Advances in Ultrasonic Nondestructive Inspection (NDI) Methods for Detecting Hidden and Deeply-Embedded Damage in Wind Blades

SAND2015-0278C

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Sandia National Labs
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Presentation Outline

NDI Test Specimen Library

Ultrasonic NDI Techniques

POD Experiment – How good are your inspectors?

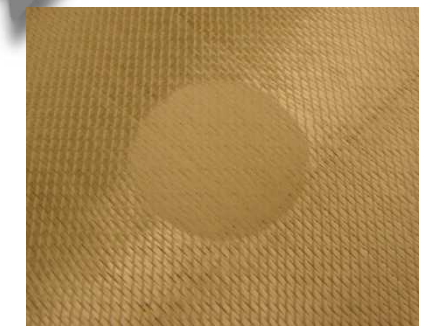
Factory and Field Deployment

Carbon Spar Inspection Challenges

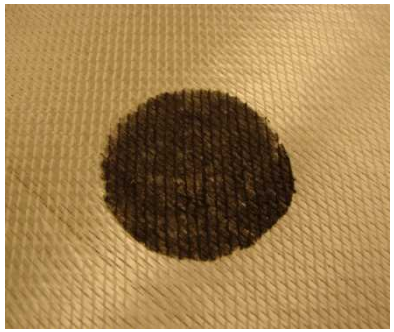
National Nuclear Security Administration

Sandia National Laboratories

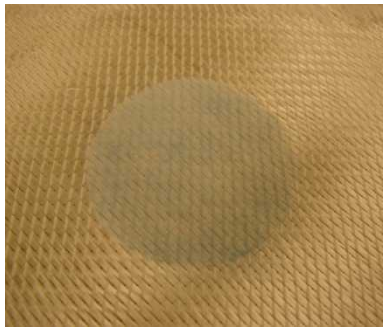
Different Flaw Types Engineered into NDI Feedback Specimens (Examples)



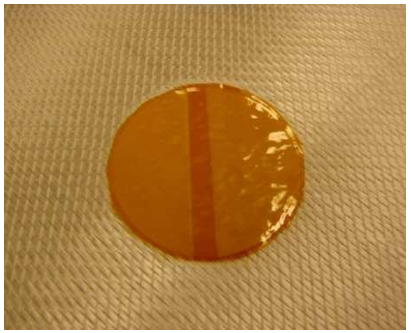
Glass Beads



Grease



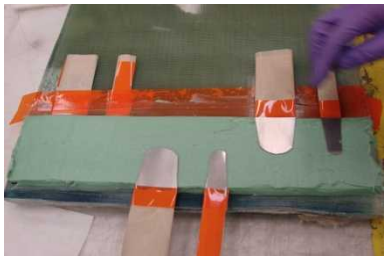
Mold Release



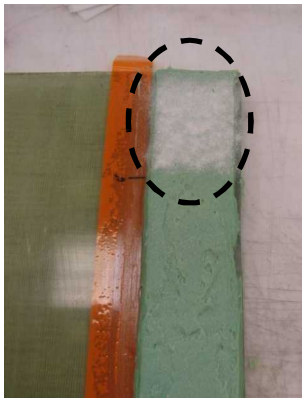
Pillow Insert

Materials inserted into multiple layers

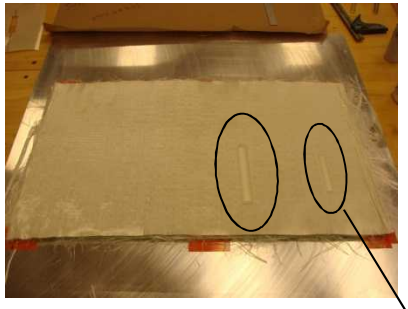
Voids in bond joint



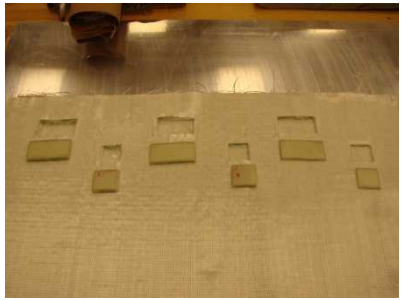
Pull tabs in bond joint



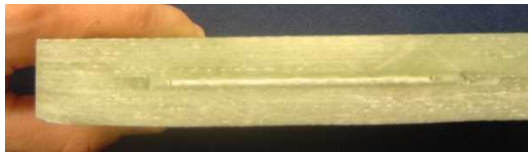
Glass beads In bond joint



Waviness produced by pre-cured resin rods and stacked plies



Dry fabric areas



Single ply of dry fabric

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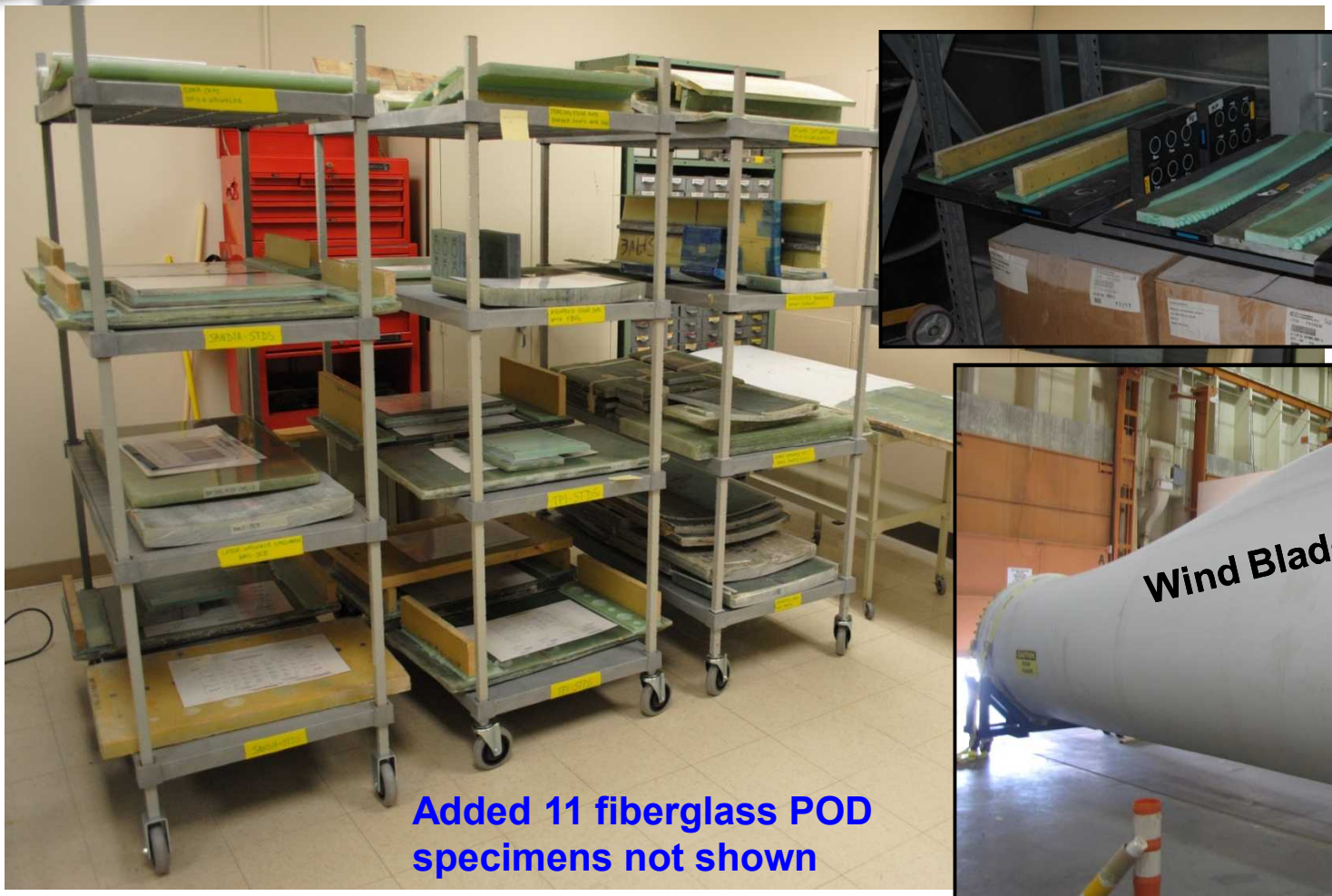
Sandia Labs Wind Blade Test Specimen Library



Additional full size samples housed at Sandia Labs

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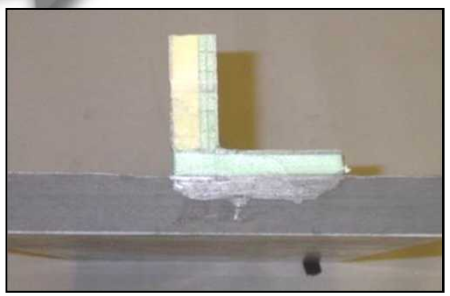
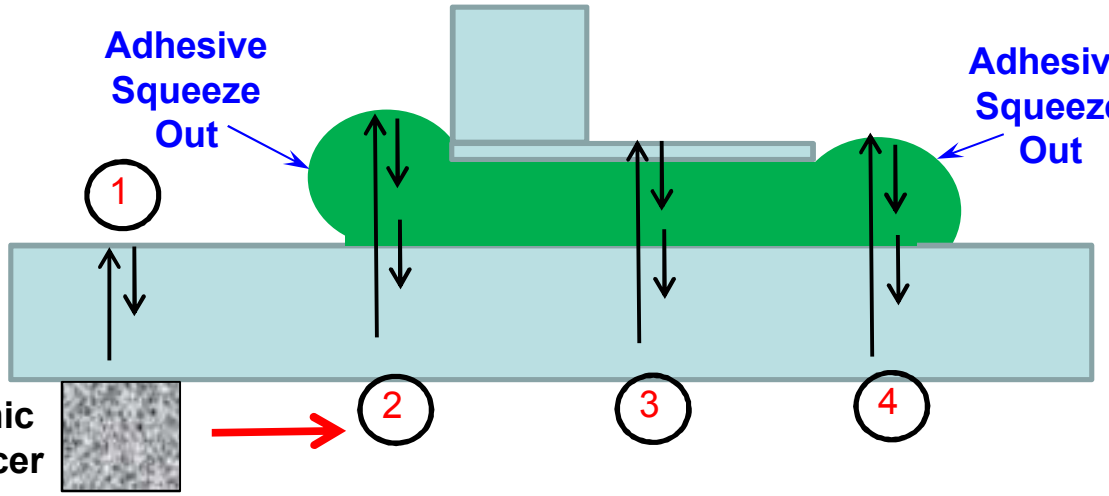
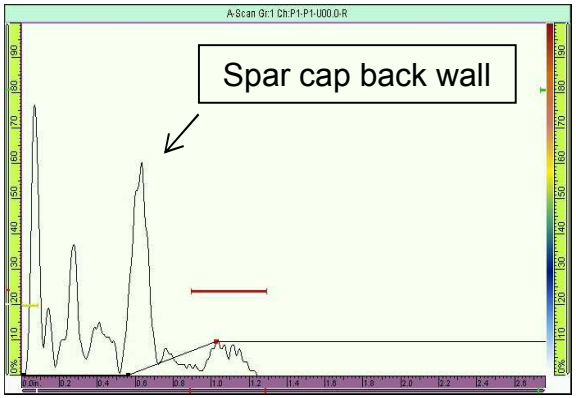
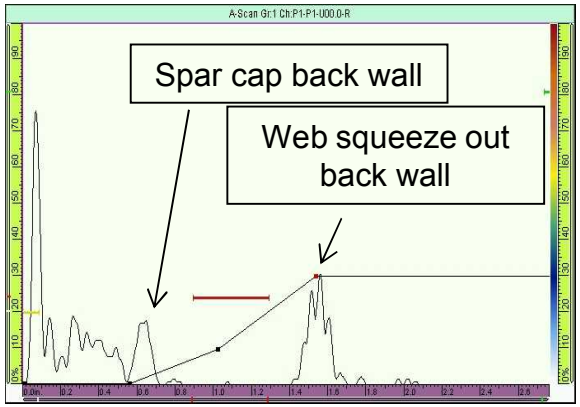
Pulse-Echo Inspection of Bond Joint



