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Title: Full-scale fatigue tests of CX-100 wind turbine blades. Part I - testing

Author(s): Stuart G. Taylor *,**
Kevin M. Farinholt*
Gyuhae Park*
Curtt M. Ammerman*

* Los Alamos National Laboratory, Los Alamos, NM
** University of California, San Diego, La Jolla, CA

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Full-scale fatigue tests of CX-100 wind turbine blades. Part I - testing

Kevin. M. Farinholt[1], Stuart. G. Taylor[1,2],
Gyuhae Park[1], Curtt M. Ammerman[1]

1. Los Alamos National Laboratory, NM, USA
2. University of California, San Diego, CA, USA

SPIE Smart Structures/NDE
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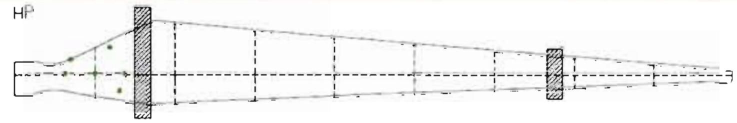
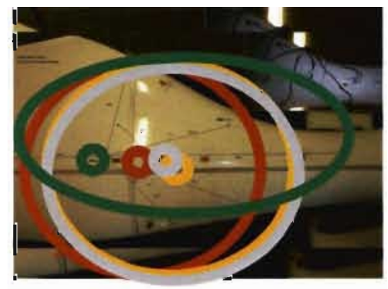
Abstract

- This paper overviews experimental methods for several structural health monitoring (SHM) methods applied to two 9-meter CX-100 wind turbine blades that underwent fatigue loading at the National Renewable Energy Laboratory's (NREL) National Wind Technology Center (NWTC). The first blade was a pristine blade, which was manufactured to standard specifications for the CX-100 design. The second blade was manufactured for the University of Massachusetts, Lowell with intentional simulated defects (primarily waviness and wrinkles) within the fabric layup. Each blade was instrumented with piezoelectric transducers, accelerometers, acoustic emission sensors, and foil strain gauges. The blades underwent harmonic excitation at their first natural frequency using the Universal Resonant Excitation (UREX) system at NREL. Blades were initially excited at 25% of their design load, and then with steadily increasing loads until each blade ultimately reached failure. Data from the sensors were collected between and during fatigue loading sessions. The data were measured over multi-scale frequency ranges using a variety of acquisition equipment, including off-the-shelf systems and specially designed hardware developed by Los Alamos National Laboratory. The hardware systems were evaluated for their aptness in data collection for effective application of SHM methods to the blades. The results of this assessment will inform the selection of acquisition hardware and sensor types to be deployed on a CX-100 flight test to be conducted in collaboration with Sandia National Laboratory at the U.S. Department of Agriculture's (USDA) Conservation and Production Research Laboratory (CPRL) in Bushland, Texas.

