2008 Wind Turbine Blade Workshop

Sensor Projects at Sandia National Laboratories

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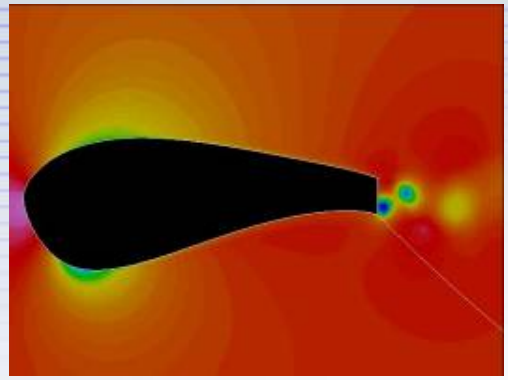
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

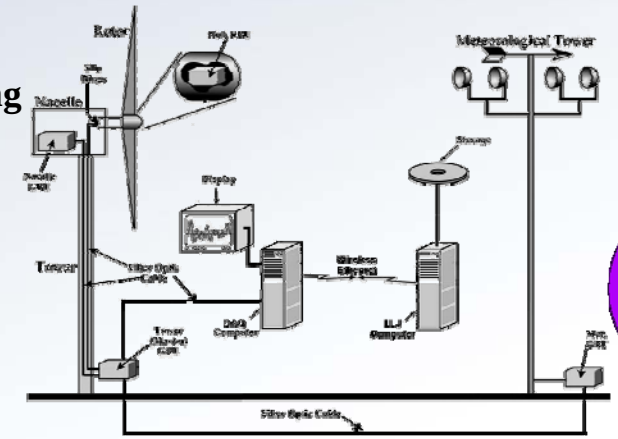
Presentation Outline

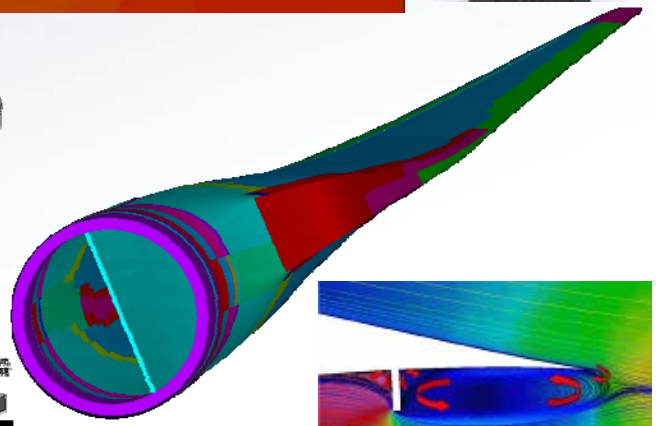
- **Background - Our Drivers and Opportunities for Sensors**
- **Sensor Blade Project**
- **Future Thoughts**

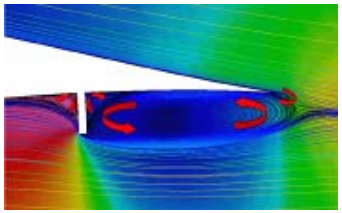
Wind Energy Technology

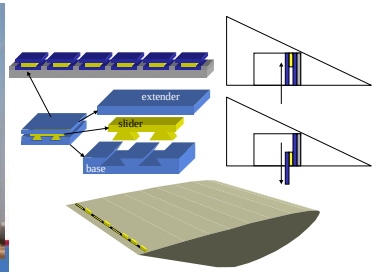
- **Blade Technology**
  - Materials and Manufacturing
  - Structural, Aerodynamic, and Full System Modeling
  - Sensors and Structural Health Monitoring
  - Advanced Blade Concepts
  - Lab - Field Testing and Data Acquisition
- **System Reliability**
  - Industry Data Collection
  - Improve reliability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











Wind Energy Technology

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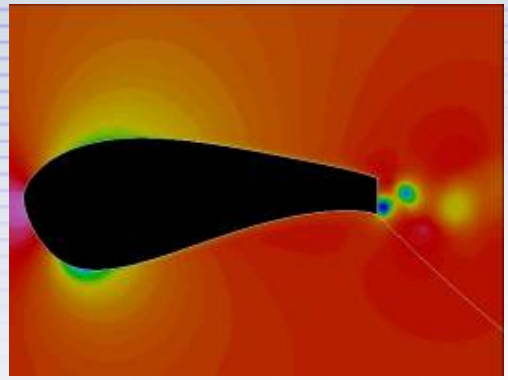
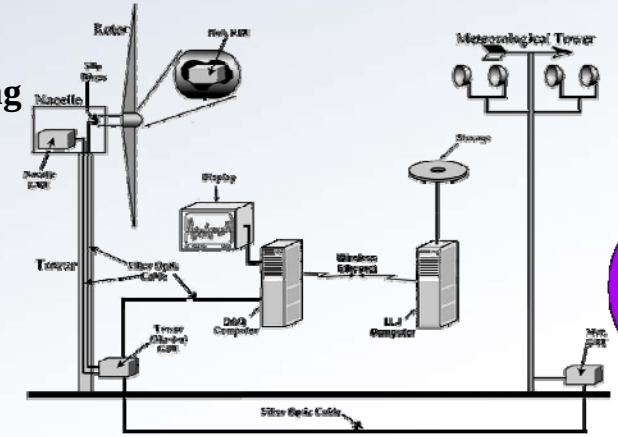
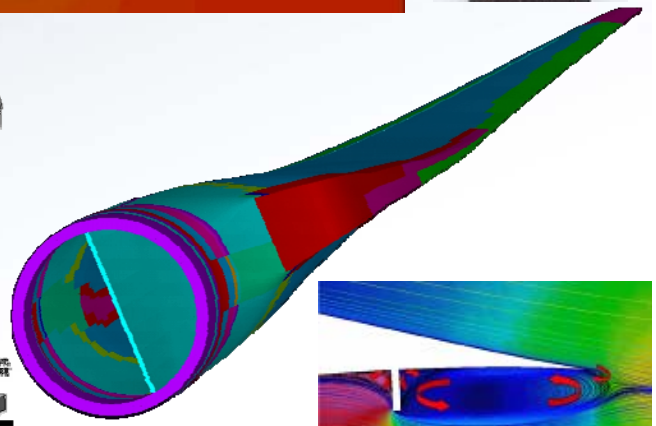
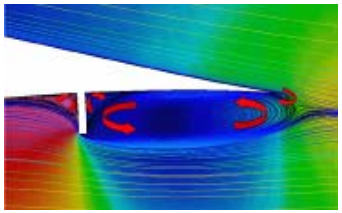
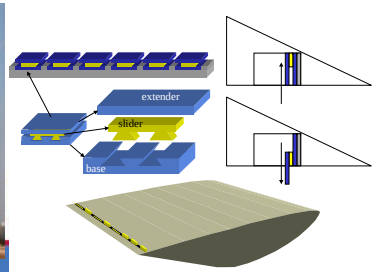