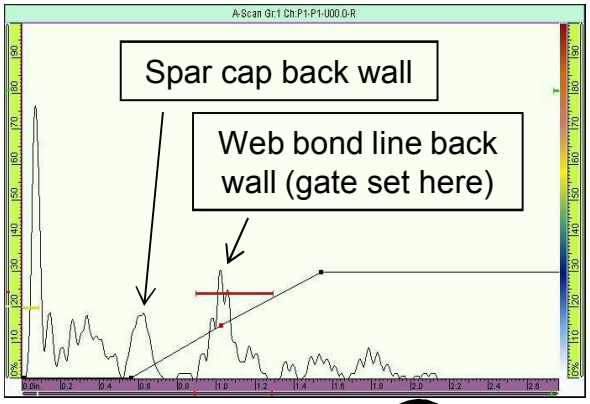




Spar Cap - 1

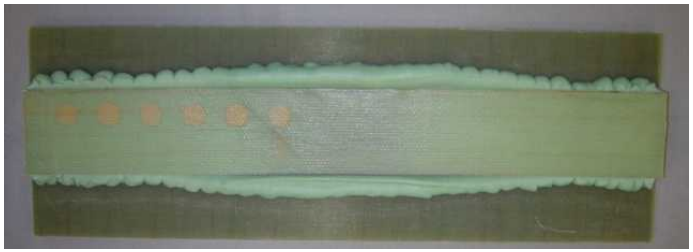


Web Squeeze Out- 2 & 4



Web Bond Line- 3

A-Scan Signals



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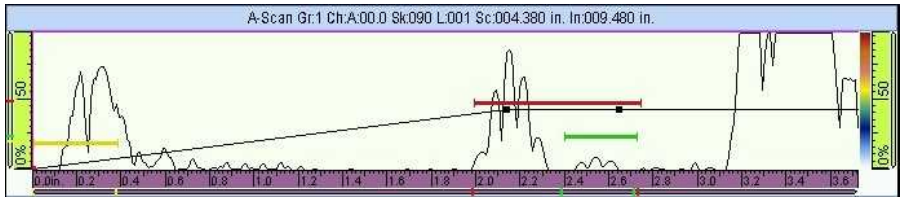
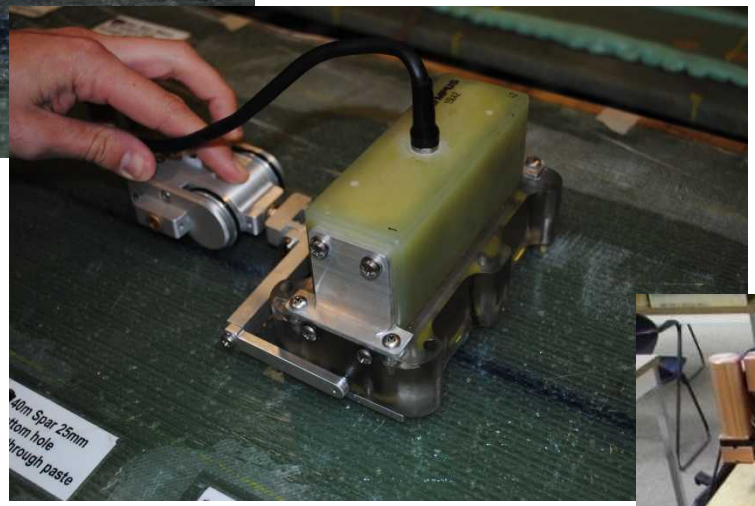
Ultrasonic Deployment Progression

Single Element Transducer varying Diameter

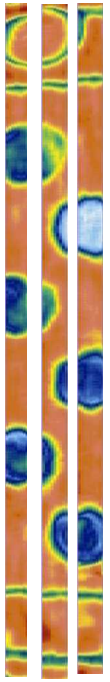
- **500 KHz, 1 MHz, 1.5 MHz**





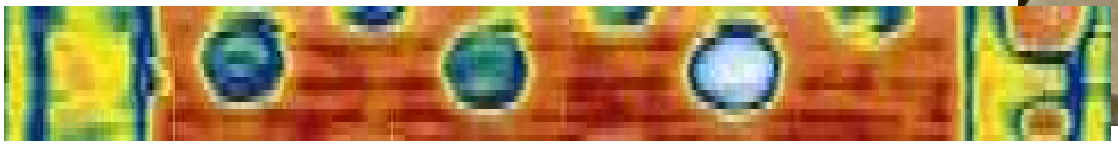
Linear Encoded Phased Array

- **500 KHz,1 MHz, 1.5 MHz**
- **Multiple linear encoders**
- **16, 32, 42 and 64 Elements**
- **5 to 10 Water Box options**



Automated and Semi-Automated X-Y Scanning

- **MAUS V Automated Scanner**
- **OmniScan X-Y Glider**
- **Marrietta Automated Scanner**



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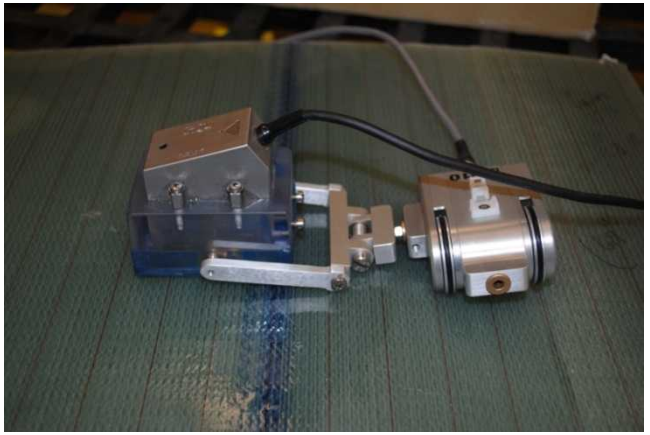
Ultrasonic Deployment Options

Examples of Linear (One Direction) Scanners

1.5L42 PA-UT Sealed Water Box with Mouse

1 MHz Sonatest RapidScan

1 MHz GE RotoArray



1.5L16 PA-UT Sealed Water Box with Mouse

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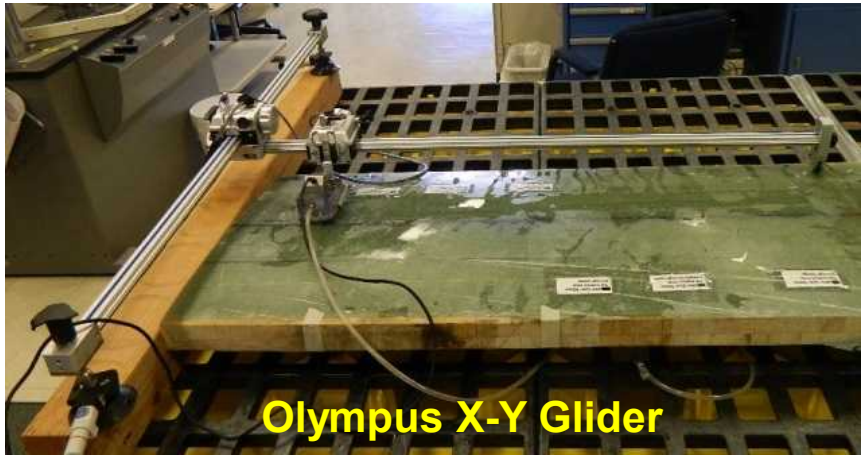
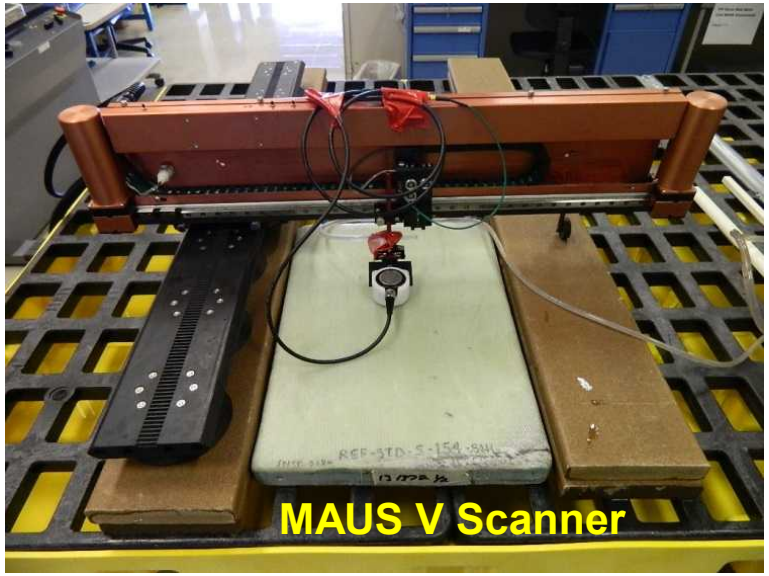
Ultrasonic Deployment Options

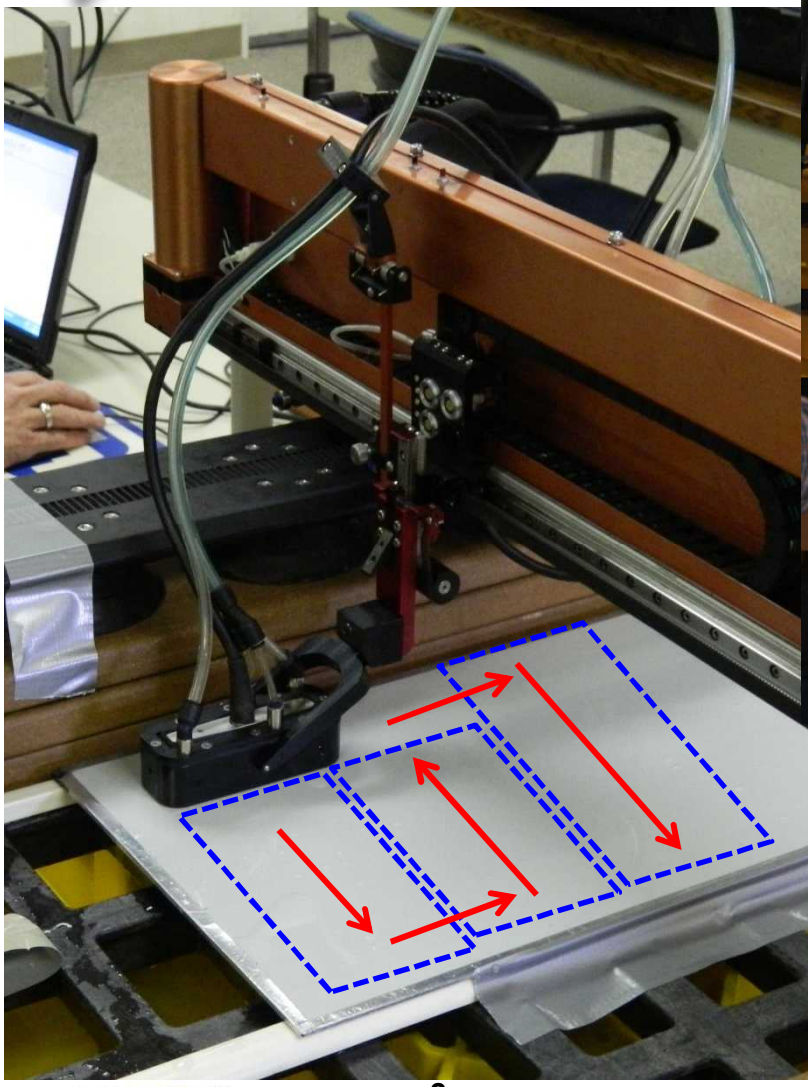
X-Y Scanners: Used to encode scans in both the X and Y direction