Presentation Outline

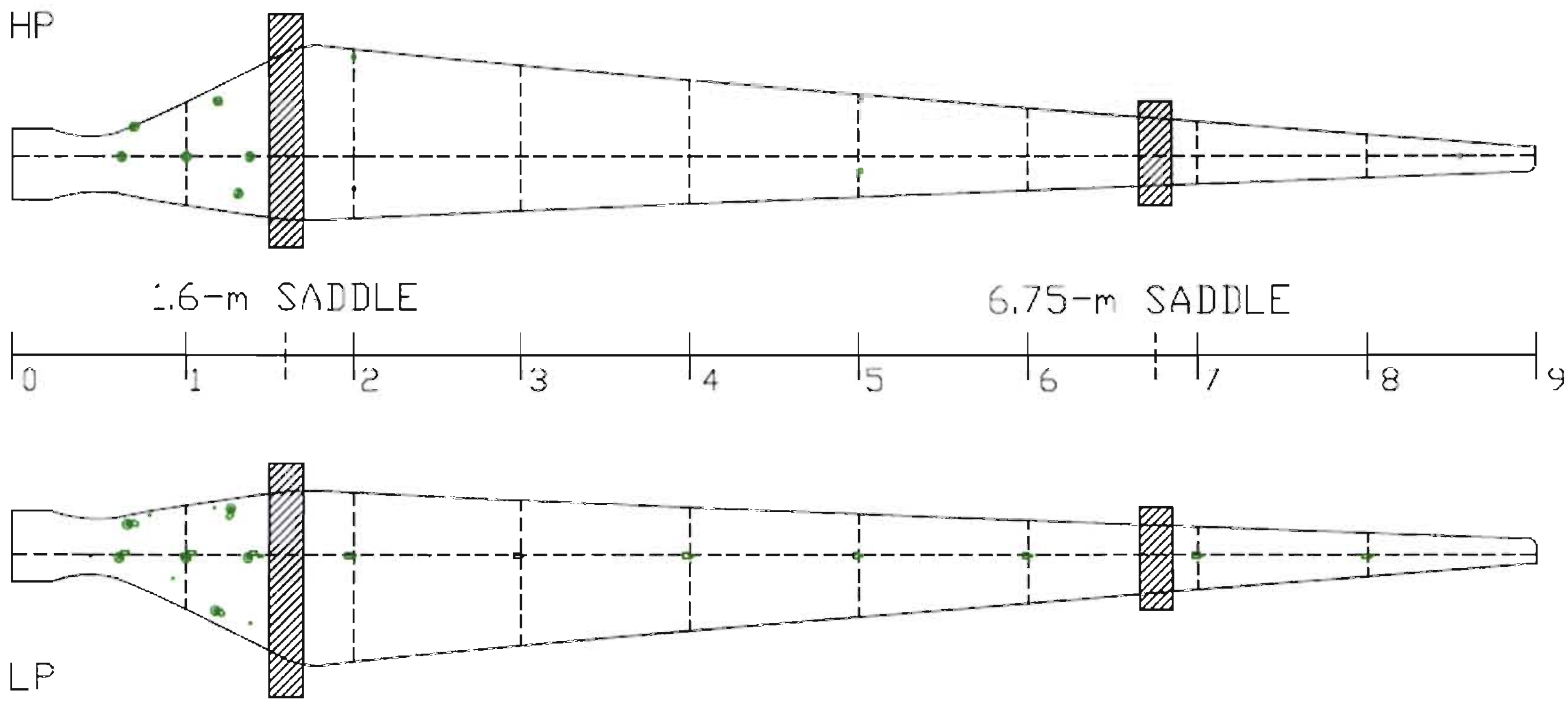


- CX-100 Wind Turbine Blade
- Fatigue Test Operation
- Sensing Systems Employed
- LANL Blade Sensor Arrays
- UMass Blade Sensor Arrays
- Testing Progress Timeline
- Ongoing and Future Work



The CX-100 Wind Turbine Blade

- 9-meters long
- Balsa wood frame
- Fiberglass Body
- Carbon Fiber Spar Cap
- Thick root section
- Saddles at 1.6, 6.75m



Fatigue Test Operation

- Fatigue test conducted at NREL's National Wind Technology Center.
- Excitation using Universal Resonant EXcitation (UREX).
- Moment Distribution Saddles at 1.6m and 6.75m
- Excitation at first natural frequency (1.8 Hz)
- Multiple Sensing and Diagnostic Systems Deployed

Active Sensing Systems

National Instruments

- **Active sensing capabilities up to 51.2kHz using MFC transducers**
- **Investigating signal transmission along the spar cap**
  - Transmission distances of 3-4m
  - Testing while blade is at rest, and under dynamic load

Bruel & Kjaer - LASER

- **Actively interrogating the CX-100 blade from 100-40,000 Hz**
  - Demonstrated detection capabilities using simulate damage in the laboratory
- **Two local sensor networks on the low pressure surface of the blade**
  - Transmission distances of 0.5-1m
- **Commercial DAQ system for Fourier analysis**

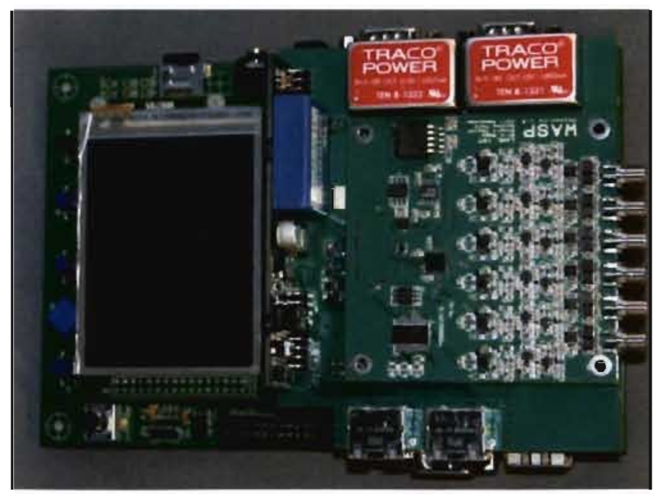
Active Sensing Systems

Metis – MD7 IntelliConnector

- **Using Lamb wave propagation at a sampling freq of 10 MHz.**
- **Damage causes distortion/ attenuation in paths**
- **Difficulties in selecting optimal frequency for fiberglass material**
  - Use 50-250 kHz at 25 kHz interval

