (Lead: Mark Rumsey)
    - **Address sensor-in-blade issues**
      - **Manufacturability** (egress/ingress, surface-mount/embed, maintenance accessibility, material compatibility, costs)
      - **Reliability**



- **Active Aero Controls and Sensor Lab**
  - **Determine sensor requirements (accuracy, reliability, cost)**
  - **Evaluate various sensing technologies**
  - **Model and validate sensor/actuation performance**
  - **Build and test subscale structures**

- **Blade Manufacturing QA tools**

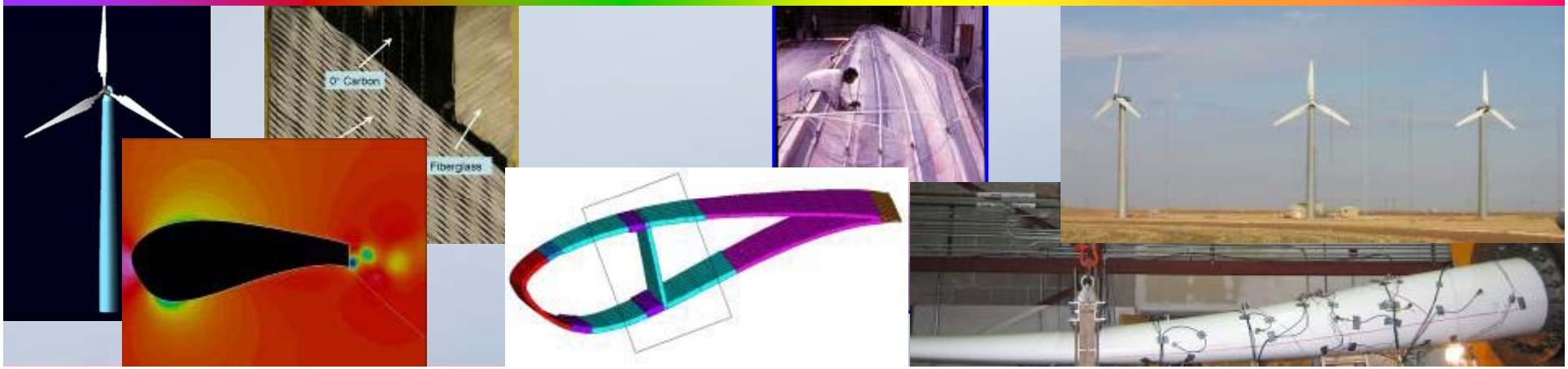
Working with Industry

System analysis identifies research initiatives with increasing industry involvement as it gets closer to the commercial product

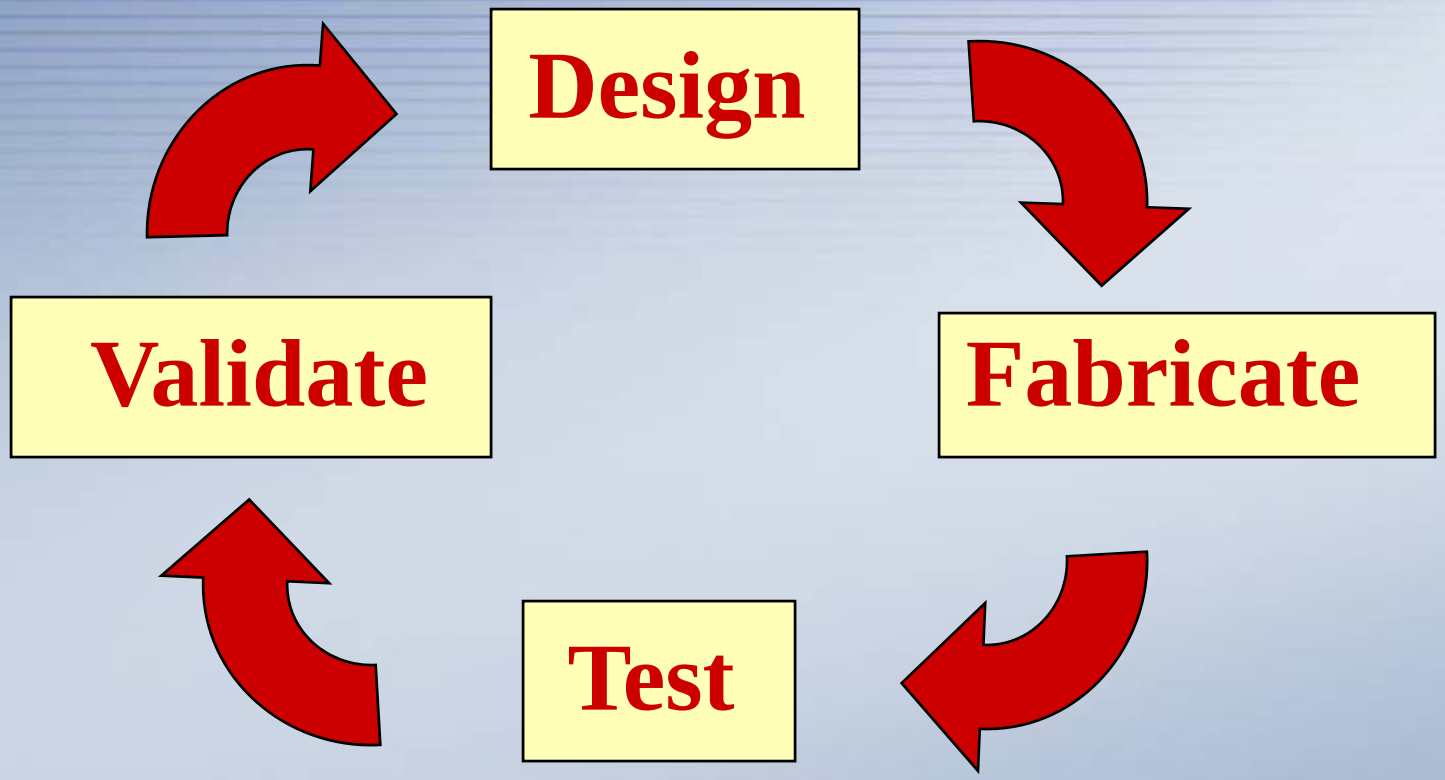
Industry Activities

SNL Program Activities

Concepts → **Preliminary Design** → **Detailed Design** → **Prototype Fabrication** → **Test and Evaluation** → **Commercial Product**



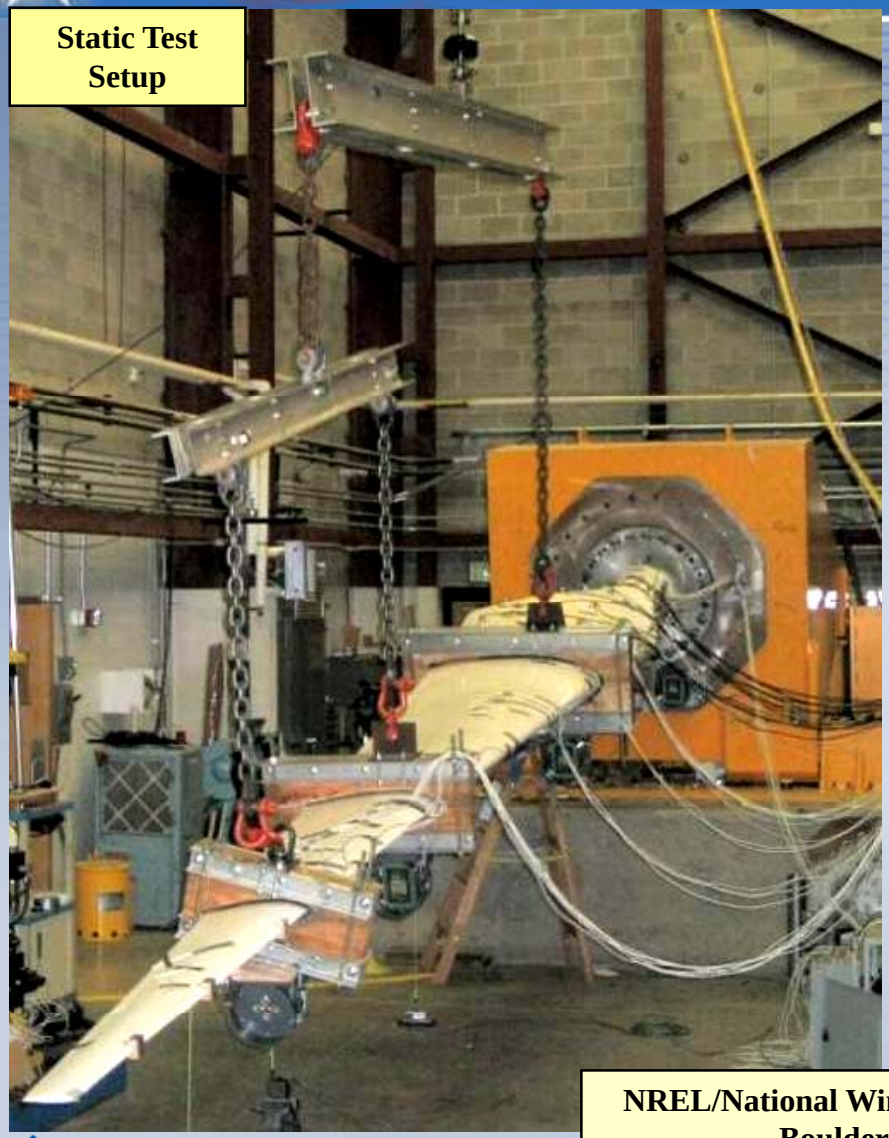
Validation Loop for Design, Models & Manufacturing Process