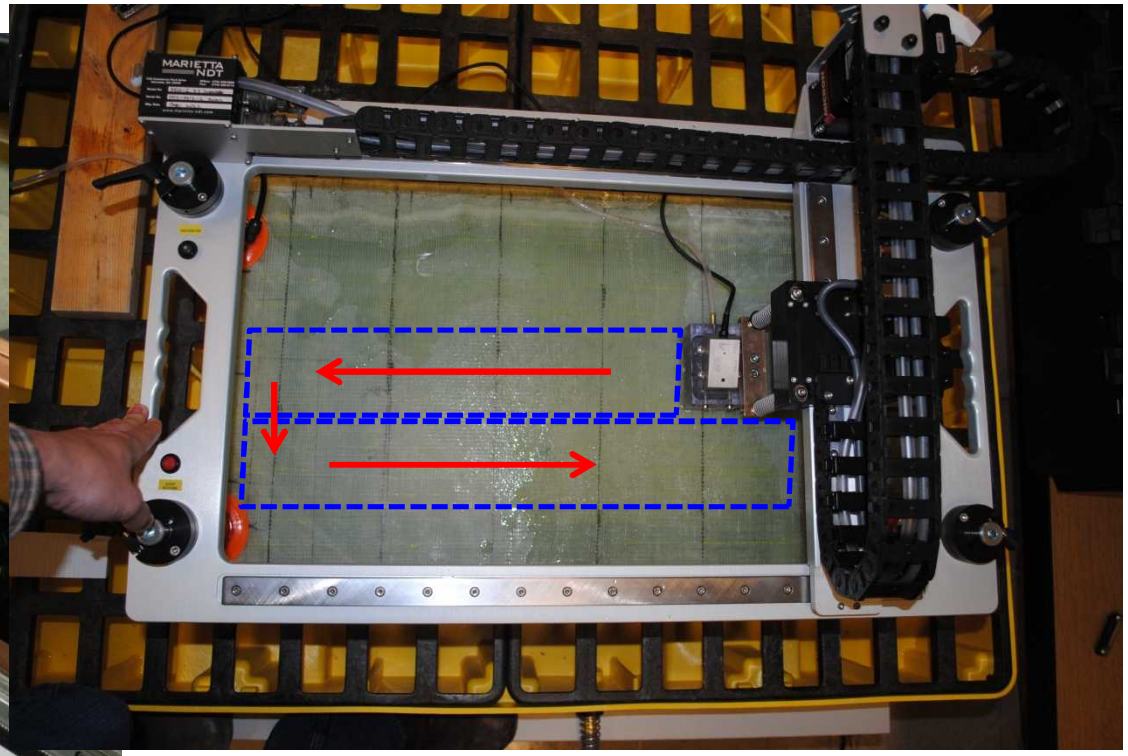




Phased array or single element transducers

Investigation of Automated and Semi-Automated Phased Array Systems For Rapid, Wide Area Inspections





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~100in^2/min scan speed (depends on probe size)

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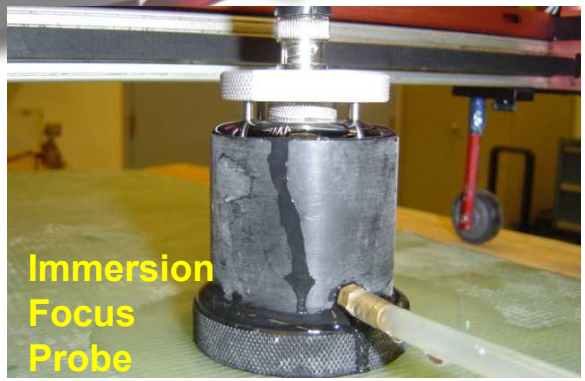
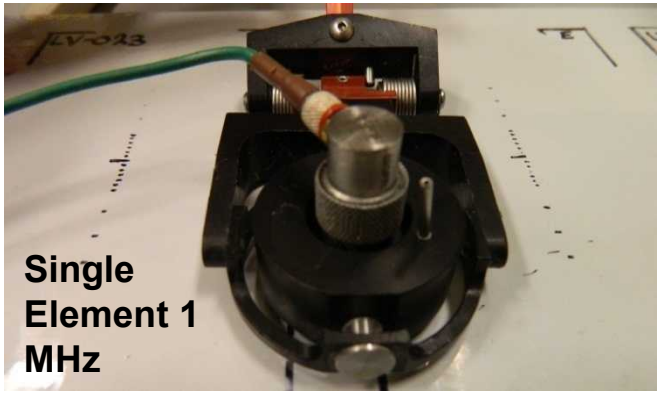
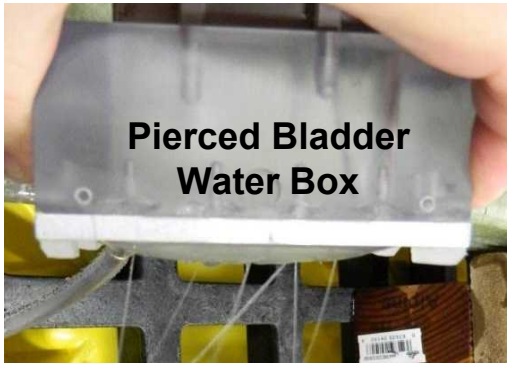
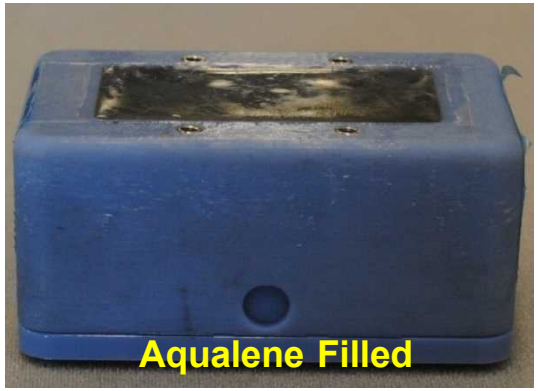
Down Selected Ultrasonic Inspection Methods



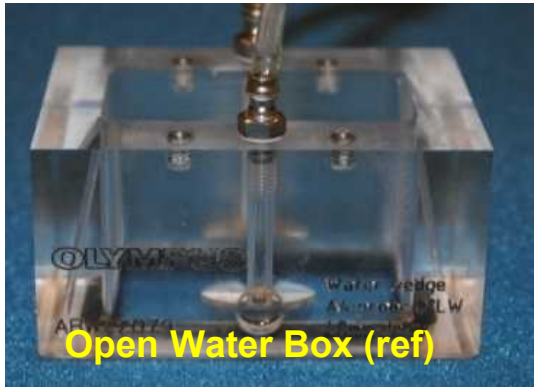






Down-selected inspection options:

- 500 KHz single-element contact
- 1 MHz single-element contact
- 1 MHz Focused immersion probe
- 1.5 MHz 16 Element PA sealed water box (pierced vs couplant TBD)
- 1.5 MHz 42 Element PA with sealed water box (pierced vs couplant TBD)
- RotoArray to come

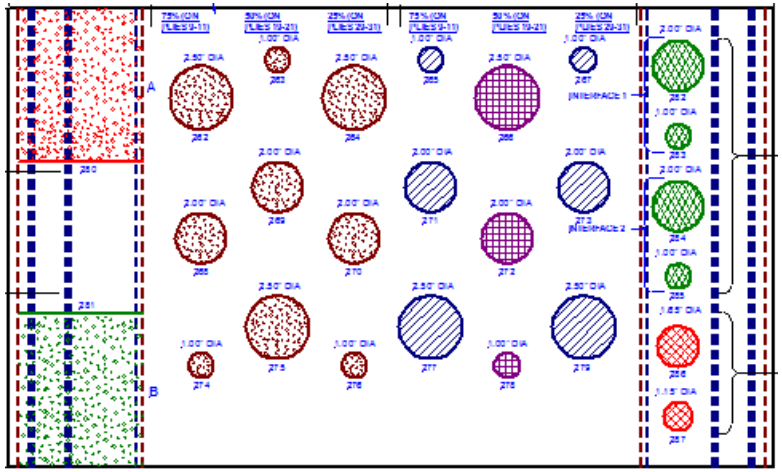


Blade Parts Selected for Down-Select Comparison

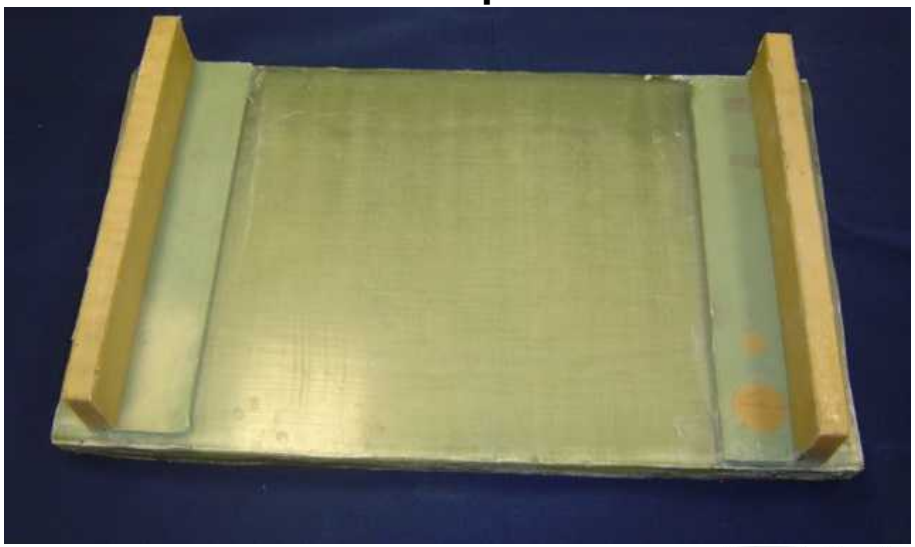
(WIND-6-180-SPAR-220)

Spar Cap Cut From Blade

(REF-STD-7-214-265-SNL-1)