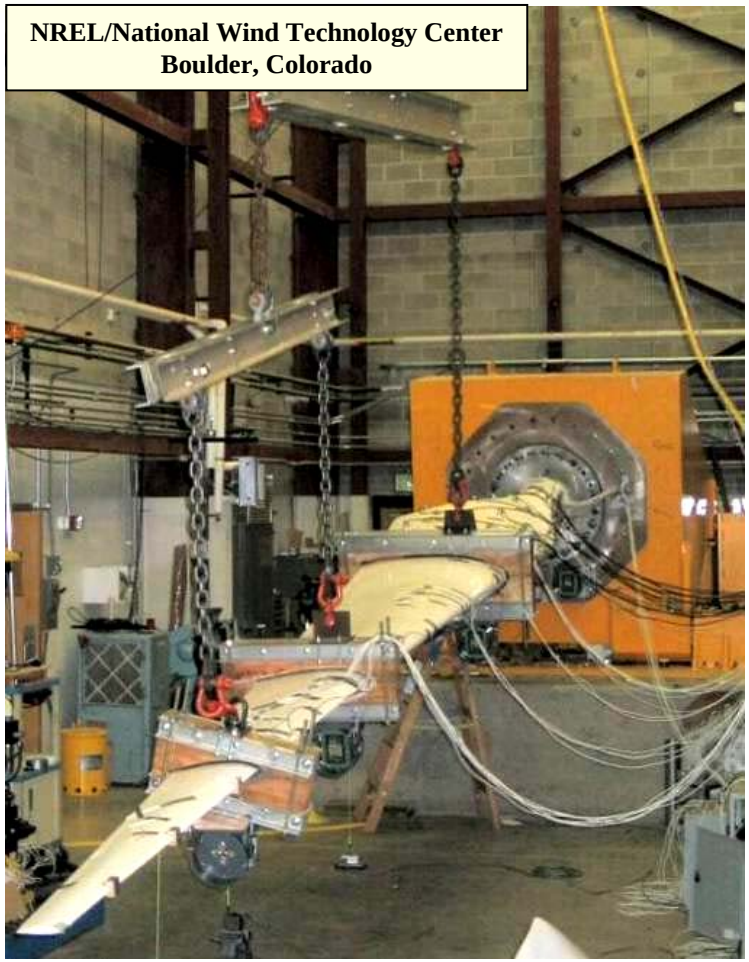


Our Drivers for Sensors

Utilize diagnostic tools in support of Wind Energy Technology R&D

Sandia National Laboratories
Albuquerque, New Mexico

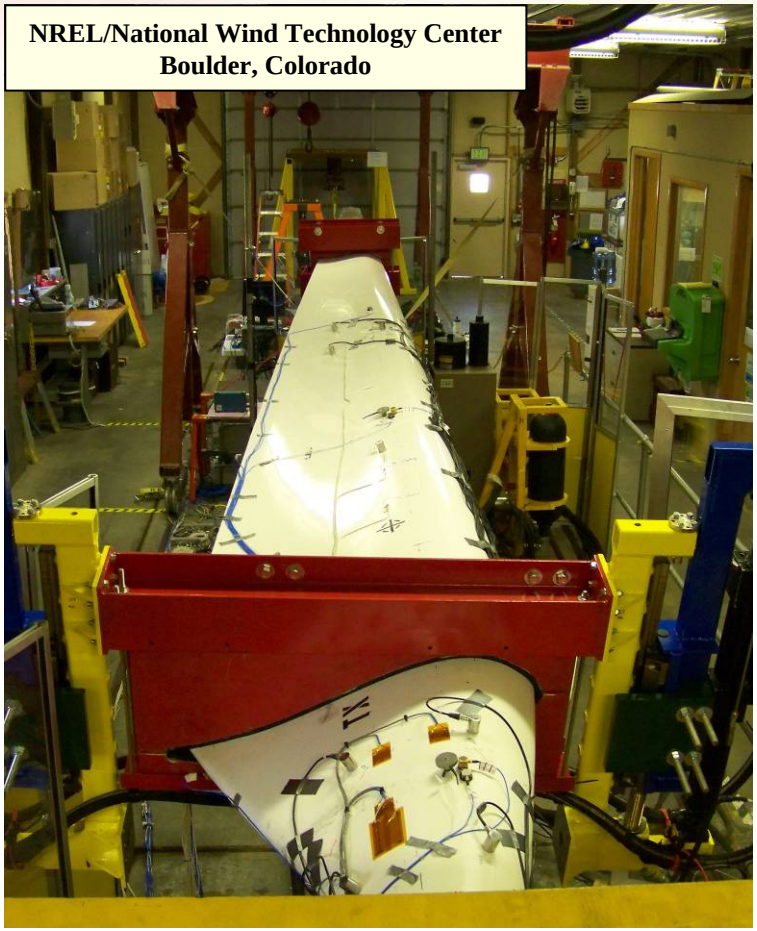
NREL/National Wind Technology Center
Boulder, Colorado