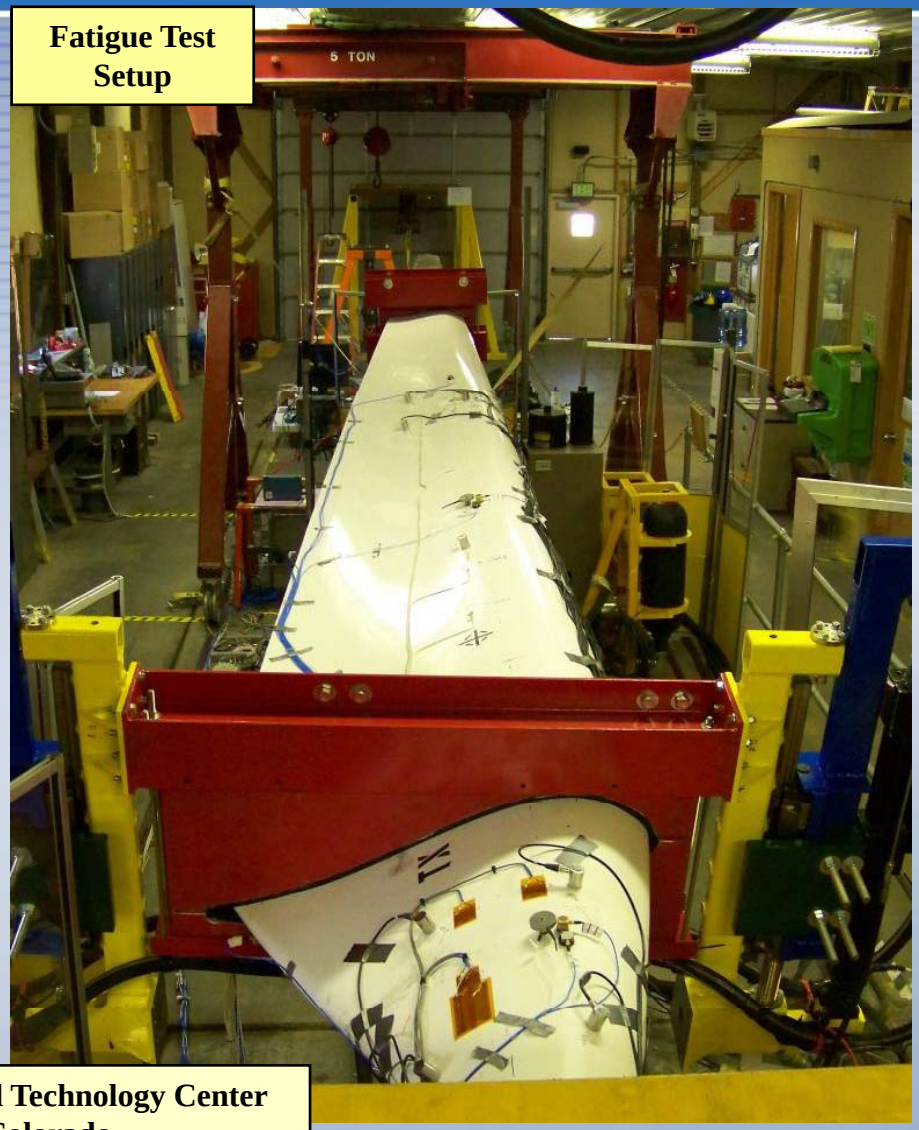
Blade Testing in the Laboratory

(Condition Monitoring)