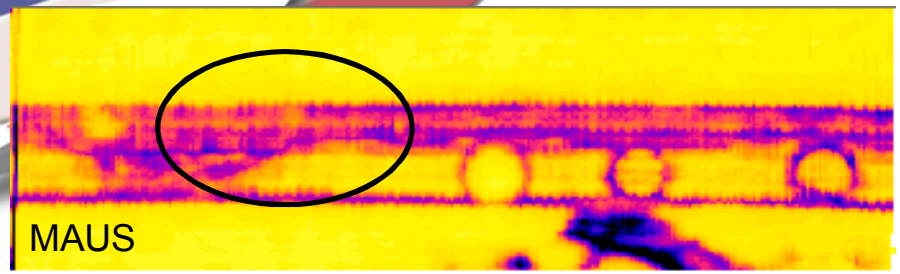


Feedback Specimen

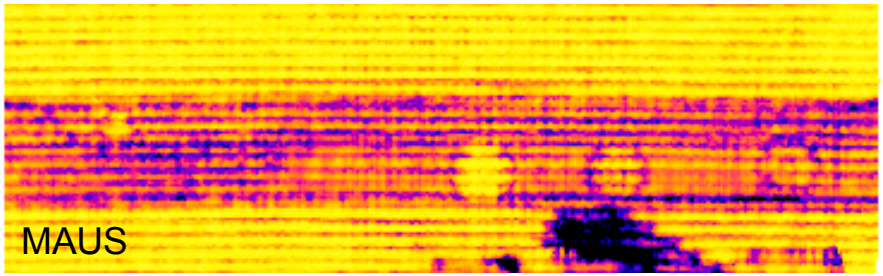


Provide a good combination of thickness, curvature and bond line challenges

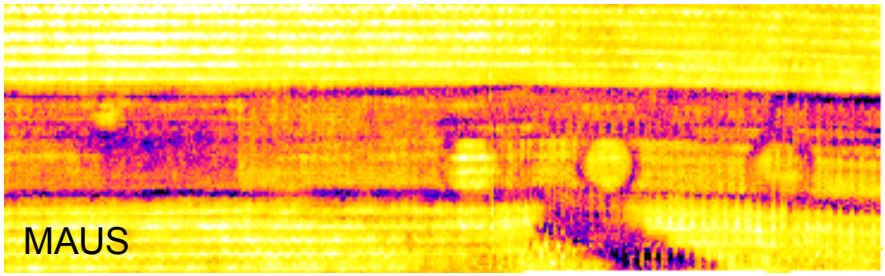
Inspection Comparison



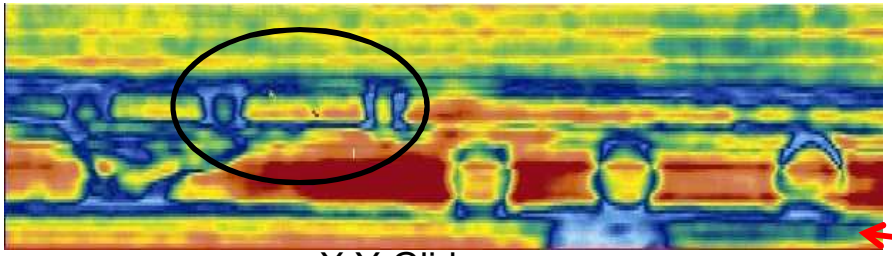
500 KHz Contact



1 MHz Contact



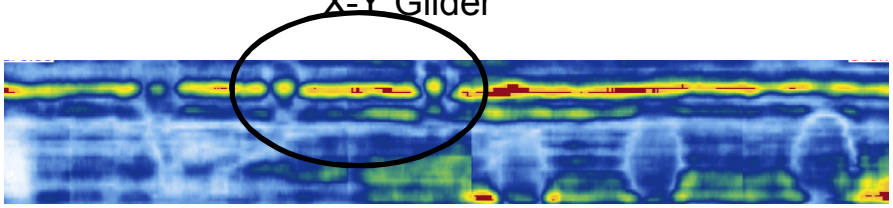
1 MHz Focused Immersion



1.5L16 (1.5 MHz) Pierced Bladder Water Box

X-Y Glider

Element normalization and added sensitivity of PA-UT



1.5L42 (1.5 MHz) Sealed Water Box

Linear Encoder

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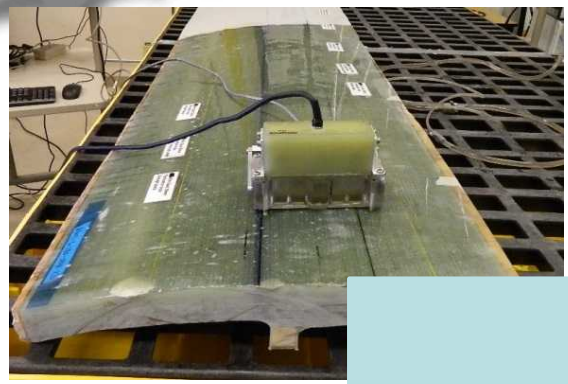
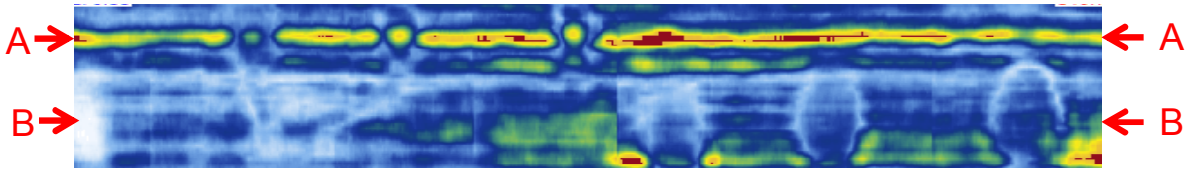
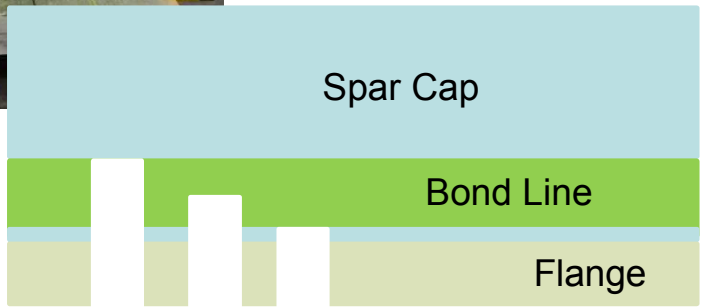
Inspection Display Options

Note: Inspection scan area ~55” with a scan width of 4.2”.



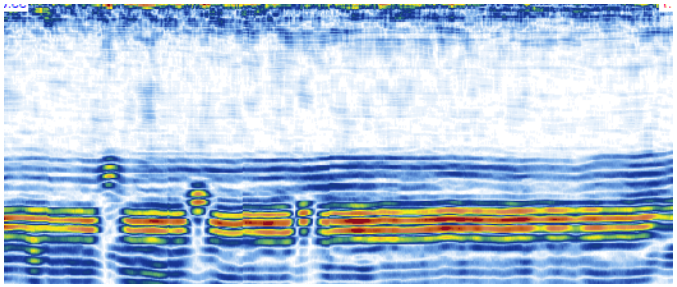


C-Scan Amplitude



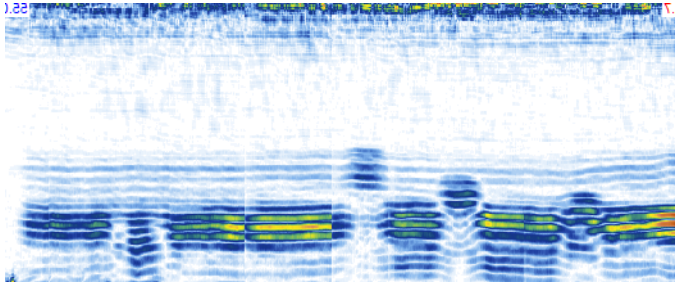
Shear Web Foam

Cross Section **A**

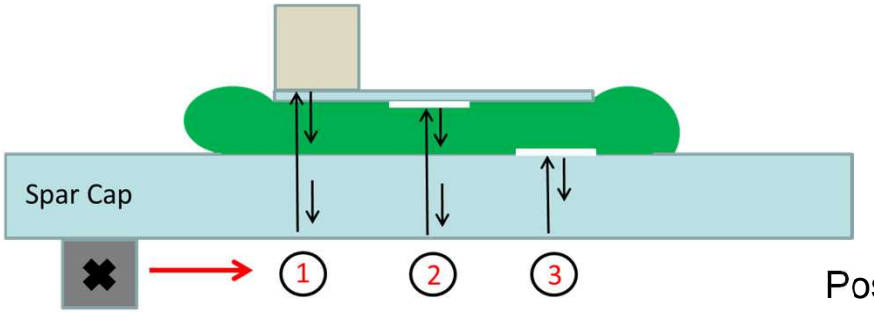


B-Scan Top Holes

Cross Section **B**

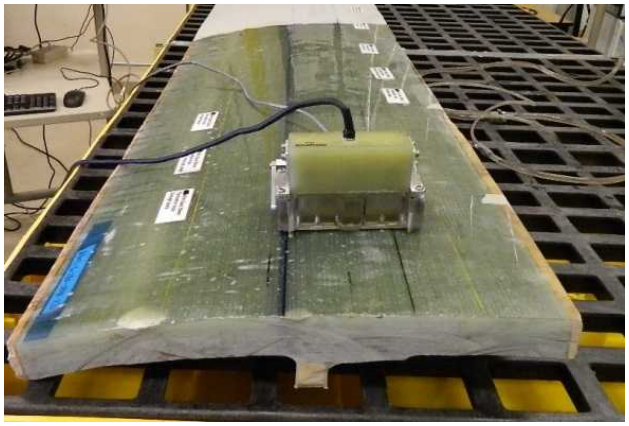


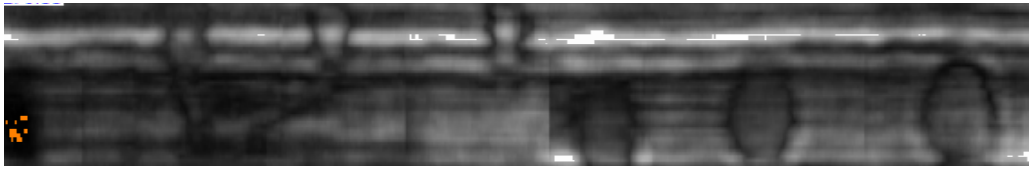
B-Scan Bottom Holes



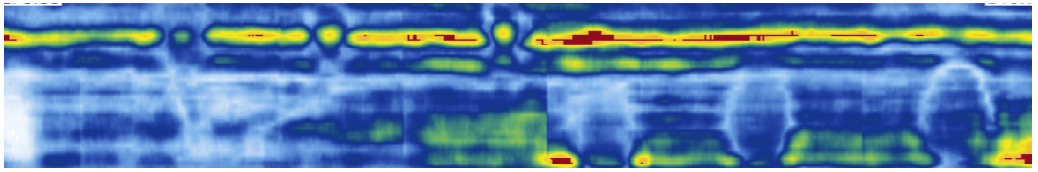
Post processing with TomoView

Inspection Display Options and Post Processing

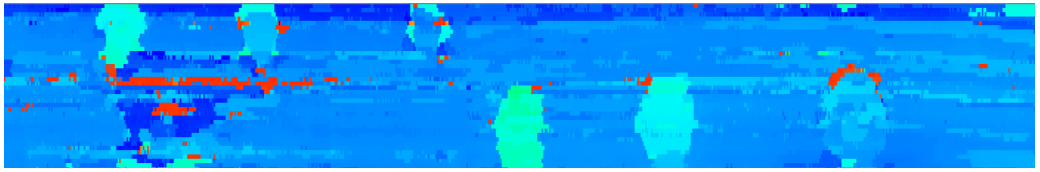




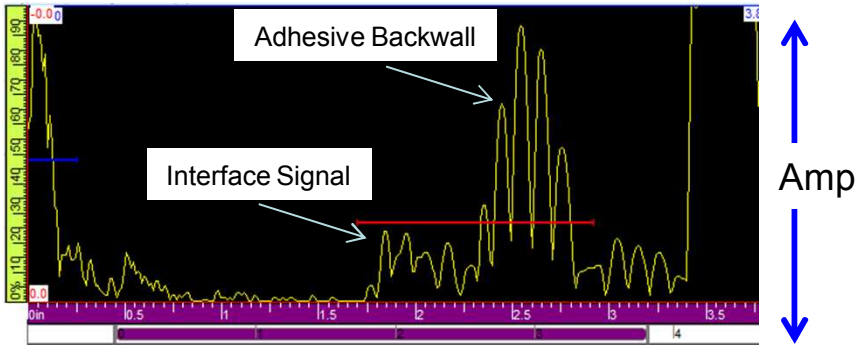
C-Scan Amplitude (Grey Pallet)