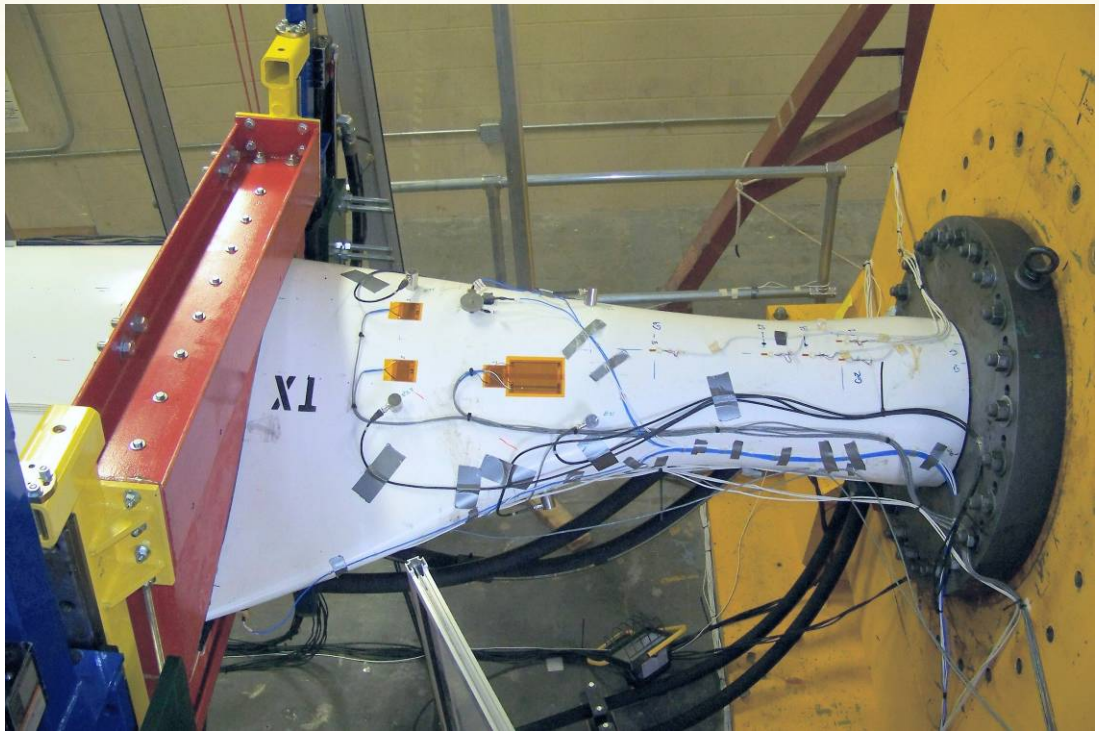


SNL and USDA-ARS
Wind Energy Test Site
Bushland, Texas

Our Drivers for Sensors - continued

NREL/National Wind Technology Center
Boulder, Colorado





Sensing Opportunities

Current location of sensors on a utility size wind turbine

- Nacelle – lots
- Tower Base – lots
- Blades – **few to no sensors!**

Desire for real-time blade sensing

- Maximize structural and aero efficiency
- Advanced controls strategies
- Damage detection and Structural health monitoring
- Increase reliability and energy capture

Goal is a Smart Wind Turbine Structure

Horns Reef wind farm in Denmark

Wind turbine
Manufacturer: GE Energy
Power Rating: 1.5 MW
Tower Height: 80 meters
Blade Length: 34 meters
Blade Weight: 6 tons
Jose's Height: 1.8 meters

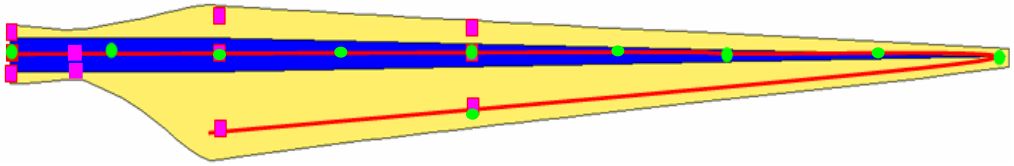
Colorado Green Wind Farm
Lamar, Colorado

Sensor Task at Sandia Labs
Wind Energy Technology Department

- **Fully anticipate advanced control strategies**

- **Address Sensor-in-Blade Issues**
  - **Incorporation** (egress/ingress, surface-mount/embed, manufacturing, maintenance accessibility, material compatibility, costs)
  - **Reliability** (sensor – yes, sensing system – ?)

- **Sensor Blade (SBlade) Project**



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

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Sensor Blade (SBlade) Project

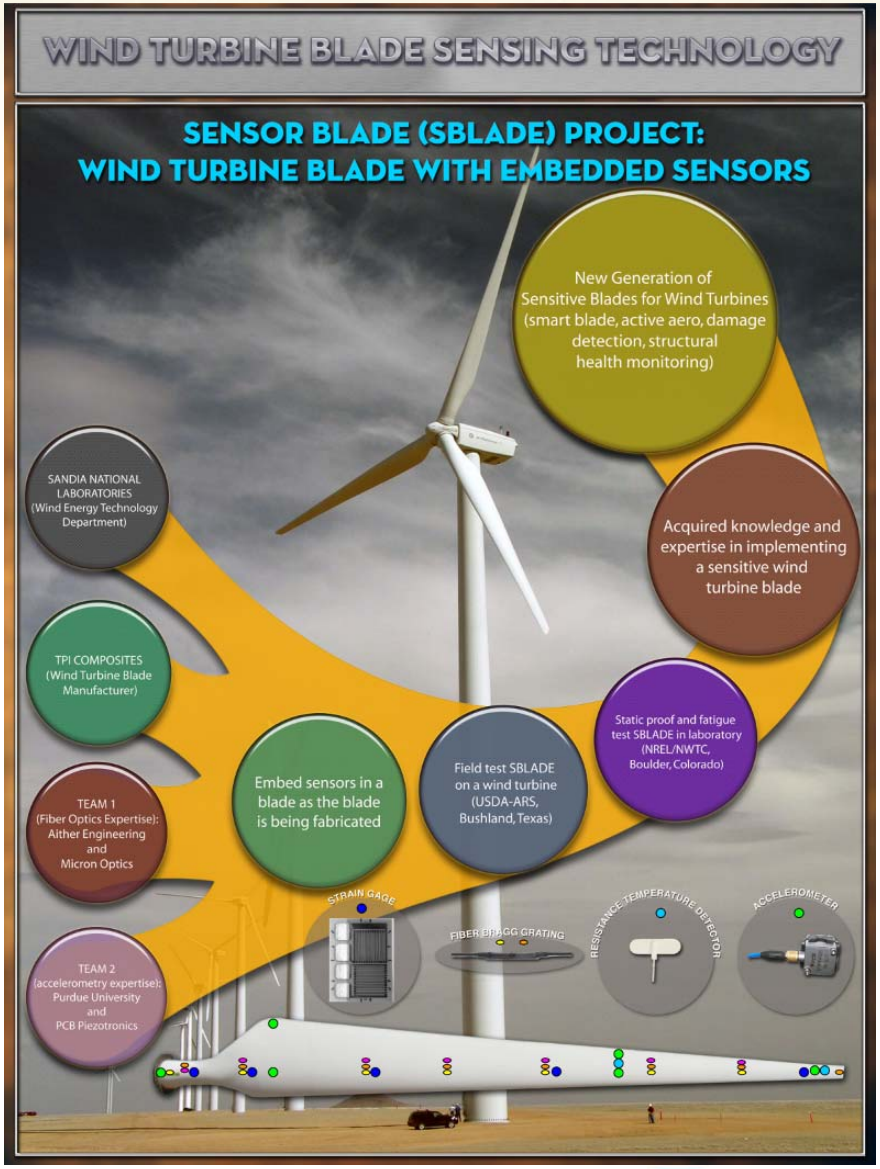
Goal: **Increase the viability of wind energy by implementing sensing technologies in blades to enable advance wind turbine control strategies**

Challenges:

- Implement sensing technologies in blades to enable advance control strategies and structural health monitoring
- Obtain operational loads and blade shape
- Sensor system reliability

Opportunities:

- New markets for sensing systems suppliers
- Increased wind turbine capability, reliability and availability
- Decrease the cost of energy from the wind