Static Test Setup



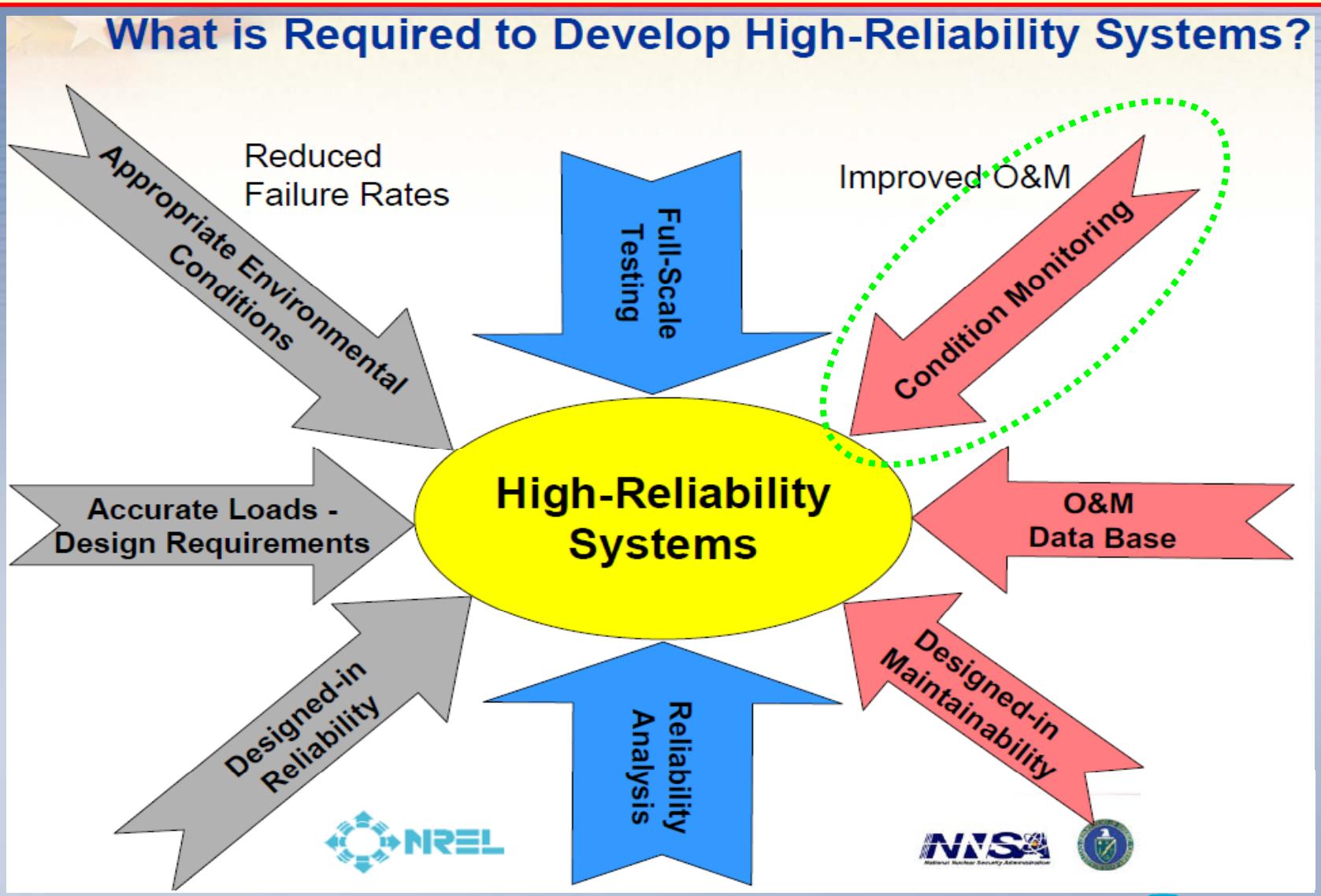
Fatigue Test Setup



NREL/National Wind Technology Center
Boulder, Colorado

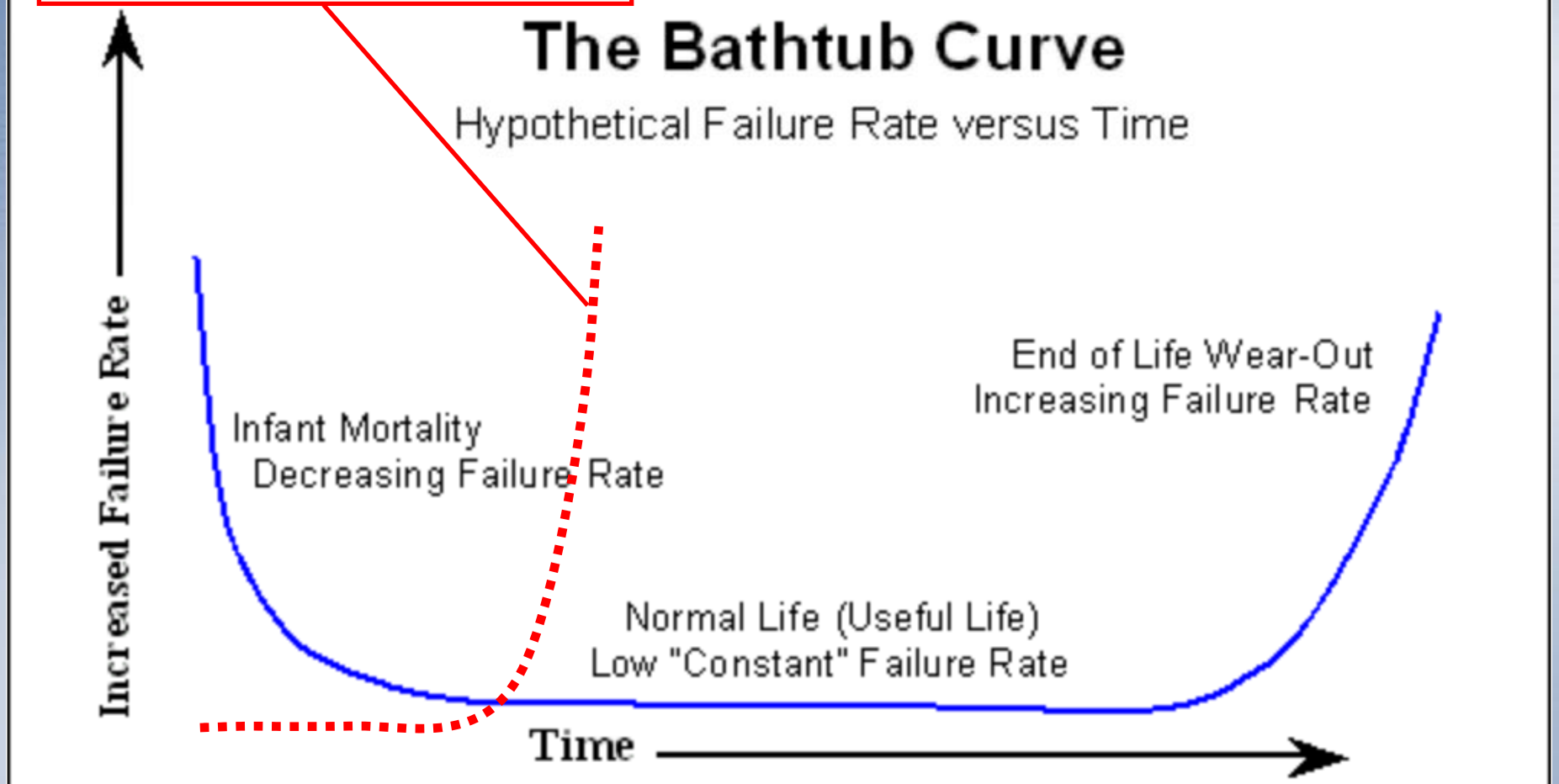
Condition Monitoring is only part of the solution

Source: Hill and Butterfield, 2006 Blade Reliability Workshop



Condition Monitoring needs to be Reliable, too!

If Condition Monitoring is used, it needs to be Reliable ... and Cost Effective.



Source: Wikipedia

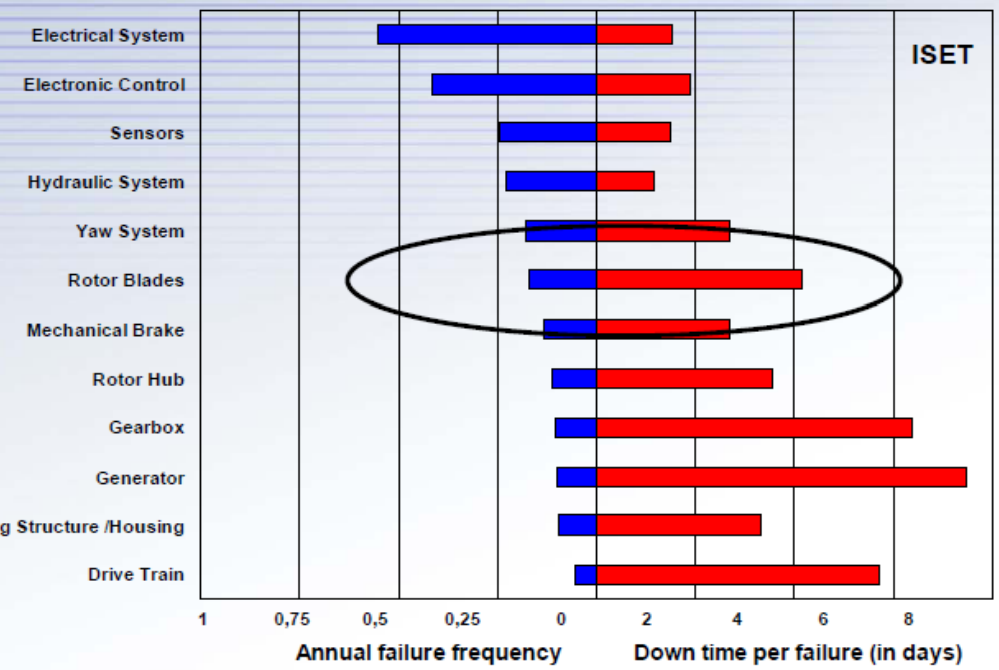
Blades have "issues"

Source!: Veers, 2008 Blade Workshop (http://www.sandia.gov/wind)

"80% of the blades that require repair have never been flown."
Gary Kanaby, Knight & Carver Wind Blade Division.

Blade Reliability

- Blades are being delivered to the site in a condition that often requires additional treatment of quality issues before they can be installed
- Rare installations need to have all the blades replaced after the discovery of a batch problem
- Blade failure can cause extensive down time and lead to expensive repairs.
- *Blade reliability issues need early attention because of the lost production and cost of significant failures*



Historical European Experience (Paul Kühn, ISET)

Blades are in the middle – medium failure rate, relatively high cost. US environments may be more aggressive.

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Challenges of Blade Condition Monitoring

"Digging Down for Reliability"

Sense What?

Strains, loads, cracks, dry-spots, voids, operational dynamics, temperature gradients, lightning, …

Sense Where? (location, location, location)

Manufacturing defects, joints, bond lines, spar/shear-web interface, impacts, …

Sense with What?

Piezoelectric sensor/actuators, acoustic emission sensors, optical strain gages (fiber Bragg gratings), metal-foil strain gages, IR thermography, …

Sense How?

Sensor specification, integration method, redundancy, interrogation, maintenance, …

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Sense How?