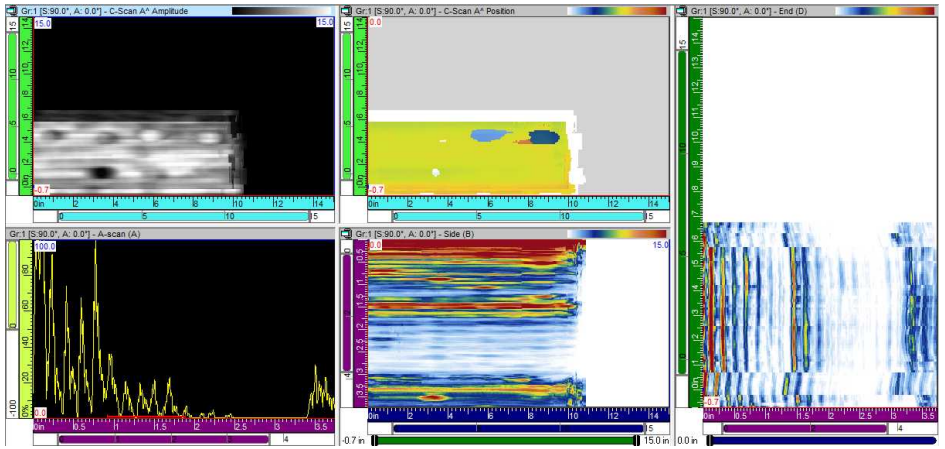


C-Scan Amplitude (Rainbow Pallet)



Time of Flight

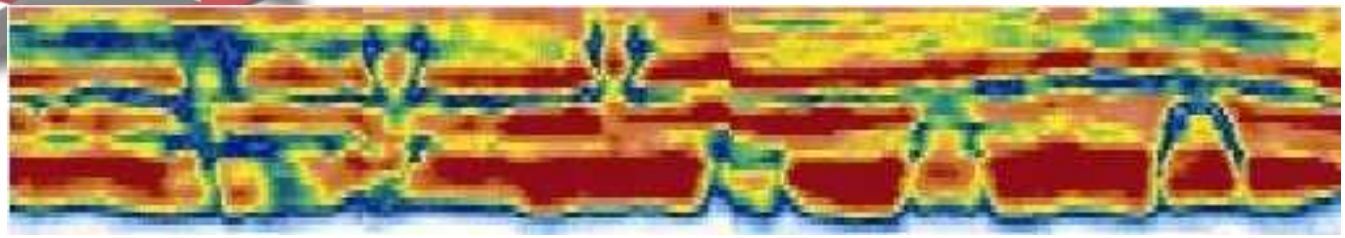




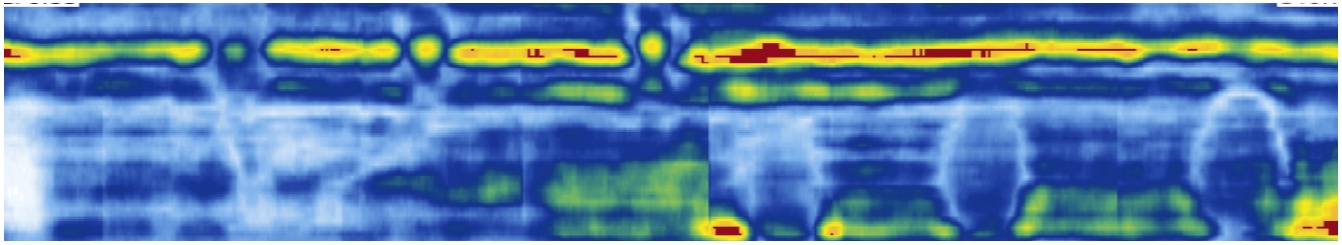
Data Post Processing in TomoView

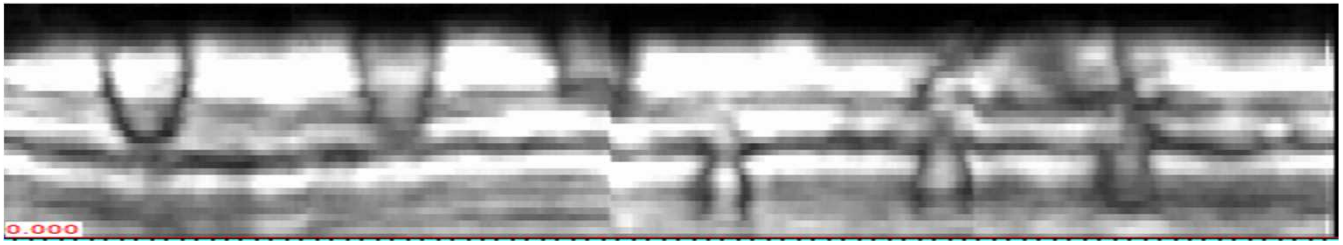
National Nuclear Security Administration

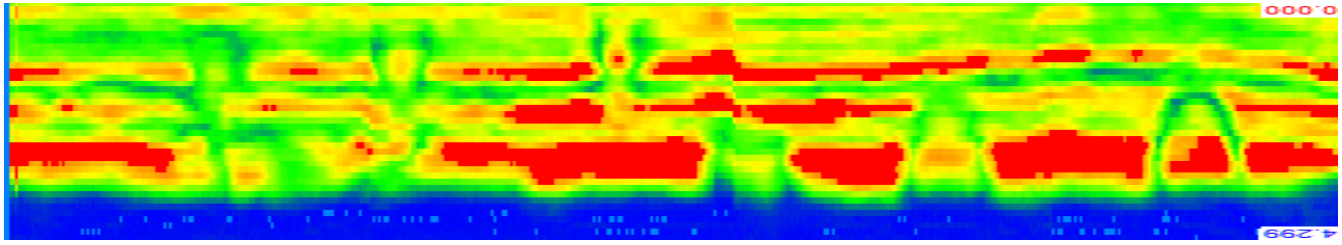
Inspection Display Options and Post Processing



Initial C-Scan

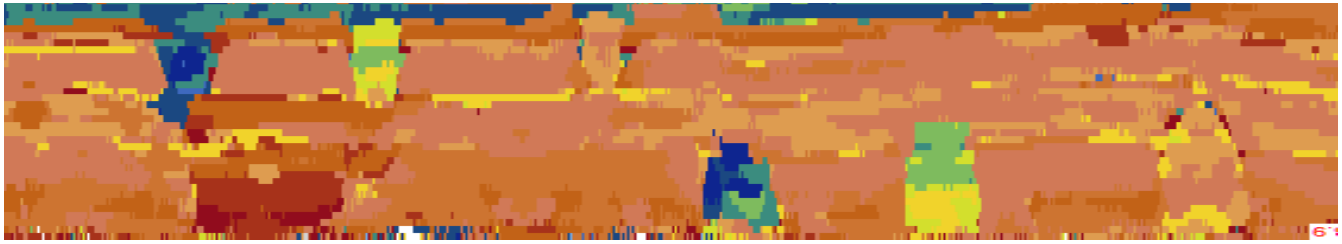






Post Processing in TomoView

Amplitude C-scan with different color pallets



Time of Flight

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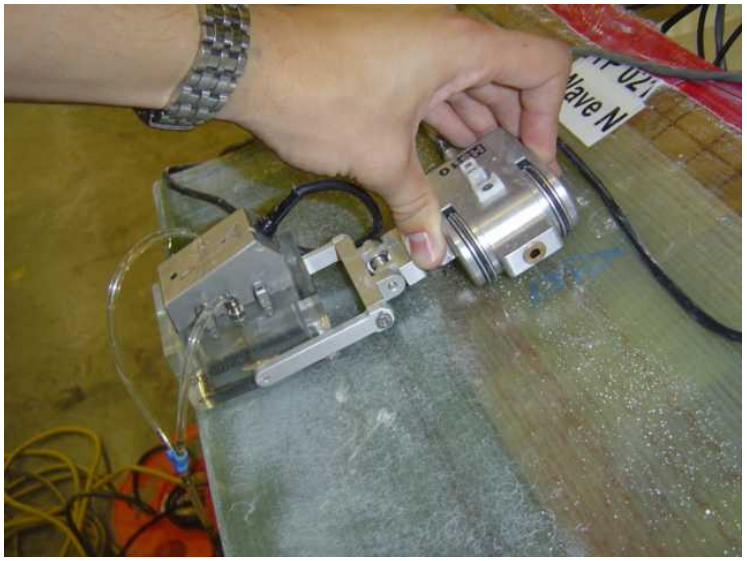
Sandia Labs On Blade Factory Inspections

Sandia **on-blade field testing** has been performed using:

- Conventional ***Single Element*** Transducer
- Hand Deployed ***Phased Array***, encoded and non-encoded using:
  - No Water Box
  - Open Water Box
  - Sealed Water Box
  - Gel Filled Box

  Conducted In-House Development and Testing
- *MAUS* ***scanner using single element transducer***
- MAUS ***scanner with Focus Probe***