LANL – Active Sensing Platform

- **Active/Passive sensing with 100 kHz bandwidth**
- **Multiple sensing modes**
  - Active, Passive, Impedance
- **Autonomous or web-driven data acquisition**
- **Higher (embedded) processing power**
- **Externally amplified excitation**



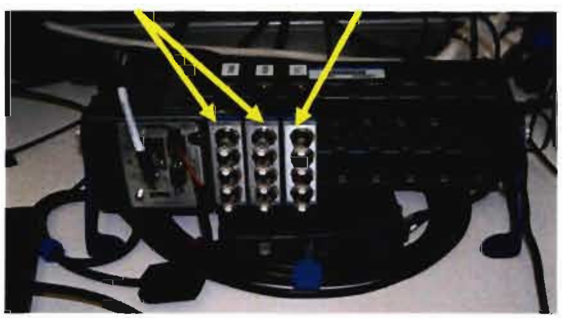
Passive/Diagnostic Sensing Systems

National Instruments - cRIO

- **Passive sensing at 1.6kHz**
  - Accelerometers
  - Piezoelectrics
  - Internal microphone
- **Commercial DAQ for embedded applications**

Banks 1-2 are configured for accelerometers.

Bank 3 is configured for PZT patches

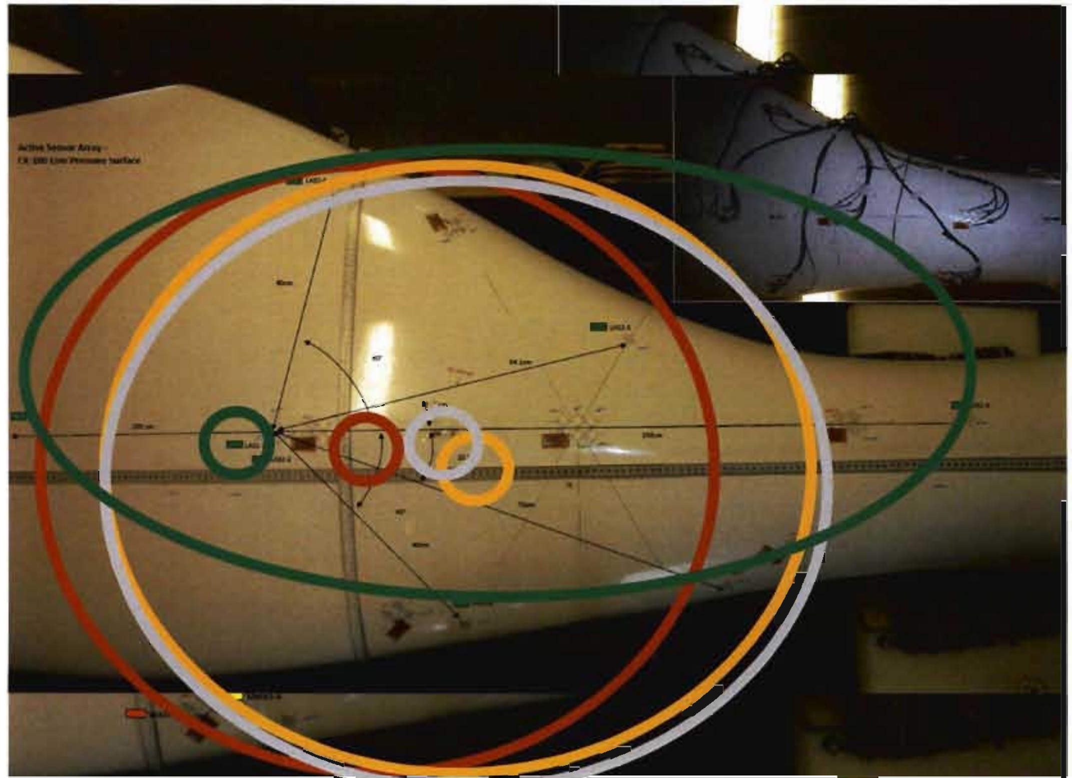


Sensor Diagnostics (HP4291A)