Sensor specification, integration method, redundancy, interrogation, maintenance, …

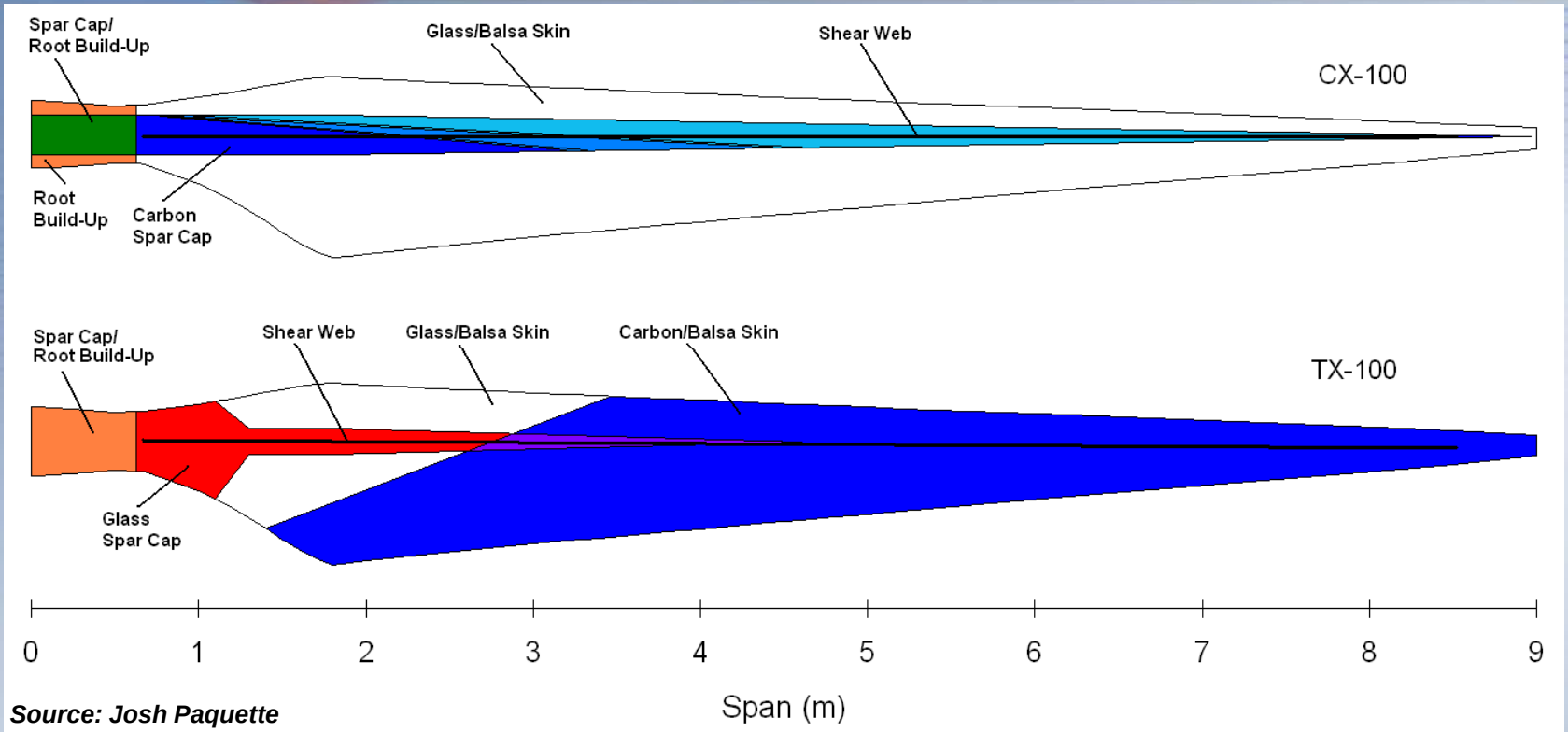
with good data

Condition Monitoring ("**Feature Extraction** and **Indicators**" and what to do with them):

data post-processing, information utilization, data management, ..., **Prognostics**

Sandia Labs' Research Blade Designs

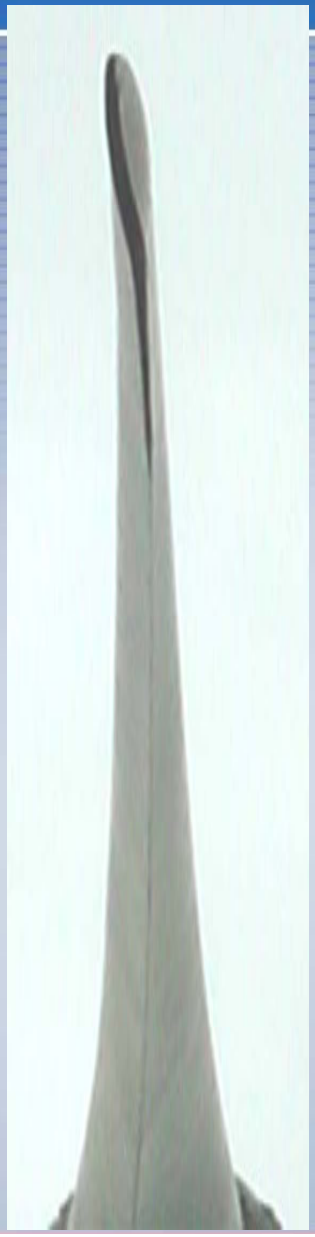
Blade Geometry and Major Laminate Regions

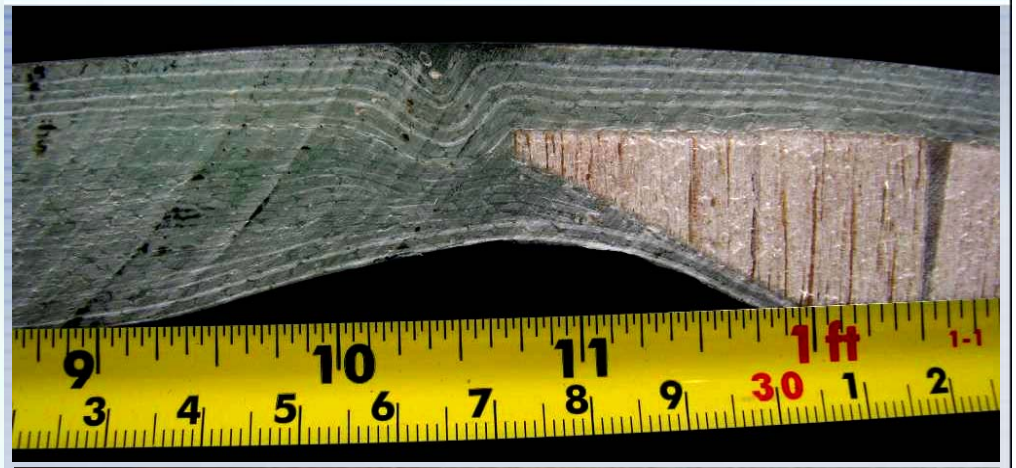


Source: Josh Paquette

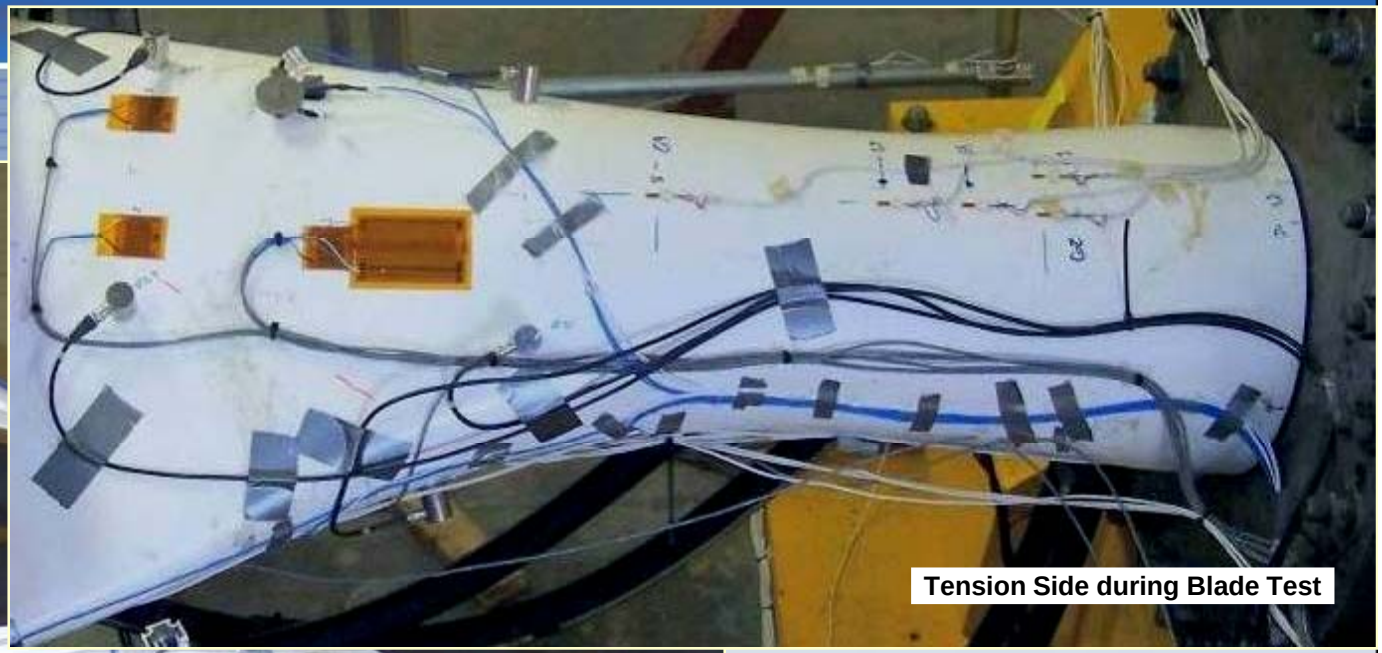
Photo of inside skin surface of TX-100 blade.