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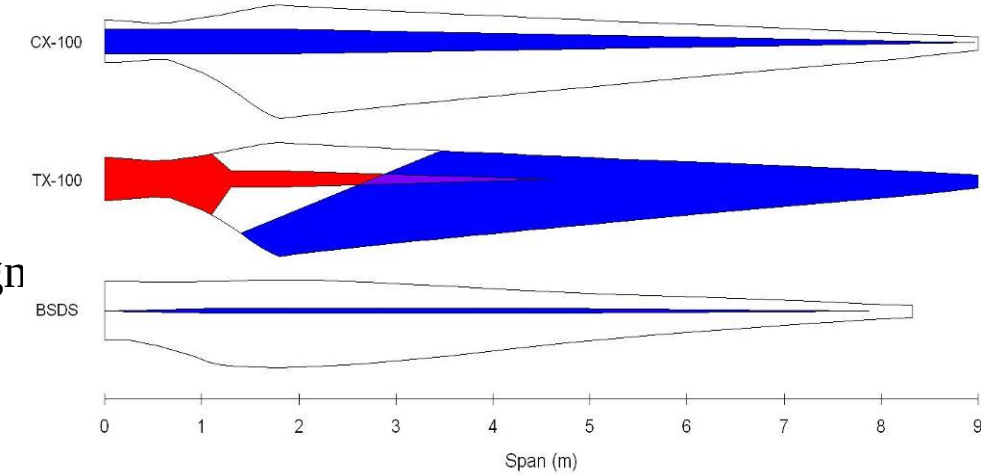
Sensor Blade is a CX-100 Blade with Sensors

- **Prototype Sub-scale Blades Manufactured (9 meters)**
  - **CX-100**
    - Carbon spar cap
    - Glass skin and shear web
  - **TX-100**
    - Carbon triax in skin for bend-twist coupling
    - Constant spar cap thickness
  - **BSDS (Blade System Design Study)**
    - Flatback airfoils
    - Carbon spar cap
    - Slenderized planform
    - Large scale architecture
    - Highly efficient structural design



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Sensor Blade (SBlade) Project

- **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**
  - **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**

TX-100 fabrication at TPI Composites

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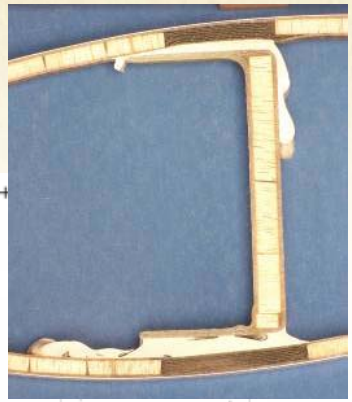
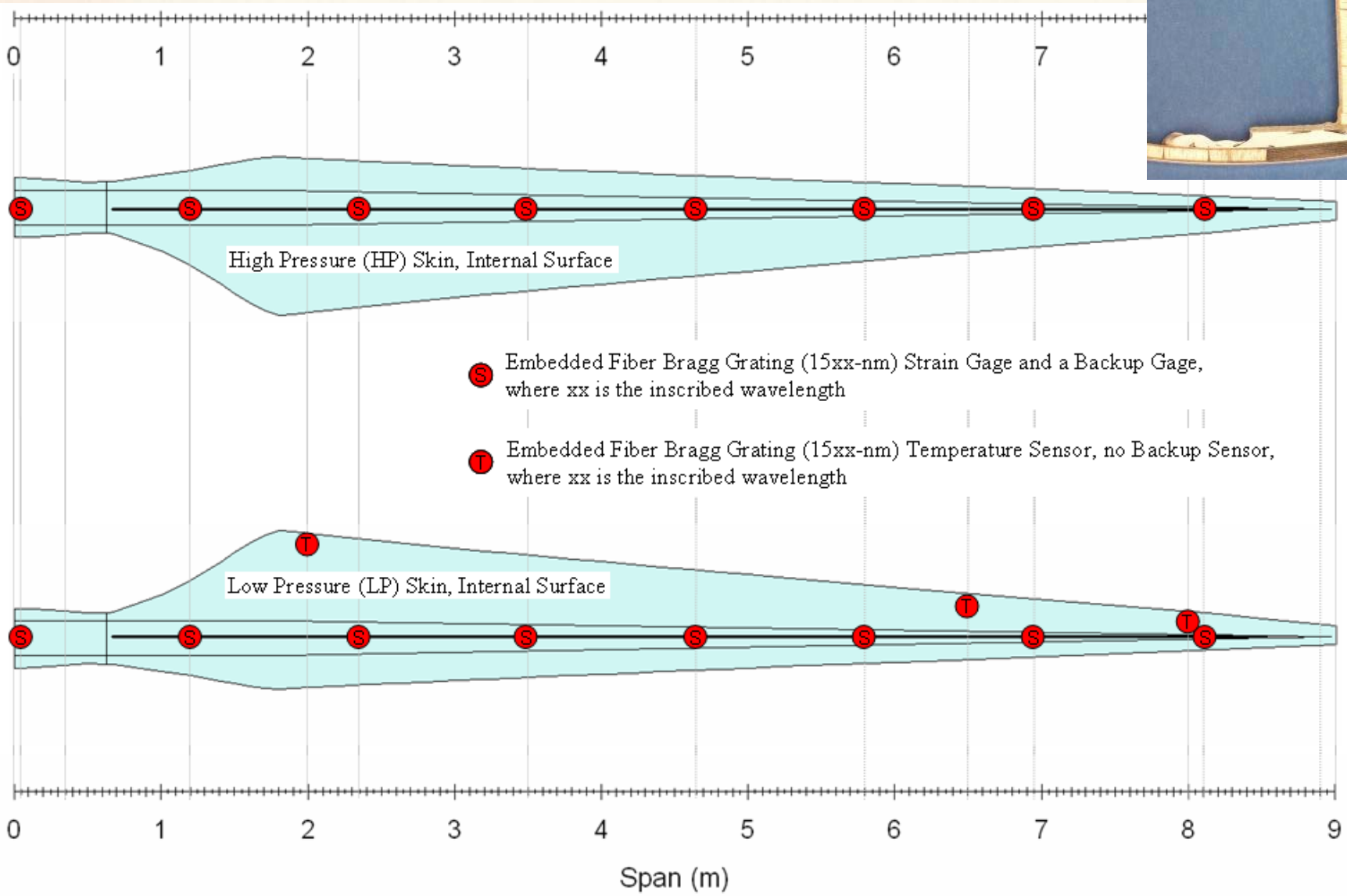
Embedded FBG Sensors in SBlade