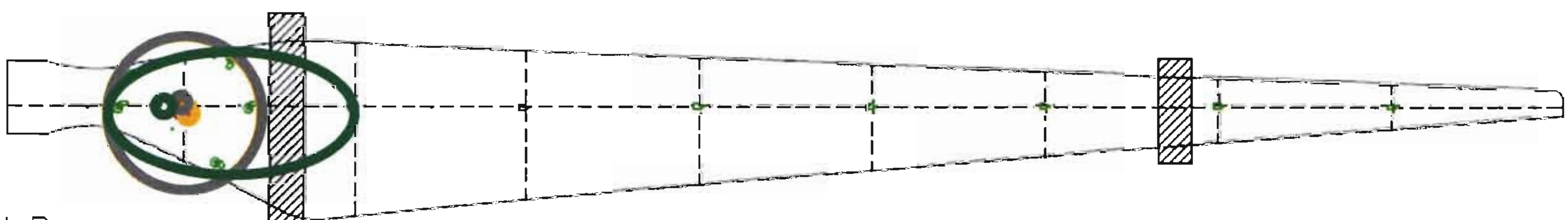
- **Impedance measurement sweeps from DC to 30kHz**
- **Imaginary part of Admittance can indicate sensor bond condition**
- **Measurements taken approximately once/week**

LANL Blade – Low Pressure Surface

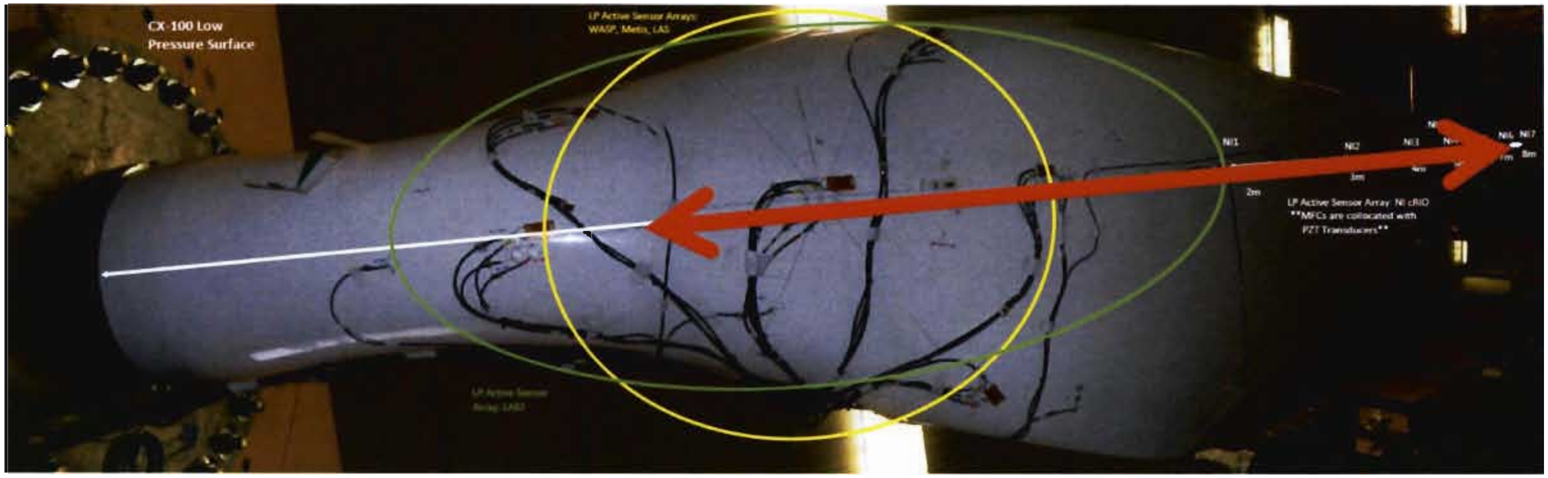
- **Active arrays on Low-Pressure Surface**
  - WASP-1
  - Metis-1
  - LASER (Inner, Outer)
- **The inner array observes a 0.75 m diameter region centered 1m from the root**
- **The outer array observes a 2m diameter region 1.5m from the blade root**