X 16 Elements

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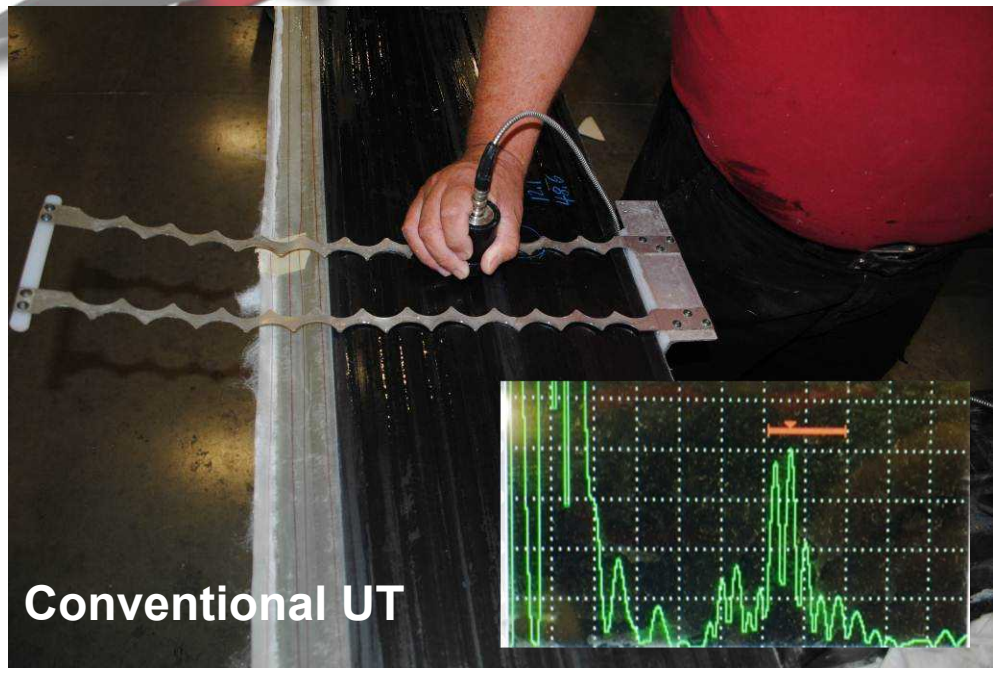
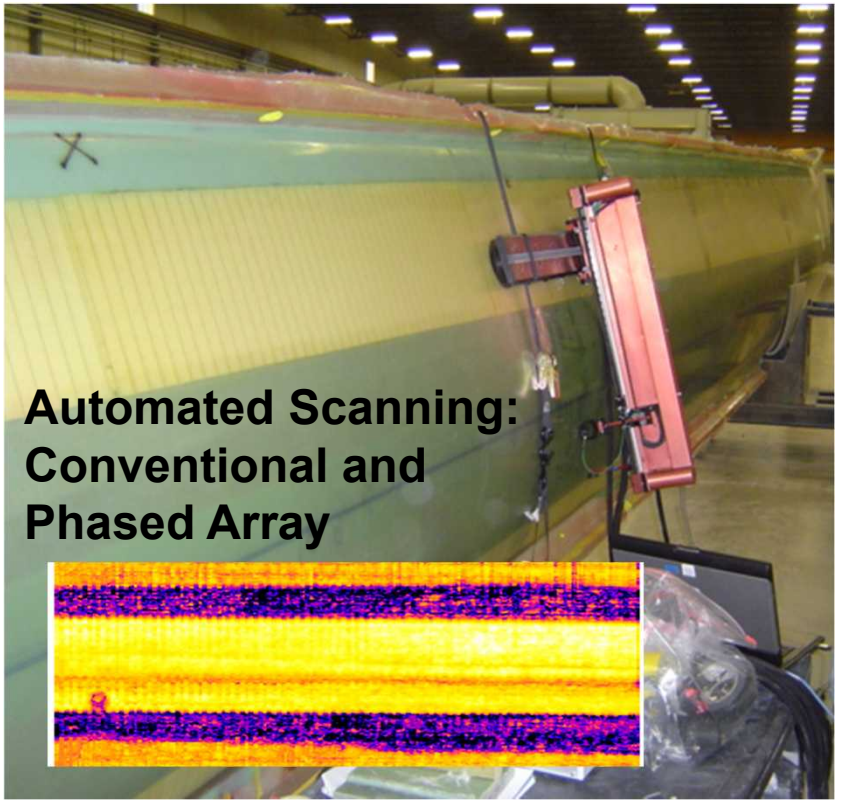
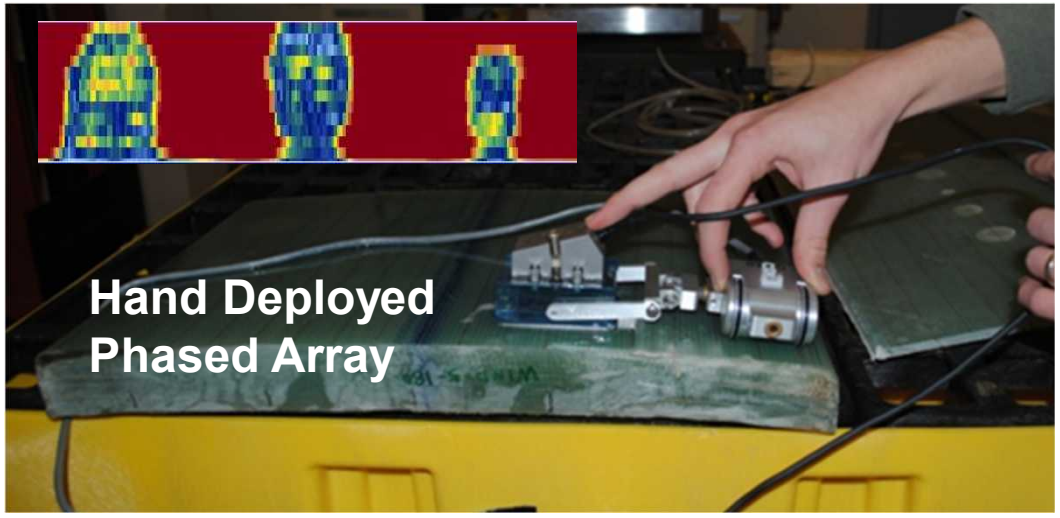
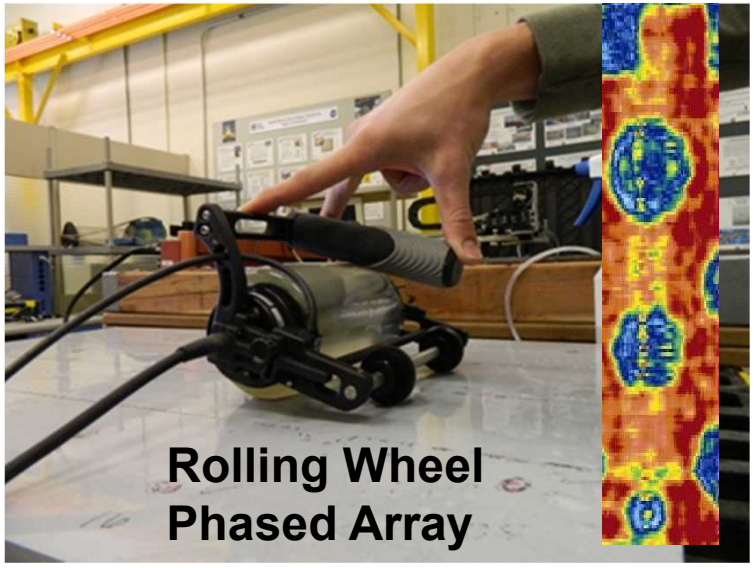
Deployment Options