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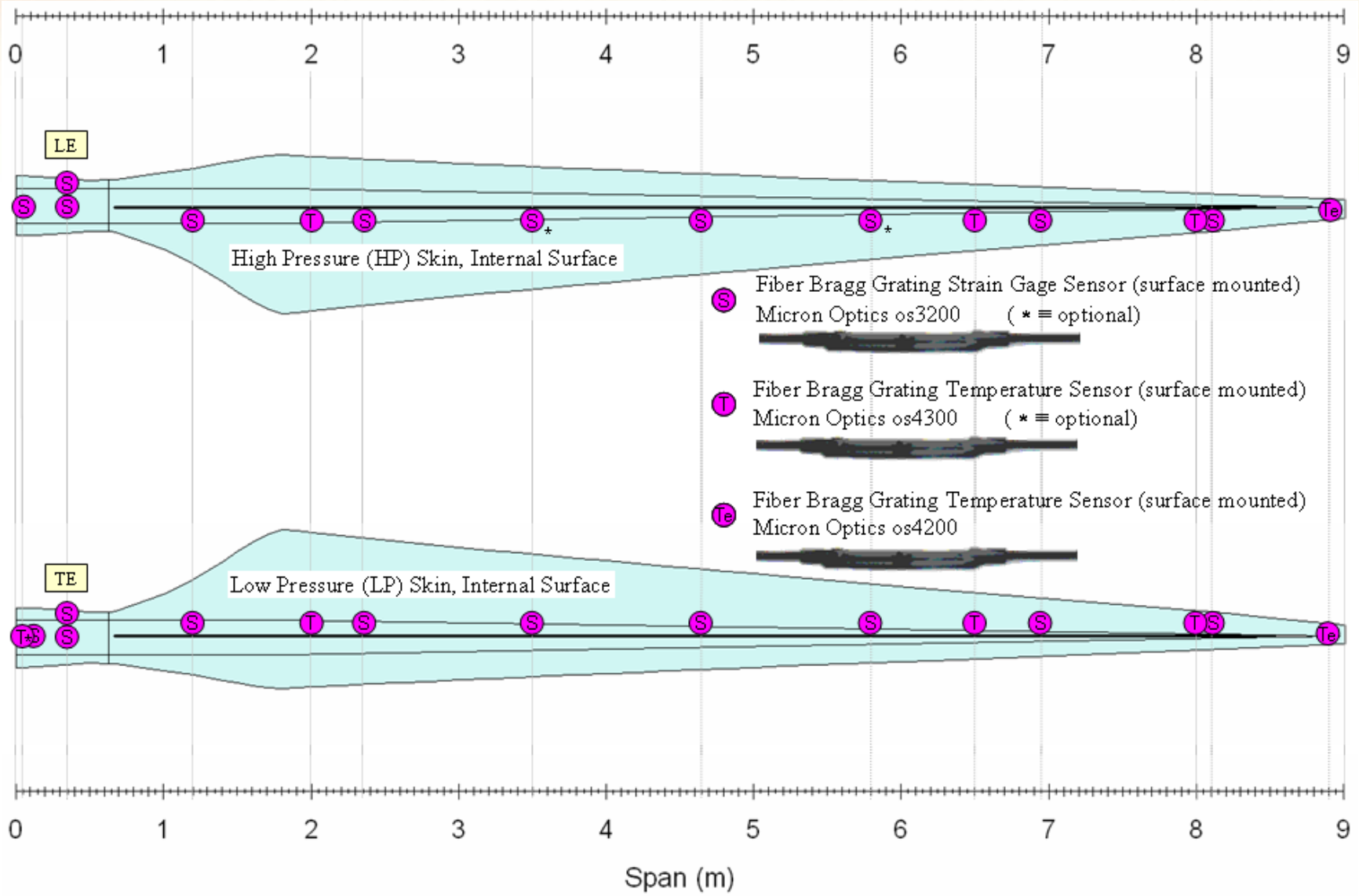
Inner-Surface mounted FBG in SBlade



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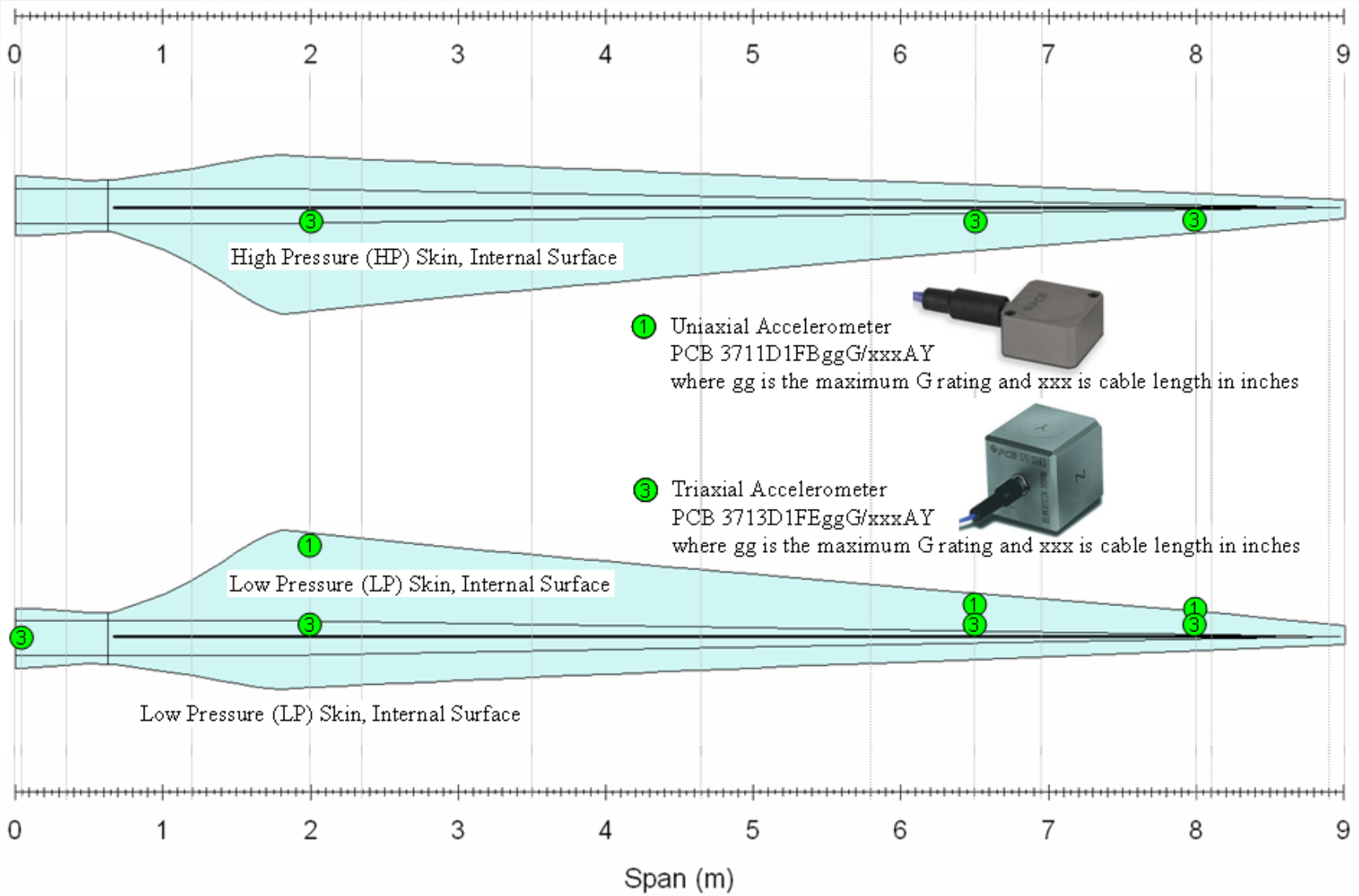
Inner-Surface mounted Accelerometers in SBlade