Defects … cosmetic or not?

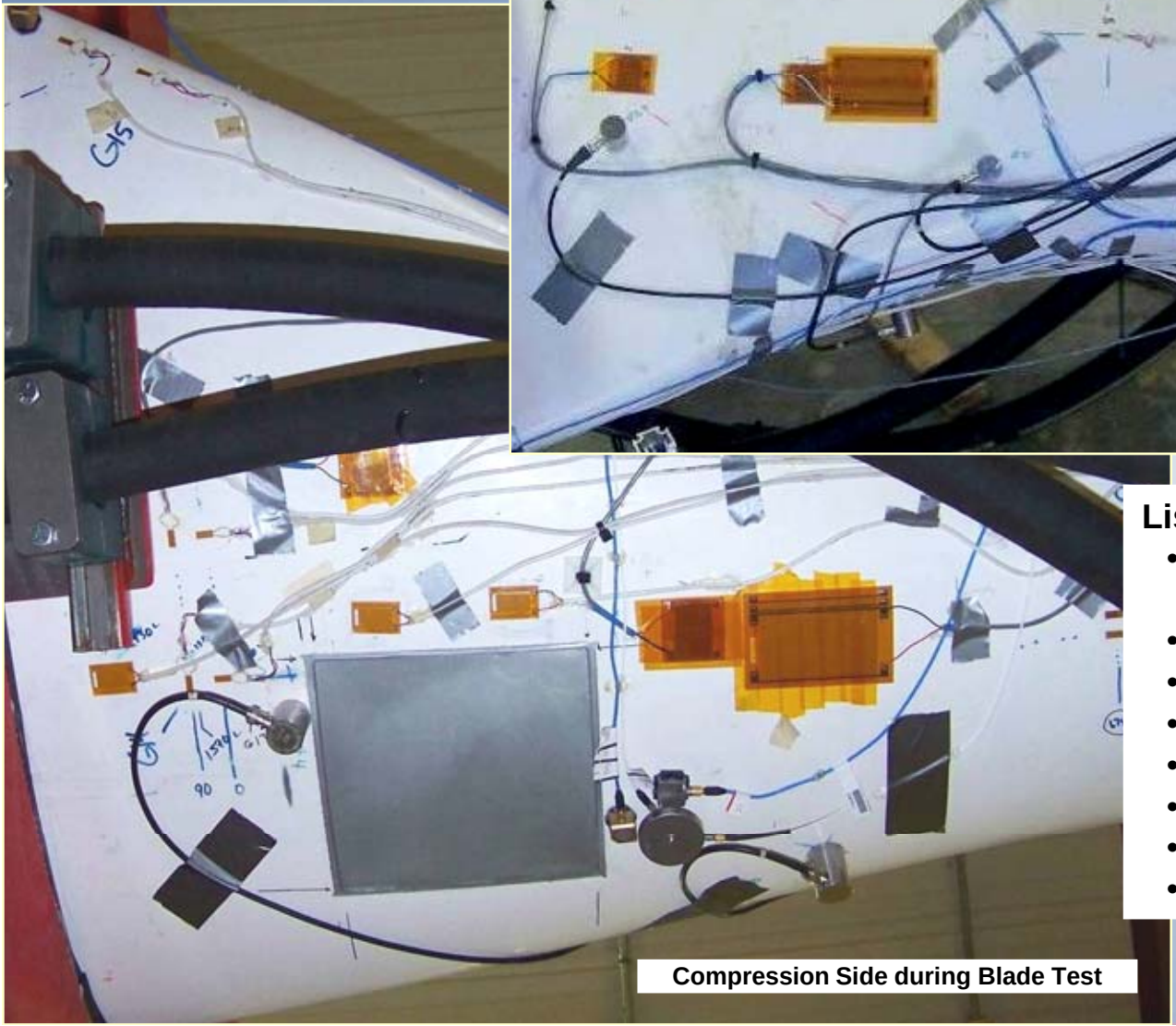




Condition Monitoring during Lab Tests



Tension Side during Blade Test



Compression Side during Blade Test

List of Sensors shown in the photos:

- Macro Fiber Composite (MFC) piezoelectric sensors/actuators,
- acoustic emission NDI sensors,
- metal foil strain gages,
- photoelastic panel,
- single axis accelerometer,
- two multi-axis accelerometers,
- force actuator
- and a force transducer

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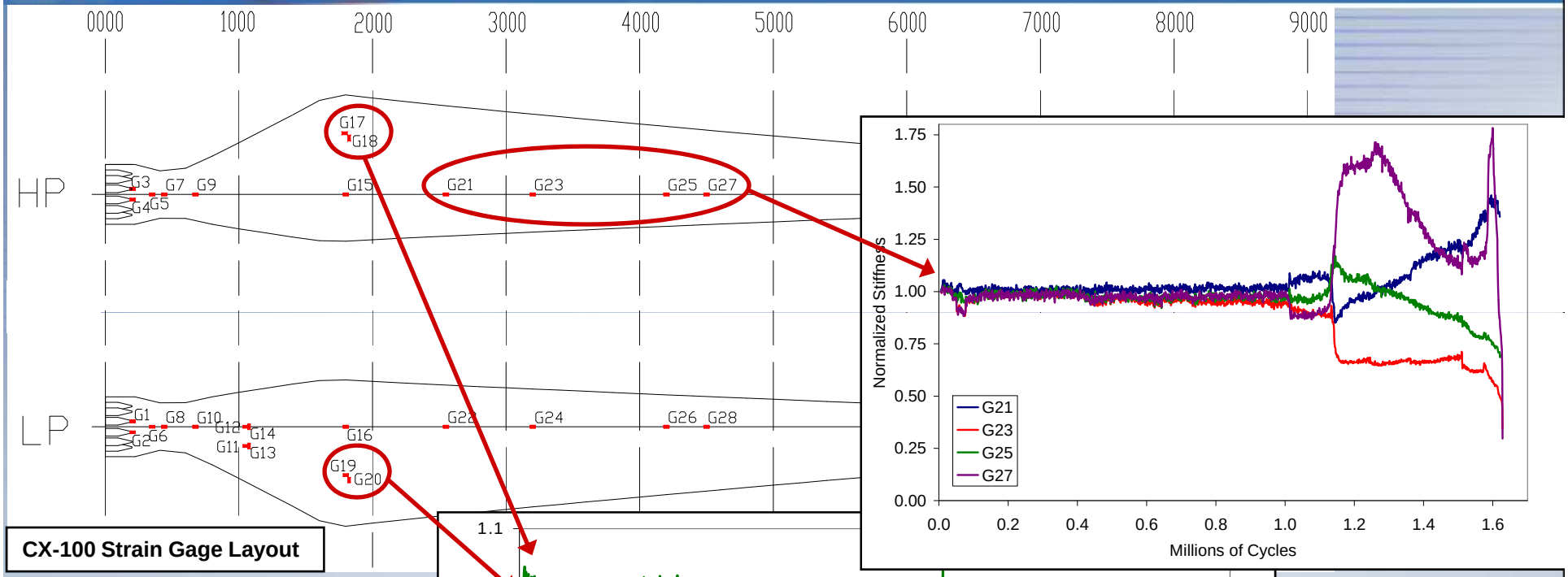
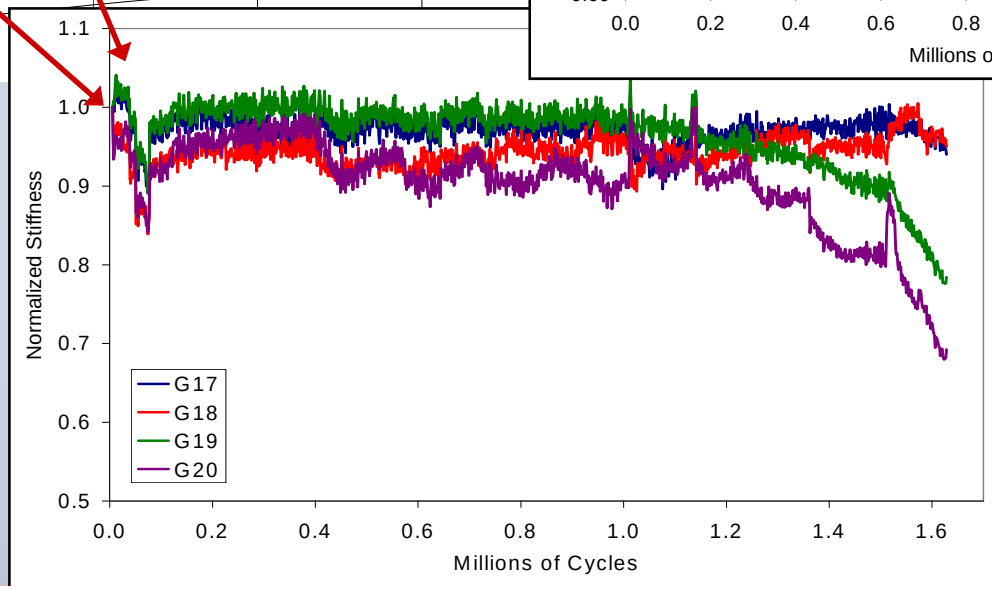
Typical Response from Strain Gages during a Fatigue Test