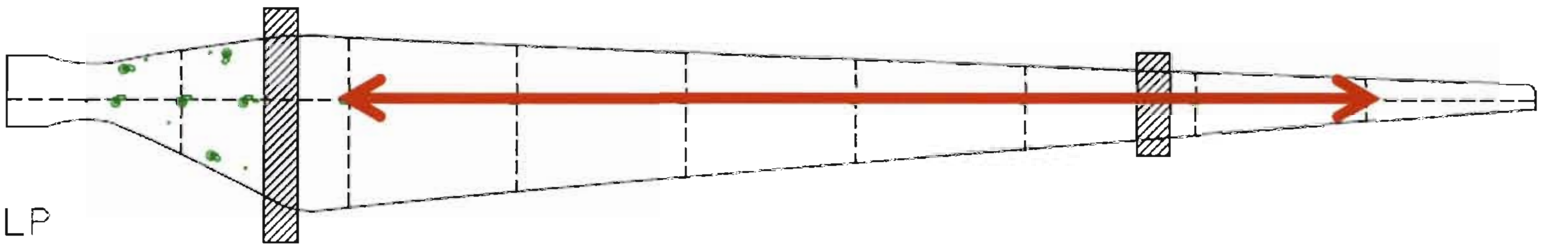


Low pressure surface transitional root area



LANL Blade – Low Pressure Surface

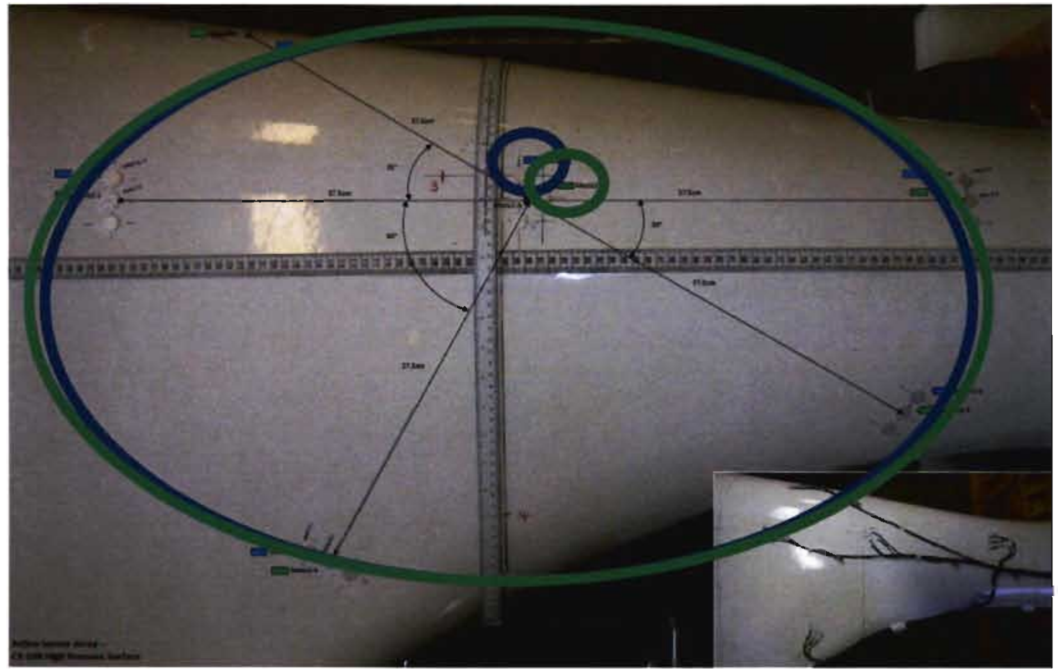




- **MFC transducers are used to excite the blade along the spar cap**
  - Sensors are positioned every meter from 2-8 m along the blade length
  - A single actuator is used to excite the blade at 5m.