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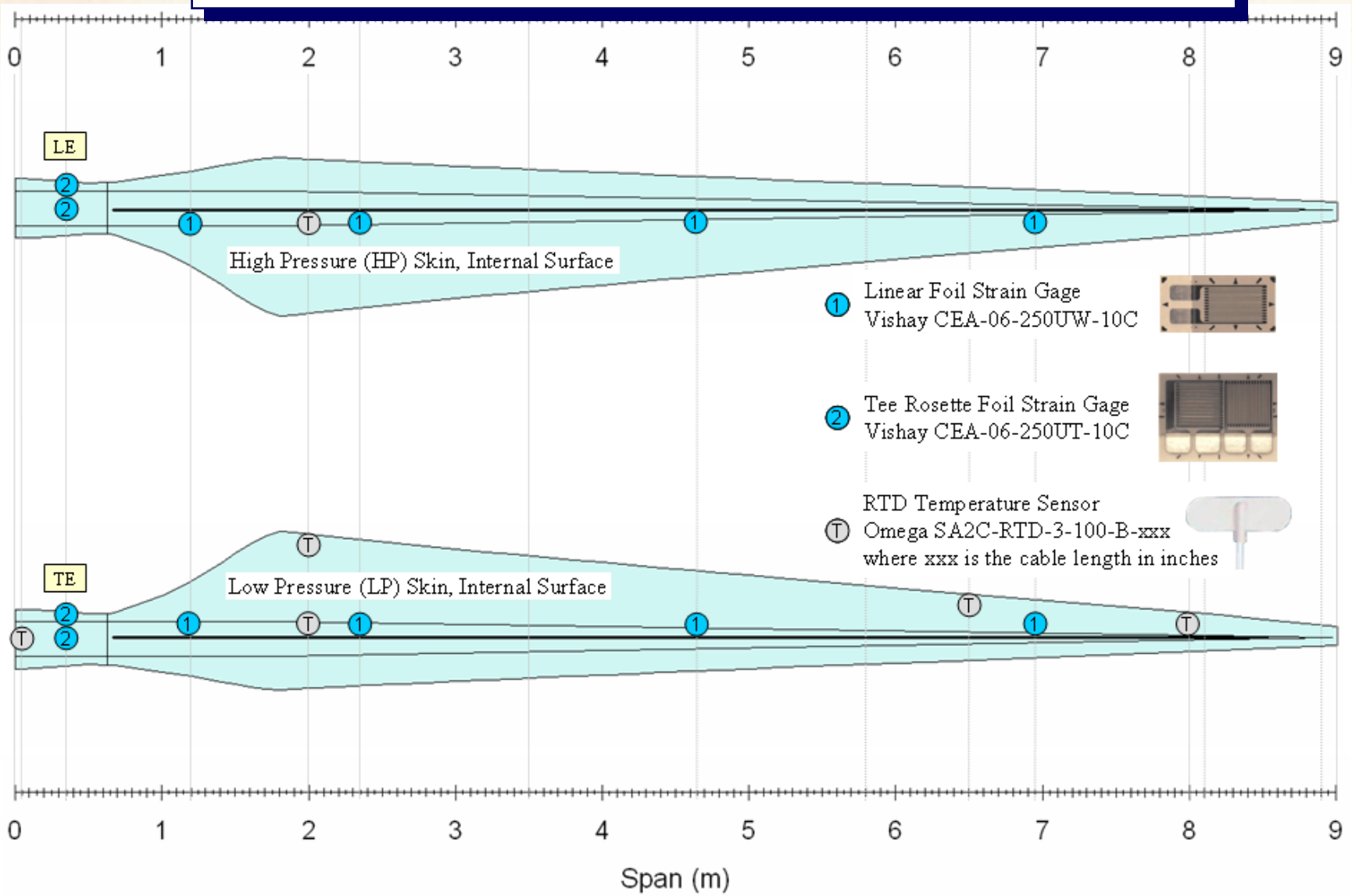
Inner-Surface mounted Foil Strain Gages and Resistance Temperature Detectors in SBlade



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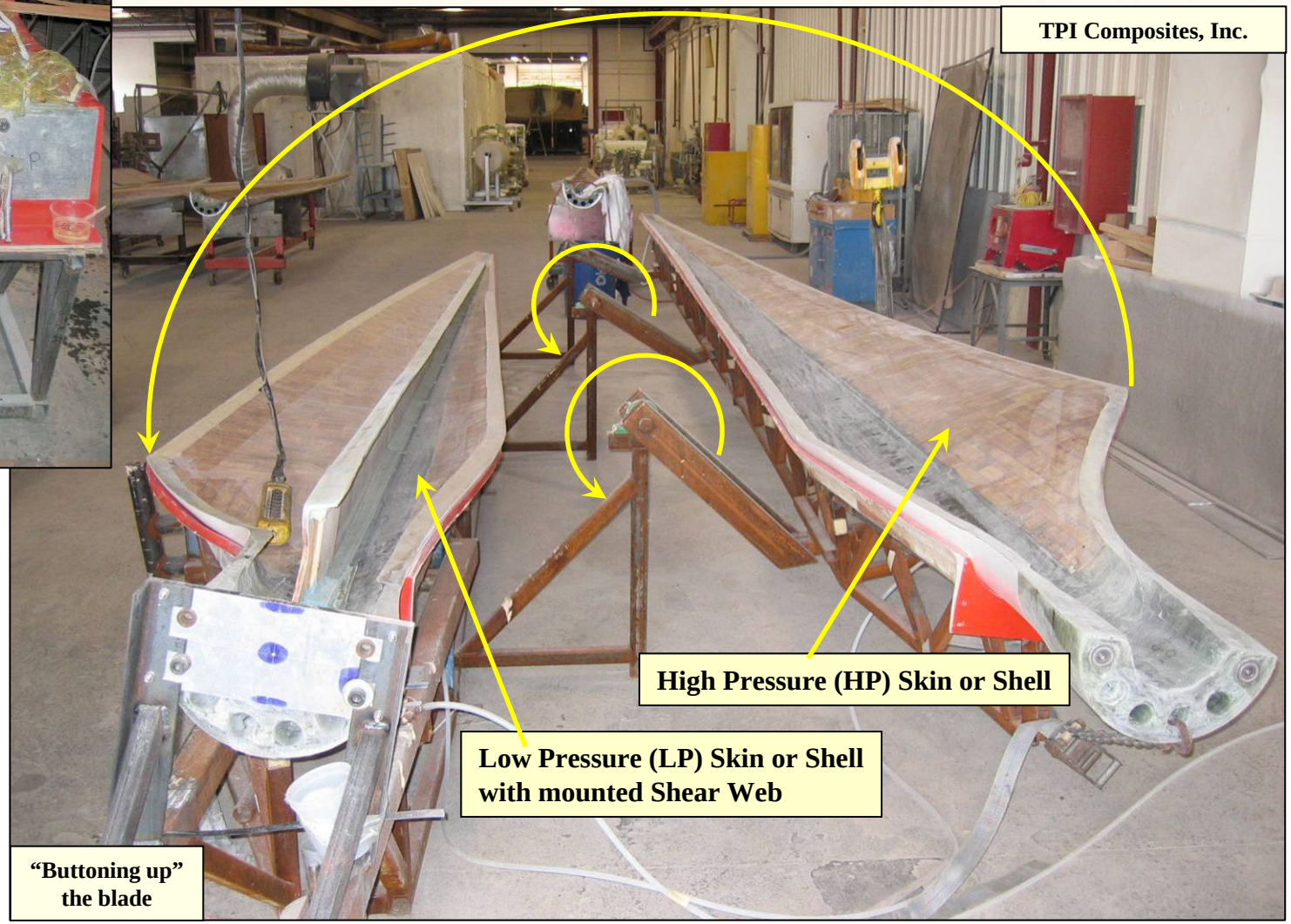
Sensor Blade Fabrication