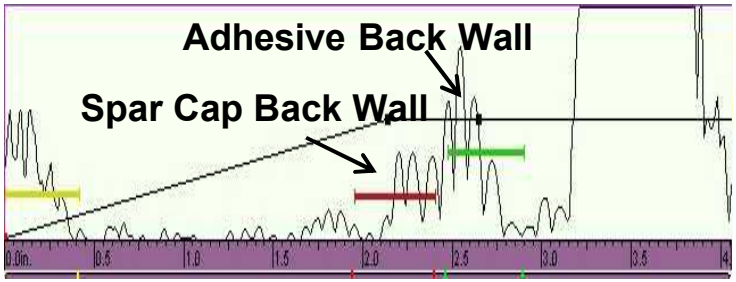




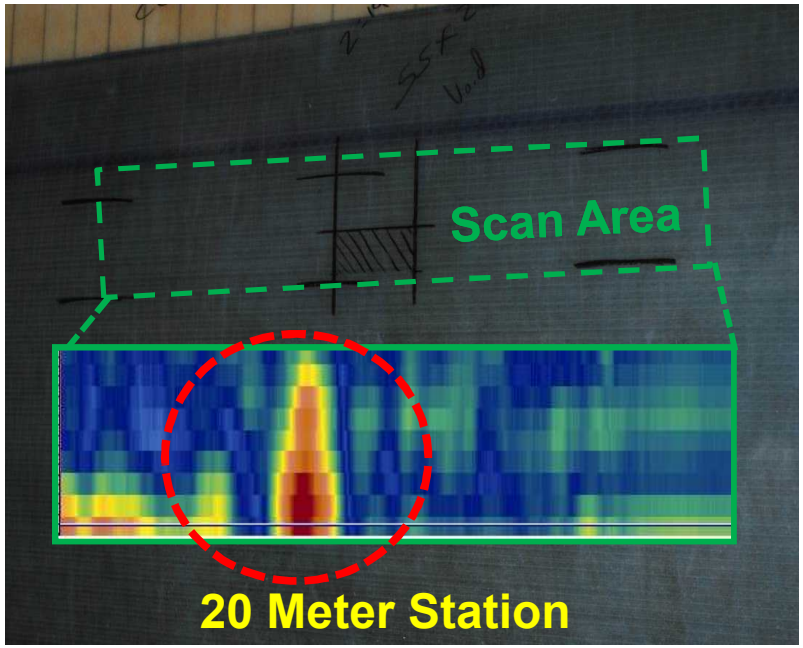


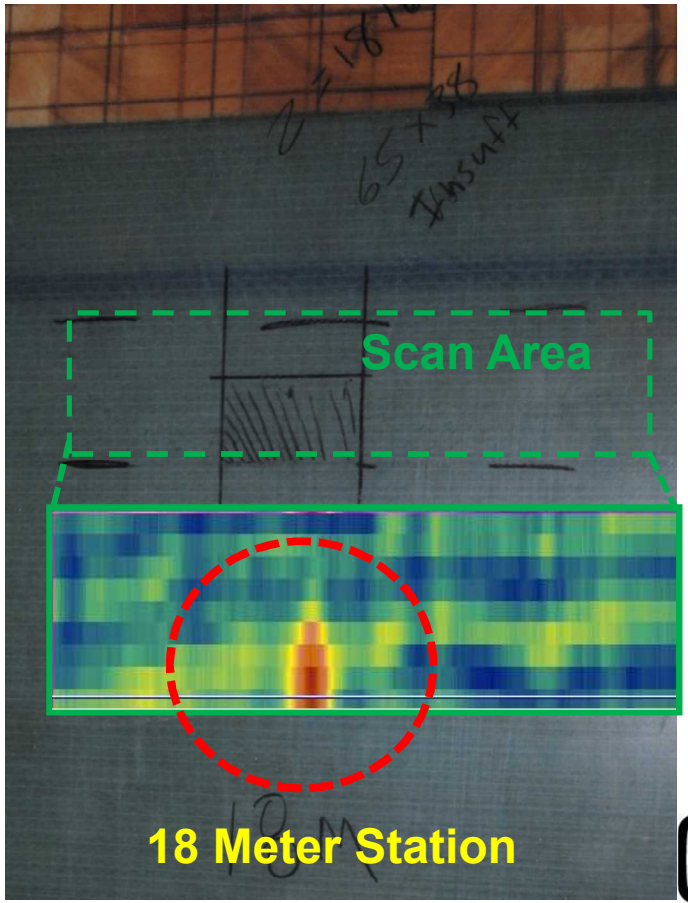


Factory Deployed Phased Array Inspections



Sample
A- Scan





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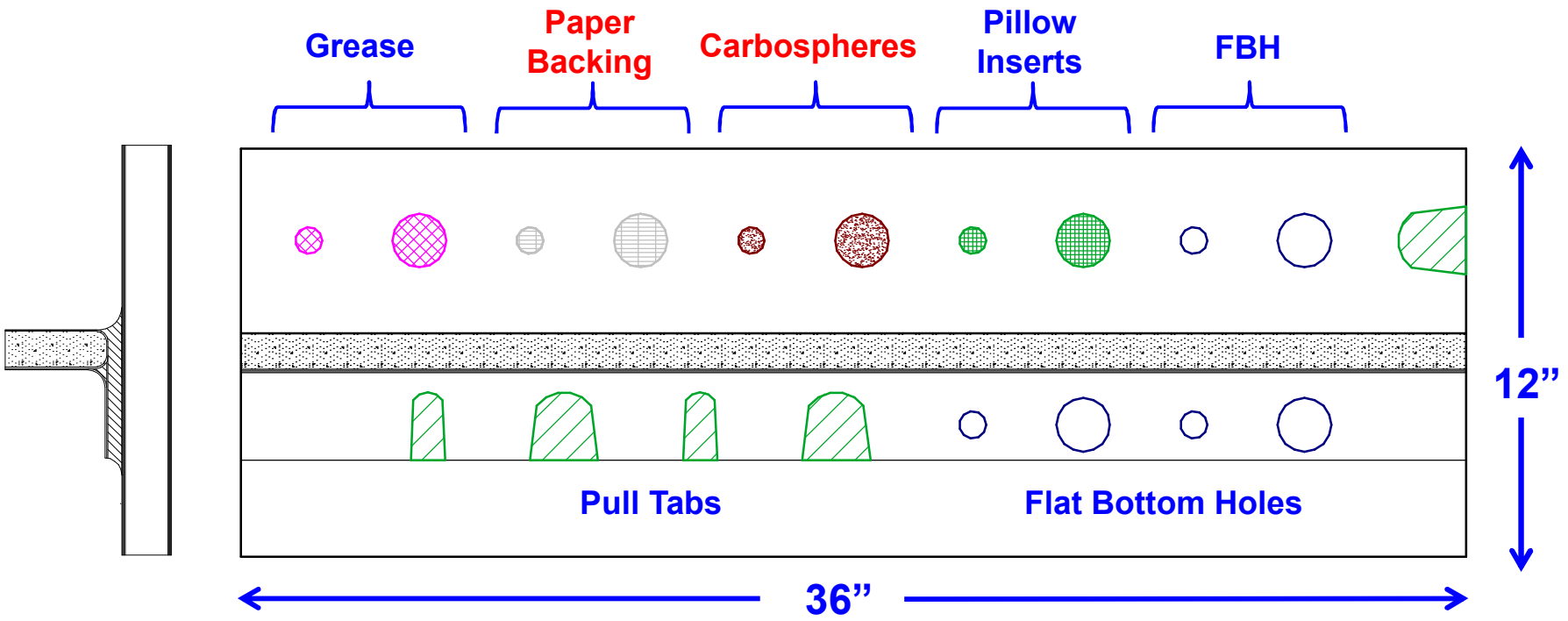
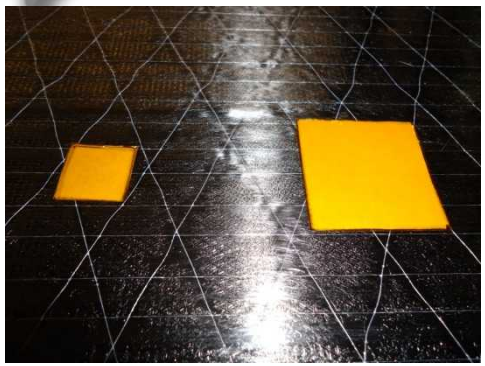
Carbon NDI Reference Standards

- Pre-Preg Carbon Material
- Up to ~ 2” thick
- Quality assurance cannot visually inspect through carbon
- Flaws more critical than in fiberglass
- Greater need for NDI during manufacturing

Carbon Fiber Spar Cap Assembly



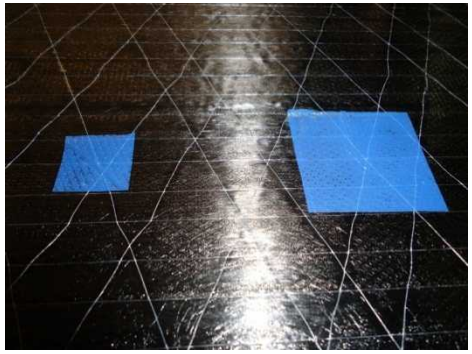
Samples of Different Flaw Types Engineered into Carbon NDI Ref Standards



Pillow Insert

Pull Tab Disbonds

Flaws were placed at varying depths and locations using a template



Pre-Preg Backing

Grease Contamination

Glass Microballoons in Bond Line

Adhesive Void

Fiberglass FOD

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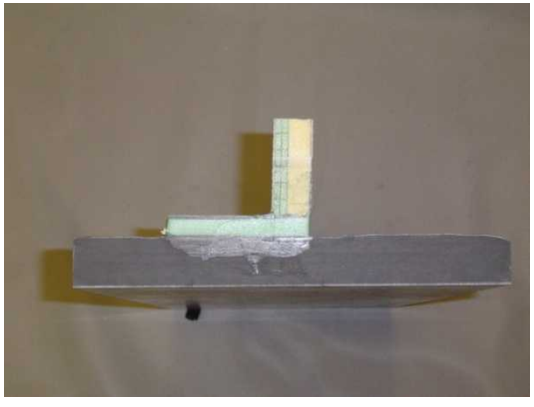
Carbon NDI Reference Standards for Use at Blade Manufacturing Facilities

- Develop and test NDI technology
- Train inspectors and familiarize them with carbon material
- Calibrate and set up NDI equipment
- Ultrasonic flaw signal characterization
- Inspection procedure development



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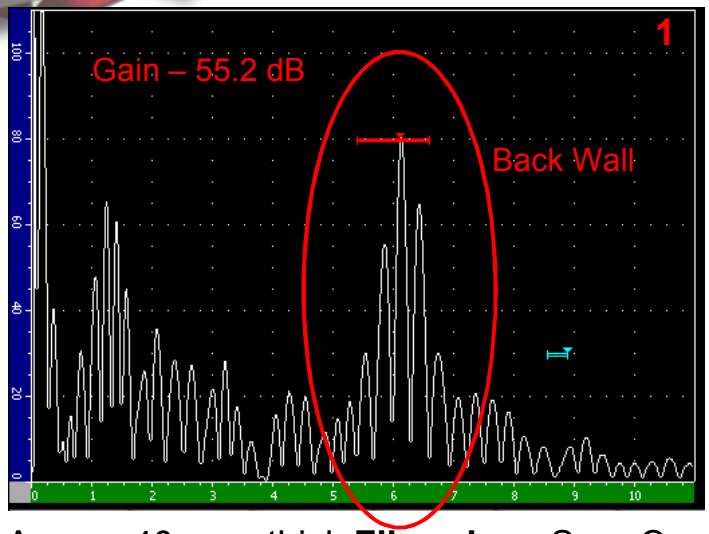
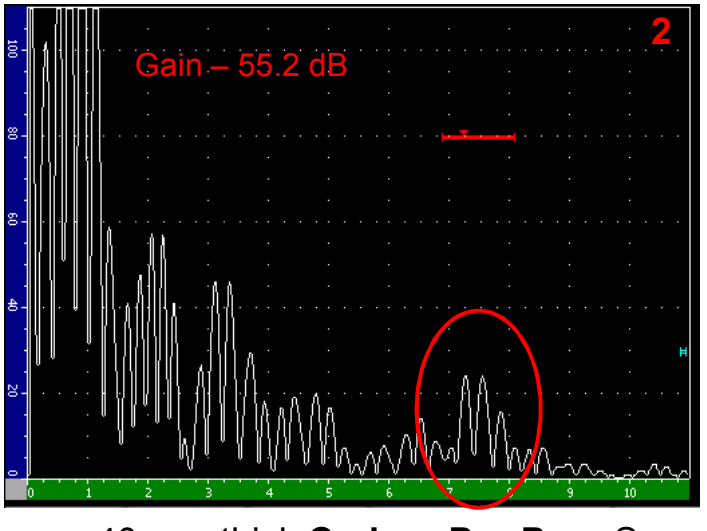
Carbon Pre Preg Spar Inspection Challenges



A-scan 40 mm. thick **Fiberglass** Spar Cap

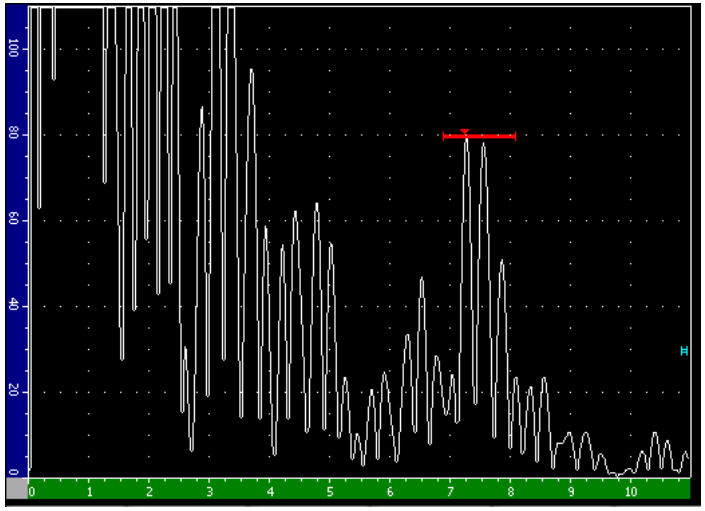


A-scan 40 mm thick **Carbon Pre-Preg** Spar Cap

Carbon Pre-Preg

200x magnification

Increase gain to achieve 80% FSH



A-scan 40 mm thick **Carbon Pre-Preg** Spar Cap

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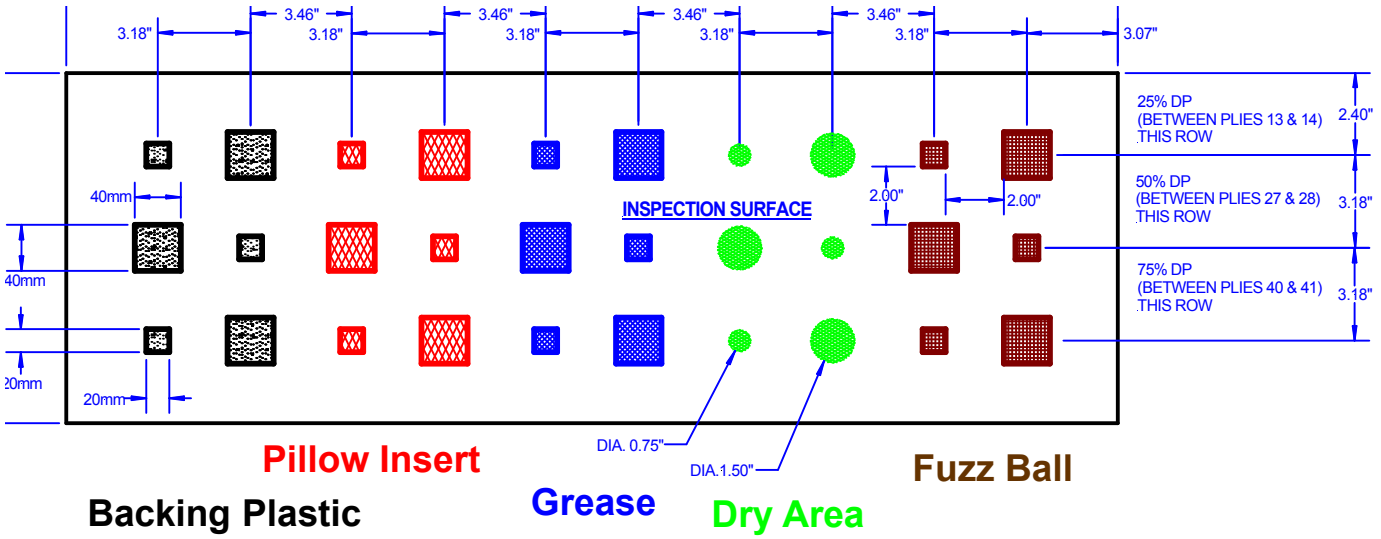
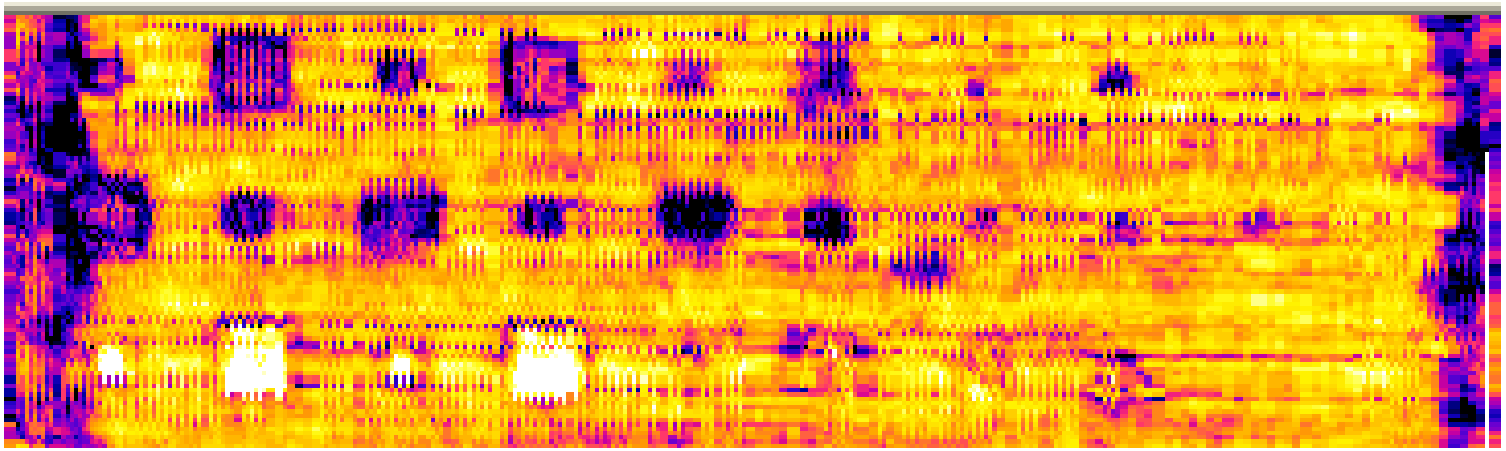
Carbon Wind Blade Specimen Characterization