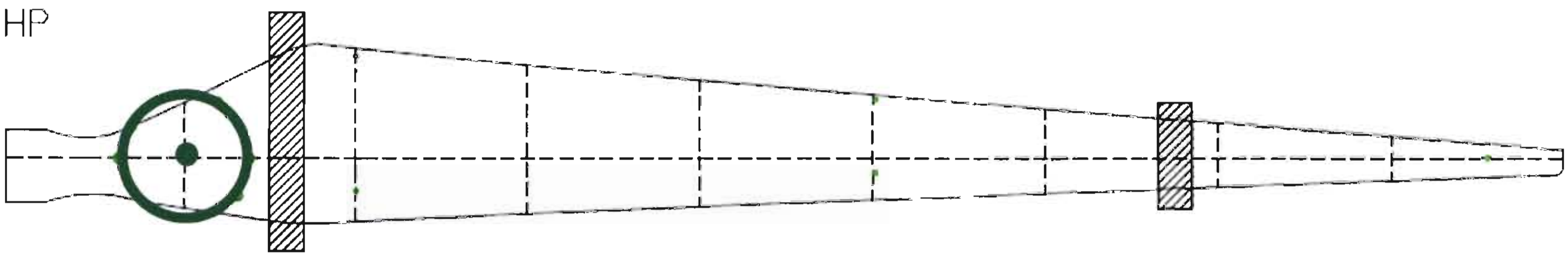
LANL Blade – High Pressure Surface

- **Active Arrays on High-Pressure Surface**
  - WASP-2
  - Metis-2
- **Each array relies on a centrally located actuator.**
  - Transmission distances are 0.37-0.5m
  - Actuators are located 1m from blade root