Infusion and blade cure



"Buttoning up" the blade

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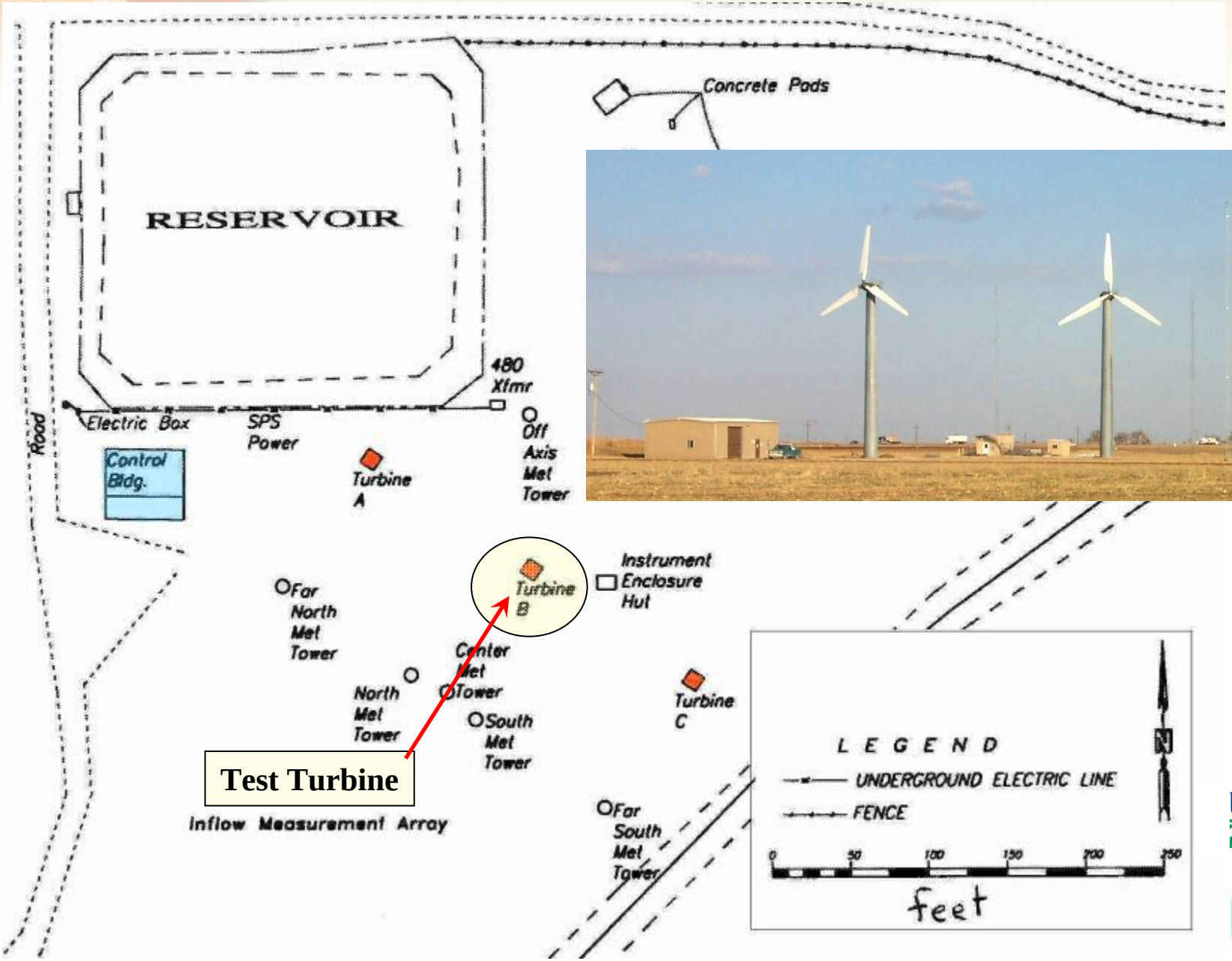
Field Test SBlade at USDA-ARS, Bushland Texas