CX-100 Strain Gage Layout



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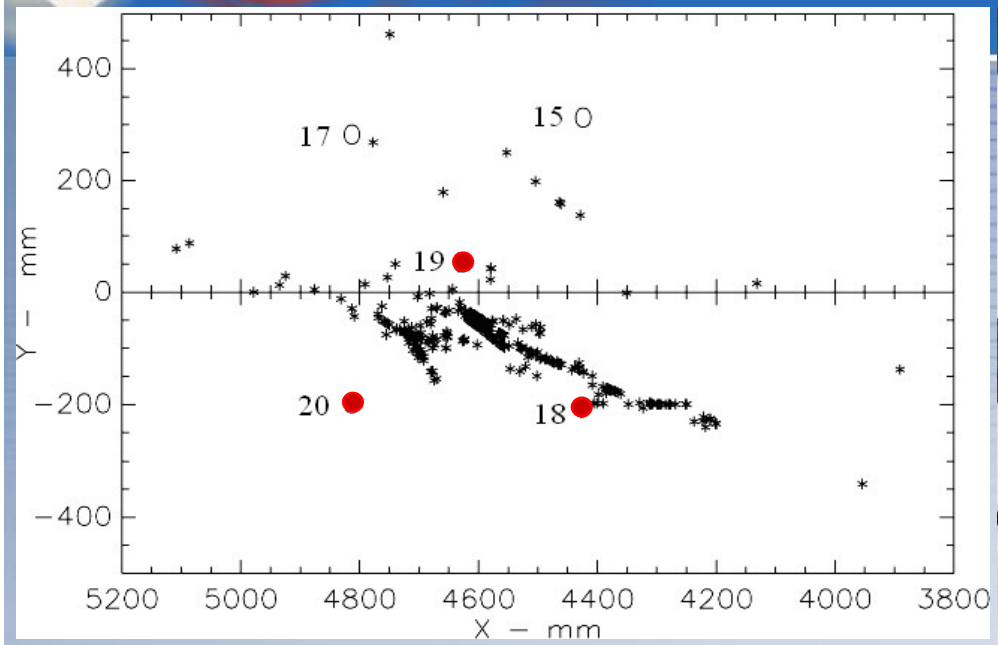
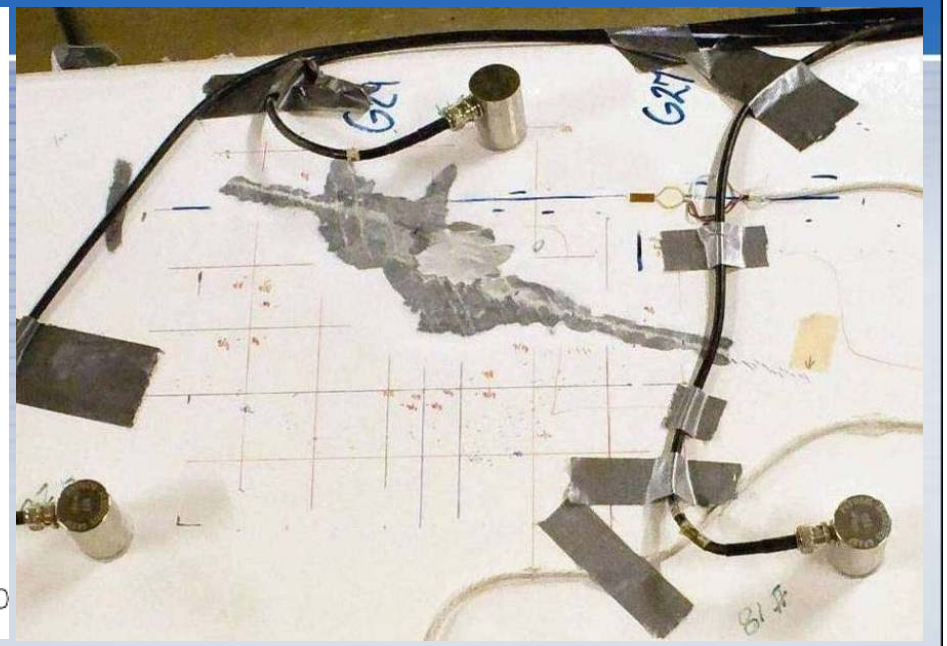
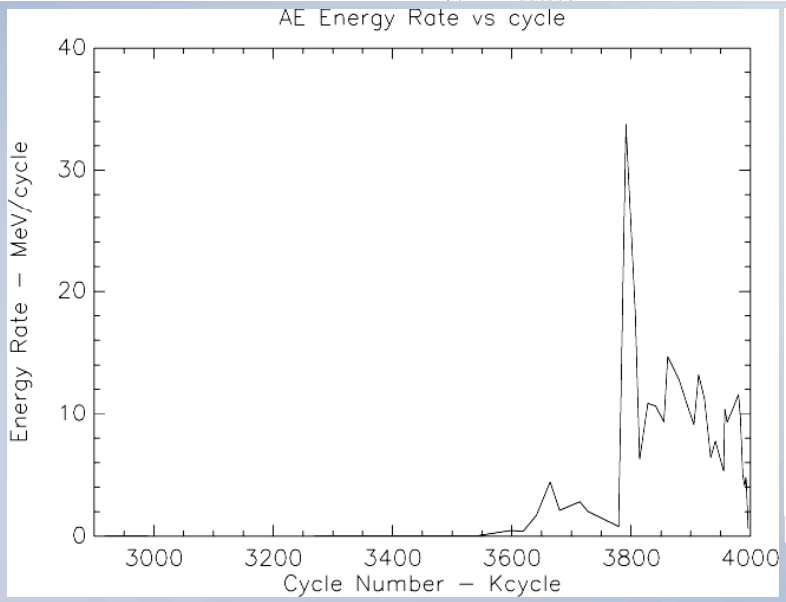
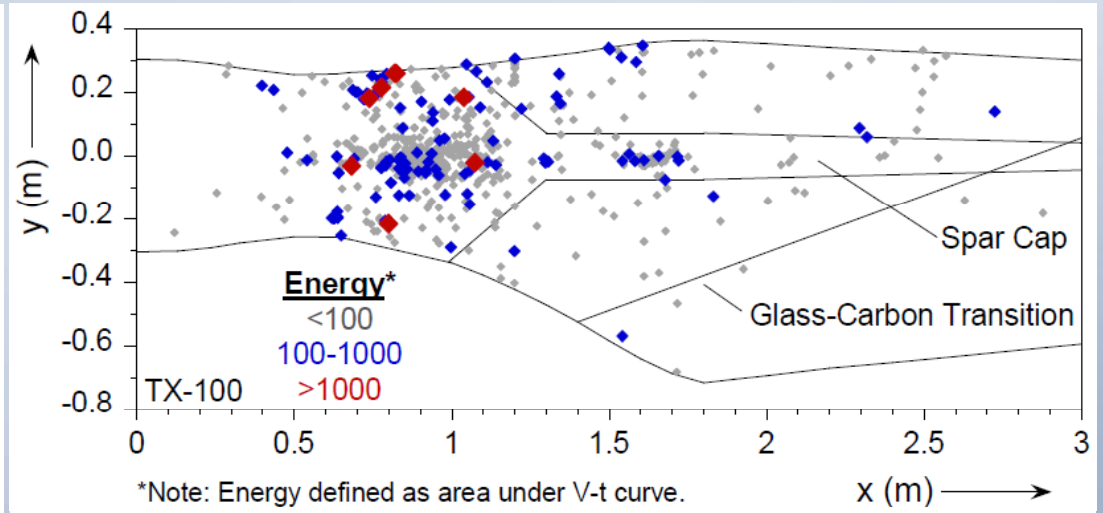
Acoustic Emission NDT