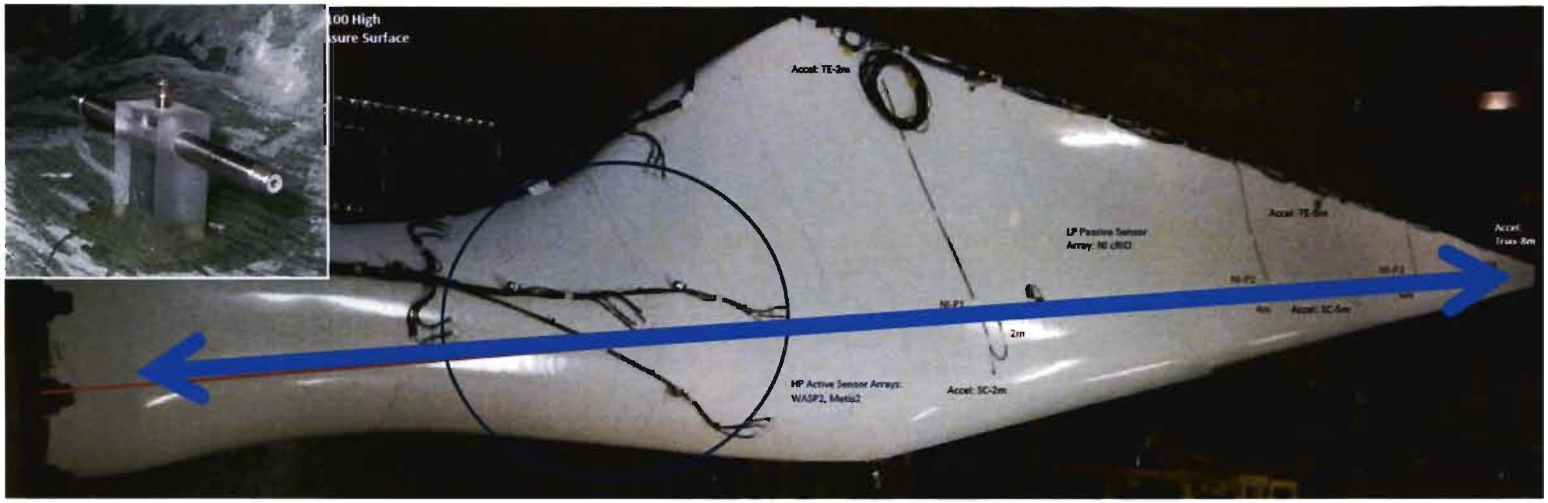


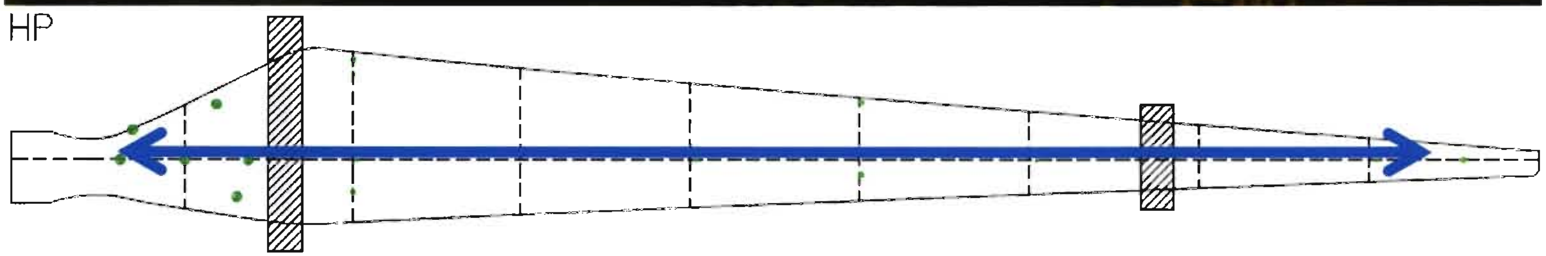
High pressure surface transitional root area