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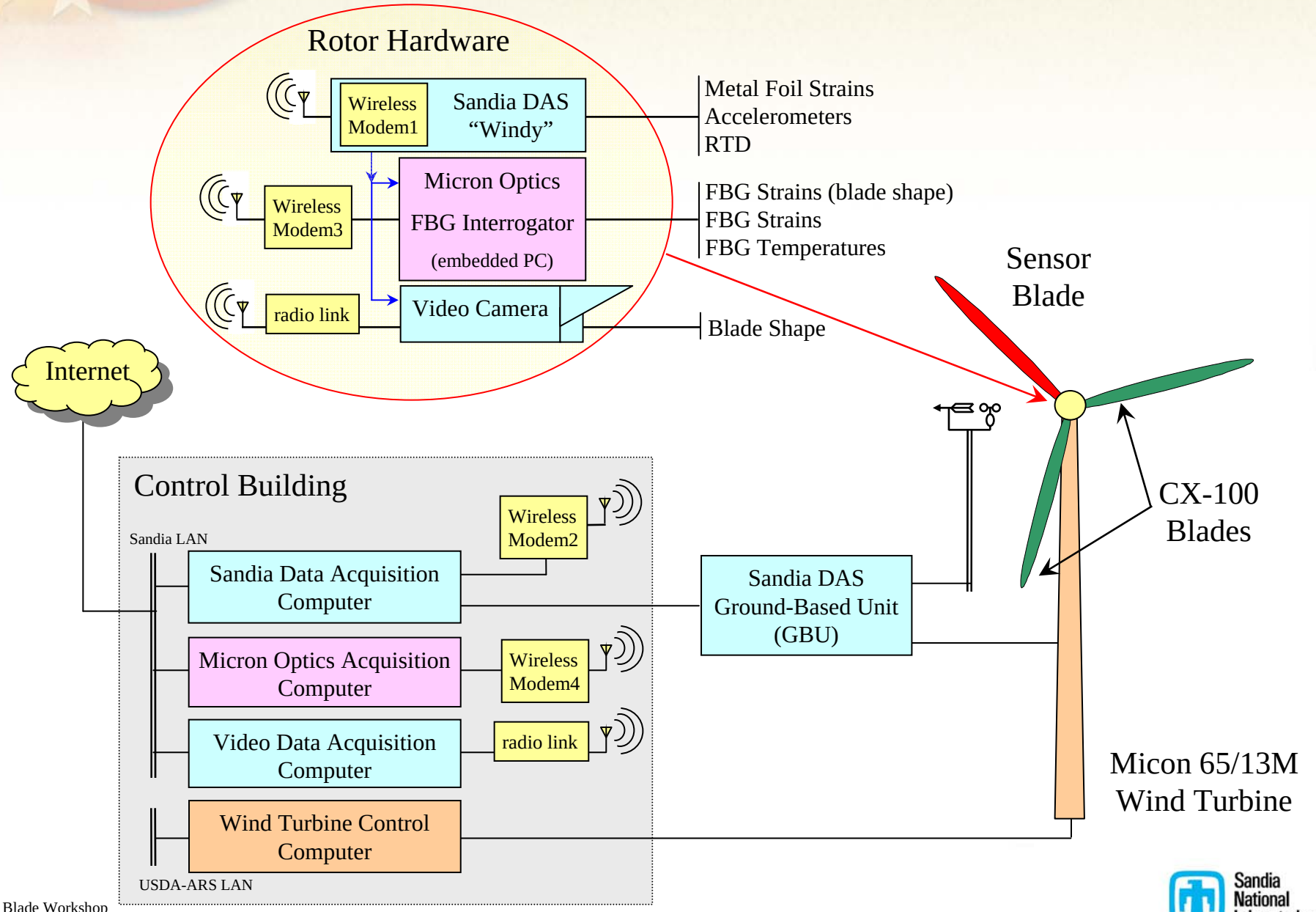


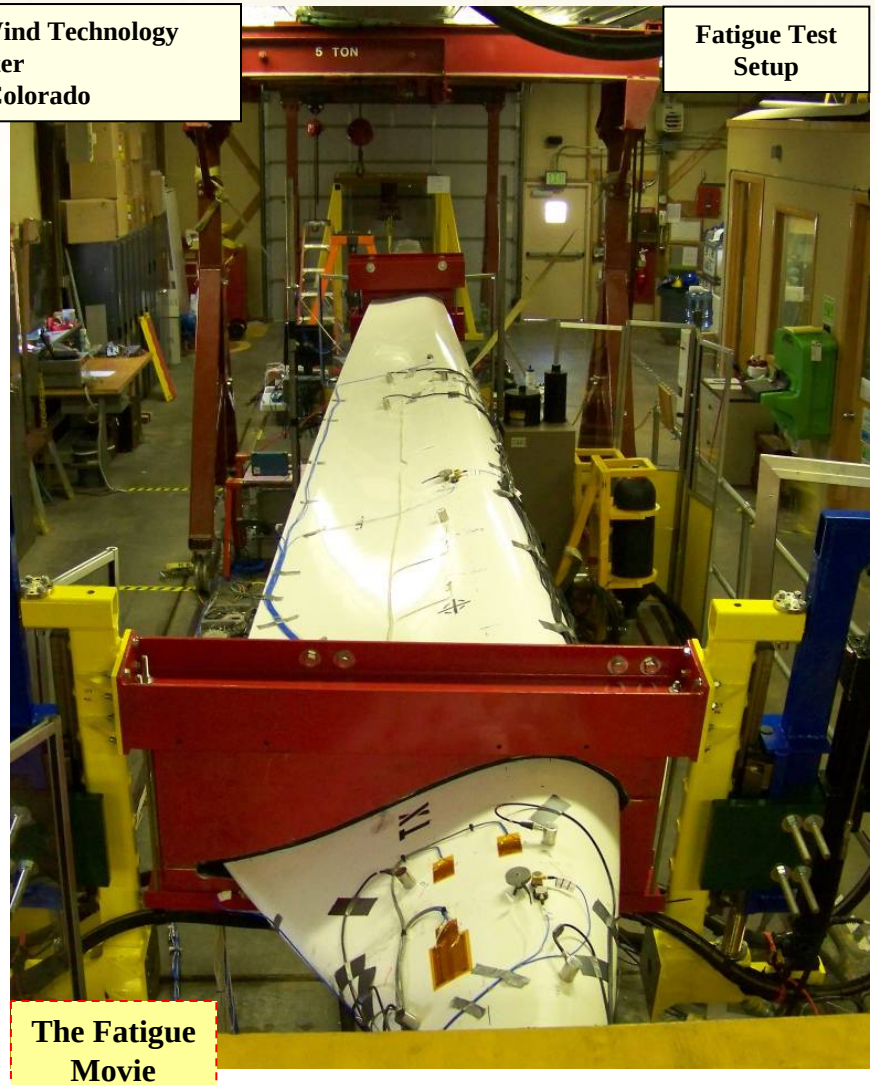
Lab Test the Sensor Blade at the NREL/NWTC

Static Test Setup

NREL/National Wind Technology Center
Boulder, Colorado

The Static Movie

Fatigue Test Setup



The Fatigue Movie

Future Thoughts

- **Learn from the Sensor Blade experience**
- **"Sensor Blade 2" –** Apply lessons-learned, monitor bond-lines, inflow sensors, angle of attack sensors, field DD and SHM techniques, smart sensors
- **Combine sensing techniques with new control strategies into prototype active aero control substructures** – Design, Simulate, Test and Evaluate
- **Continue looking for and evaluating new sensor/sensing technologies**

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Sensor Blade Team

Joshua Paquette and Wesley Johnson – Sandia National Laboratories (Wind Energy Technology Dept.)
Colleagues in crime

Jason Kiddy and Chris Baldwin – Aither Engineering, Inc.
Sensor Blade shape using embedded fiber Bragg grating strain sensors

Alan Turner and Tom Graver – Micron Optics, Inc.
Sensor Blade operational loads and temperature distribution using surface mounted fiber Bragg grating sensors

Jonathan White and Douglas Adams – Purdue University
Accelerometry-based Sensor Blade shape and estimation of operational loads (and Structural Health Monitoring)

Steve Nolet and Derek Berry – TPI Composites, Inc.
Sensor Blade manufacture and an open shop floor

Jeff Carlson – Sandia National Laboratories (Energy Systems Analysis Dept.)
Sensor Blade deflections using processed video images

Nolan Clark, Adam Holman, Byron Neal and Donnie Cagle – USDA-ARS
Field test Sensor Blade on an operational wind turbine

Scott Hughes, Jeroen van Dam and Mike Jenks – NREL/NWTC
Static and fatigue test Sensor Blade in the laboratory