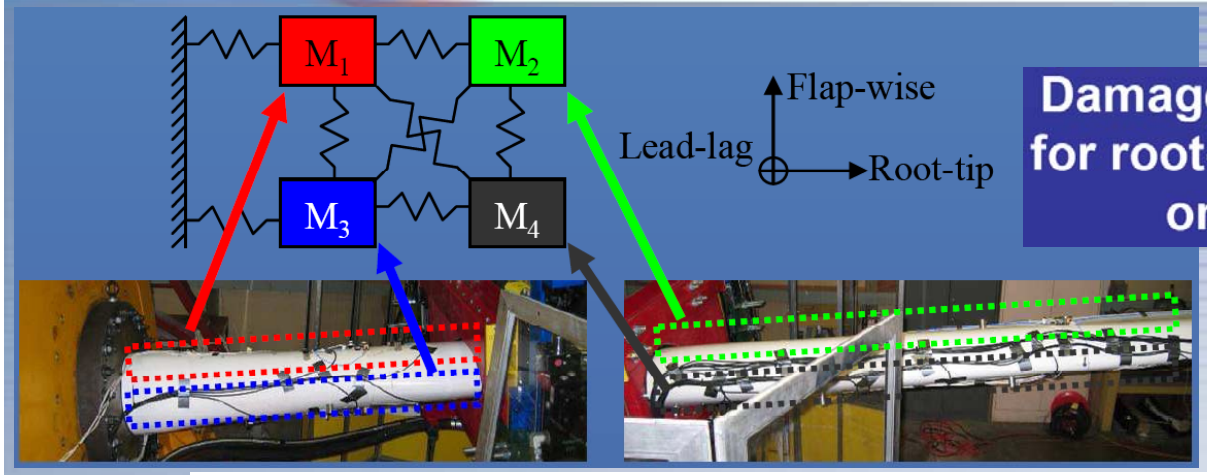




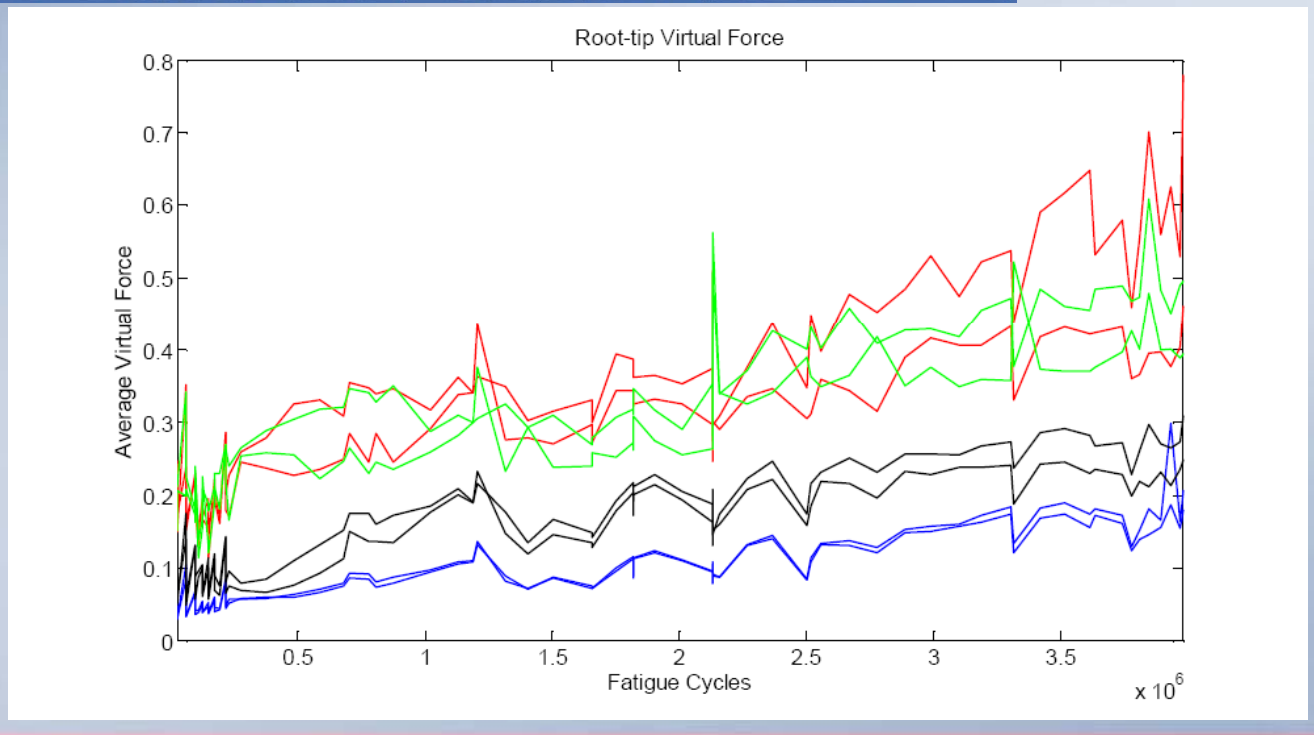


Source: Paquette, "Structural Testing of 9 m Carbon Fiber Wind Turbine Research Blades "

Active Damage Detection using Accelerometry



Damage growth was most significant for root-tip in-plane damage detection on the high-pressure side.



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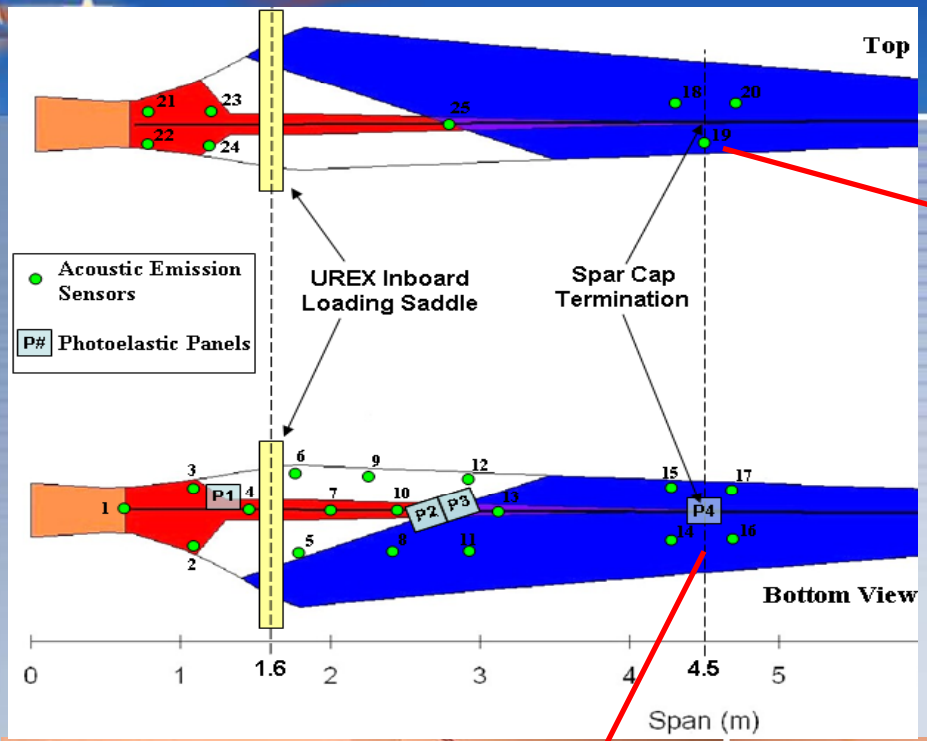
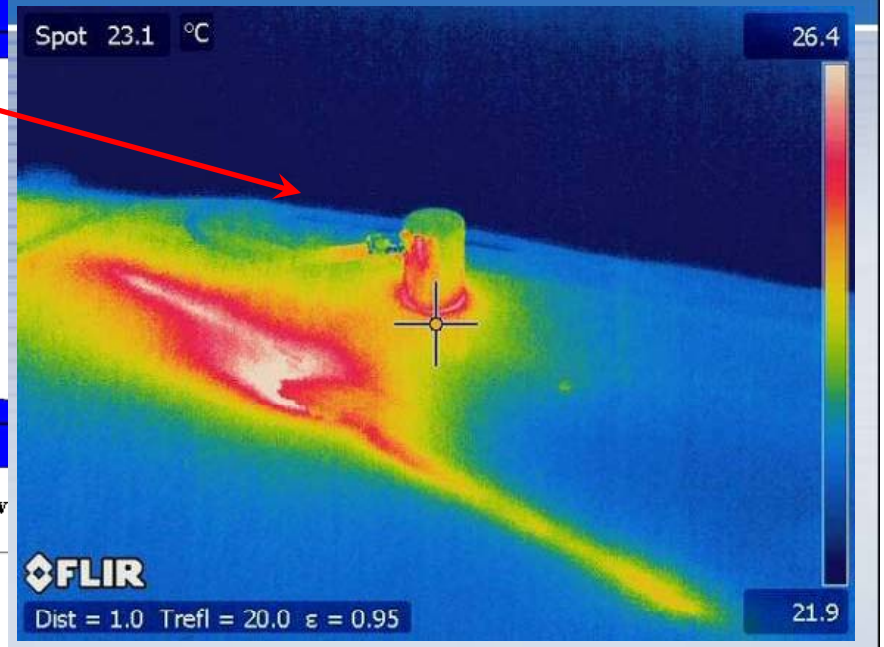
Photoelastic and Infrared Thermography