HP



LANL Blade – High Pressure Surface

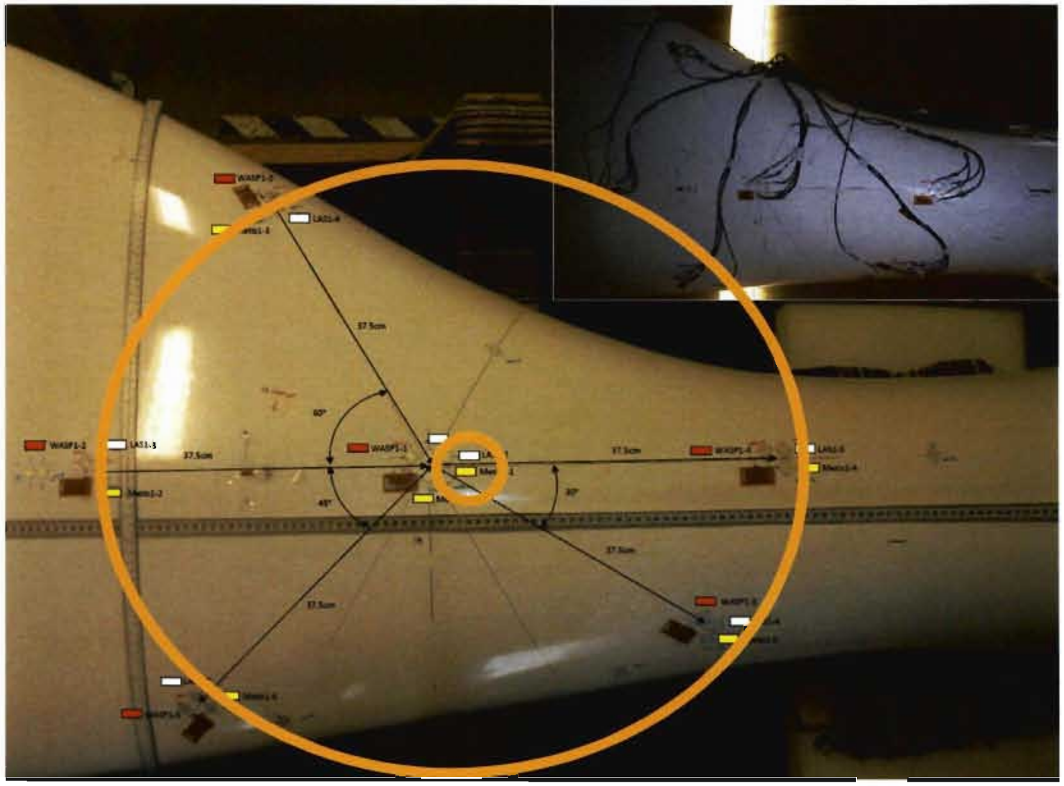




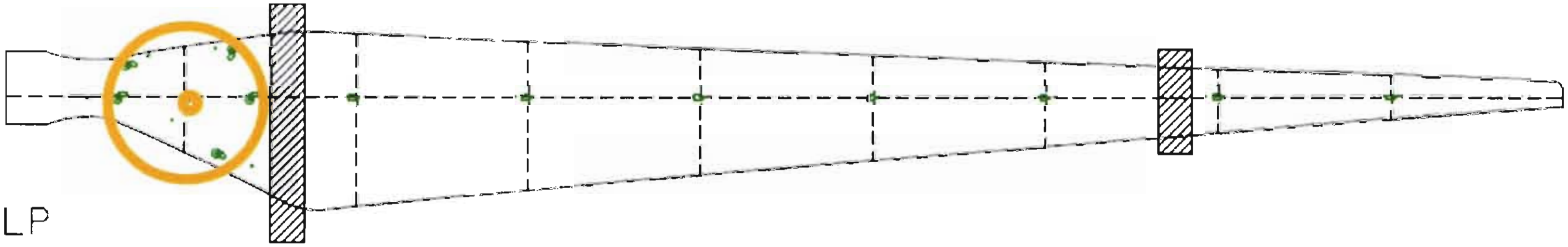
- **Seven accelerometers are mounted along the length of the blade**
  - Five monitor flap-wise motion, One edge-wise motion, One axial motion
- **One microphone is located within the blade**
- **Four piezoelectric transducers monitor strain along the spar cap**

UMass Blade – Low Pressure Surface

- **Active arrays on Low-Pressure Surface**
  - LASER Inboard
- **This array parallels the inner arrays on the LANL blade, observing a 0.75m-diameter region centered 1m from the root**



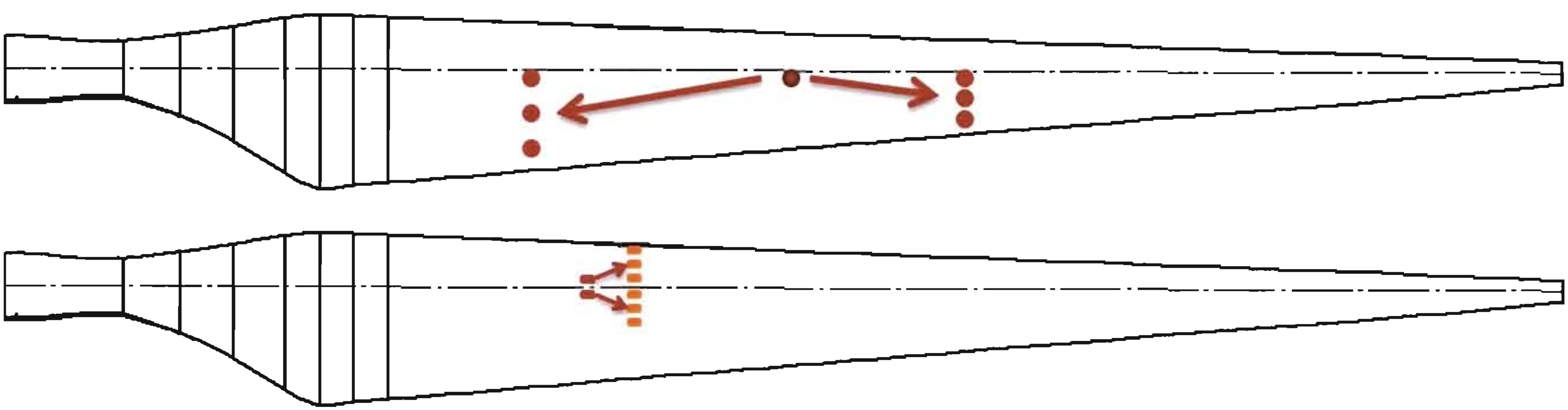
Low pressure surface transitional root area



UMass Blade – Aerodynamic Area

- **Active sensing systems on aerodynamic surface**
  - LASER Outboard
  - WASP Outboard
- **This array observes specific locations in the blade in which defects were seeded.**

- **Active sensing systems embedded in the aerodynamic portion**
  - Metis Interior 1
  - Metis Interior 2
- **This array focuses on an internal defect in the fiberglass layup**



Active Sensing Platform Deployment

- **Fatigue tests of CX-100 9-m blade**
  - Test 0 in 2010 (Sandia Nat. Lab)
  - Test 1 (pristine blade) Fall 2011
  - Test 2 (defective blade) Winter 2012
- **Flight deployment**
  - CX-100 Spring 2012
  - Whisper 500 Summer 2012

Ongoing and Future Work

- Two blades have failed; we are conducting post-mortem analyses through physical inspection and with the data that have been collected.
- In conjunction with Sandia National Laboratory, a third blade will be flown this spring as a test bed for our embedded systems.

Acknowledgments

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