Shot at maximum load: maximum compression load on lower surface, maximum tensile load on upper surface.

Shot at minimum load: minimum compression load on lower surface, minimum tensile load on upper surface.

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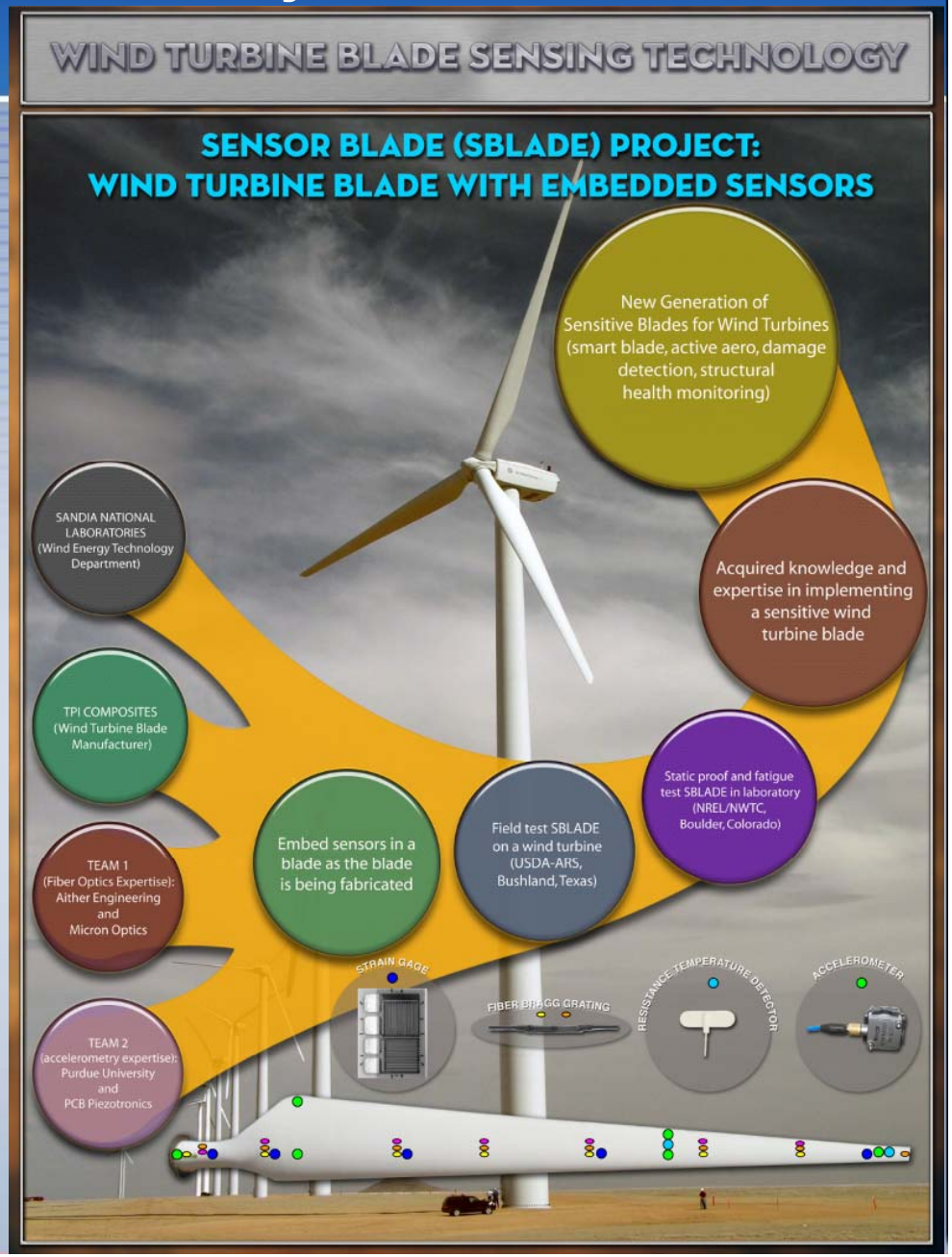
Sandia Sensor Blade Project

Goal: **Increase the viability of wind energy by implementing sensing technologies in blades to enable advance wind turbine control strategies**

Approach:

- Submit a competitive solicitation
  - Implement sensing technologies in a blade
  - Obtain operational loads and blade shape
  - Static and fatigue test blade to failure
  - Sensor system reliability
  - … quickly



Sensor Blade Team

Mark Rumsey, Joshua Paquette and Wesley Johnson – Sandia National Laboratories (Wind Energy Tech. Dept.)

Key colleagues in the department

Jason Kiddy and Chris Baldwin – Aither Engineering, Inc.

Sensor Blade shape using embedded fiberoptic-based strain sensors

Alan Turner and Tom Graver – Micron Optics, Inc.

Sensor Blade operational loads and temperature distribution using surface mounted fiberoptic-based sensors

Jonathan White and Douglas Adams – Purdue University

Sensor Blade loads, shape, and Structural Health Monitoring using accelerometry

Steve Nolet and Derek Berry – TPI Composites, Inc.

Sensor Blade manufacture in an open-shop floor environment

Jeff Carlson and Kevin Brink – Sandia National Laboratories (Energy Systems Analysis Dept.)

Sensor Blade tip deflections using processed video images

Nolan Clark, Adam Holman, Byron Neal and Donnie Cagle – USDA-ARS

Sensor Blade field test on an operational wind turbine

Scott Hughes, Jeroen van Dam and Mike Jenks – NREL/NWTC

Sensor Blade static and fatigue tests in the laboratory

Sensor Blade Project
(Sequence of Events)

- **Build a Sensor Blade (TPI Composites, Inc., Warren, Rhode Island)**
  - **Incorporate sensors in a blade during blade manufacture**
  - **Sensor list:**
    - Embedded FBG sensors (strain and temperature, blade shape)
    - Inner-surface mounted FBG sensors (strain and temperature, loads)
    - Inner-surface mounted accelerometers (blade shape, loads, SHM)
    - Metal foil strain gages (strain, loads)
    - RTD (temperature)
    - Streaming video on rotor (blade shape)

- **Field Test Sensor Blade (U.S. Department of Agriculture – Agriculture Research Service, Bushland, Texas)**
  - **On-the-ground checkouts and calibrations**
  - **In-the-air checkouts and calibrations**
  - **Obtain sensor datasets, measure loads and blade deflections during turbine operation**
  - **Real-time video monitoring**

- **Static and Fatigue Test Sensor Blade (National Renewable Energy Laboratory / National Wind Technology Center, Boulder, Colorado)**
  - **AE NDT and SHM**
  - **Static Proof Test**
  - **Fatigue test to SBlade failure**

- **Analyze datasets and report results**

Thank You!

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