Example C-Scan: Difficult inspection to perform due to signal attenuation levels in the material

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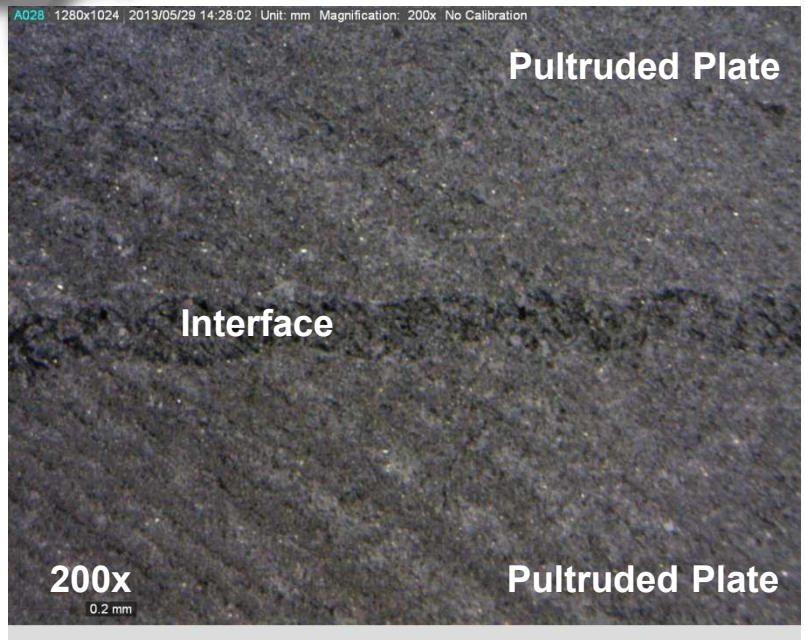
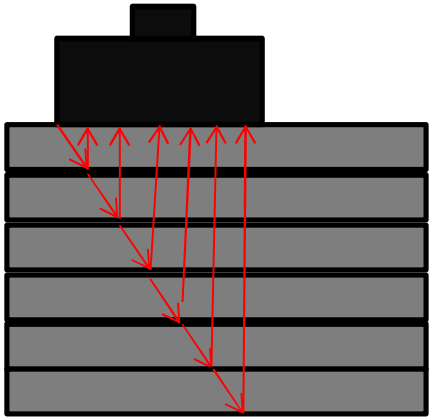
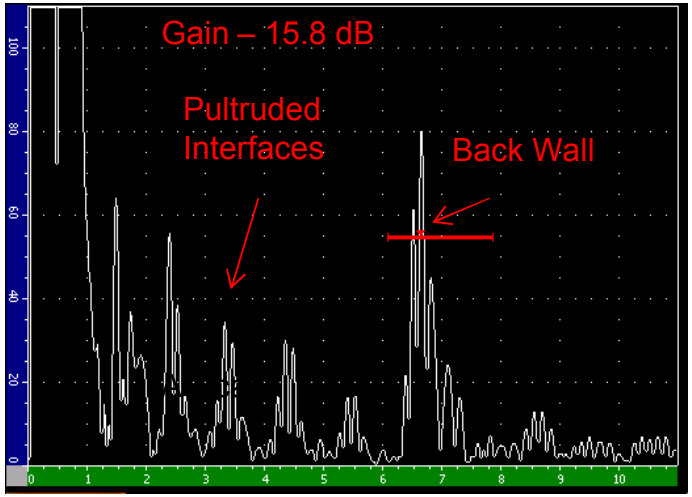
Pulturded Plate Spar Cap Inspection

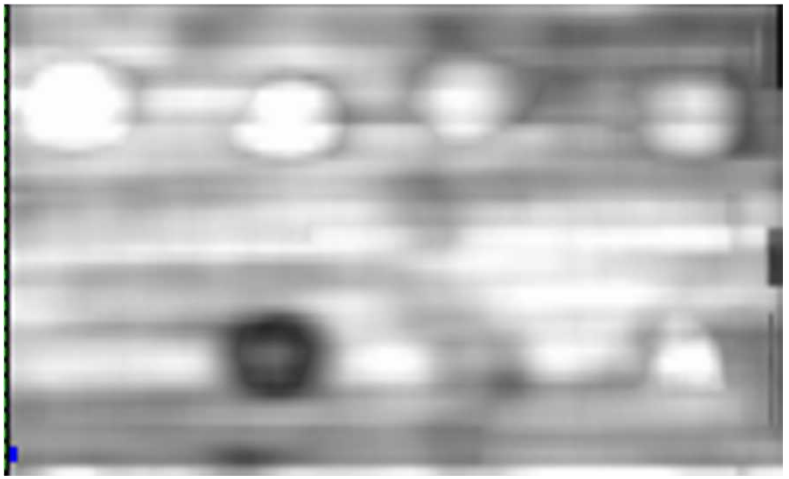




Signal return schematic of pulturded sheet interfaces shown on A-Scan

Working with material manufacturers to ensure inspectability of their product





Amplitude C-scan showing detection of pillow inserts at varying depths

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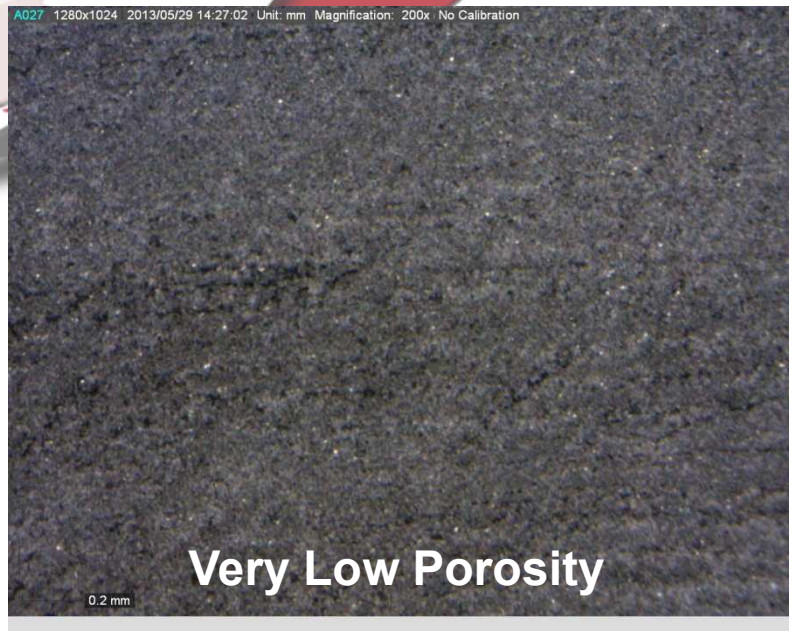
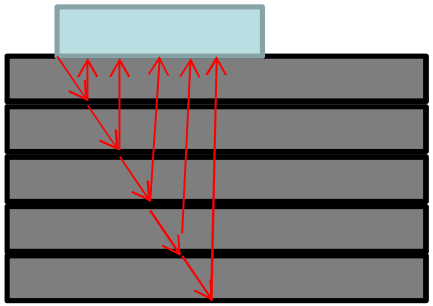
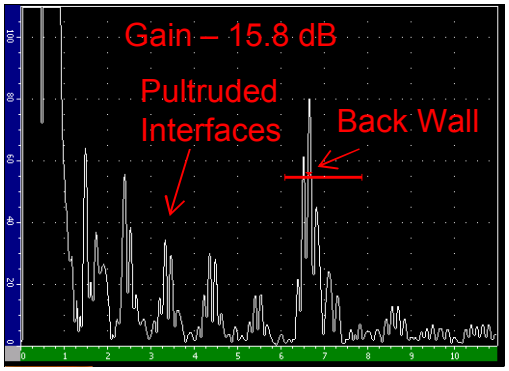
Pultruded Plate Spar Cap Manufacturing and Inspection

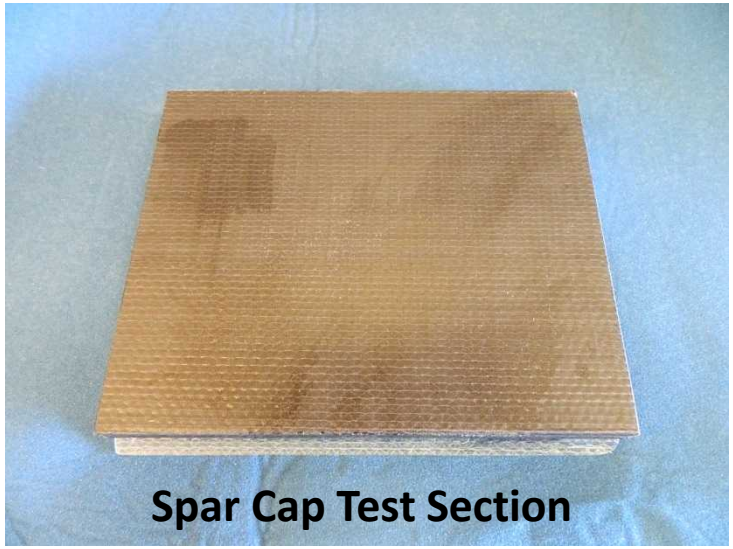


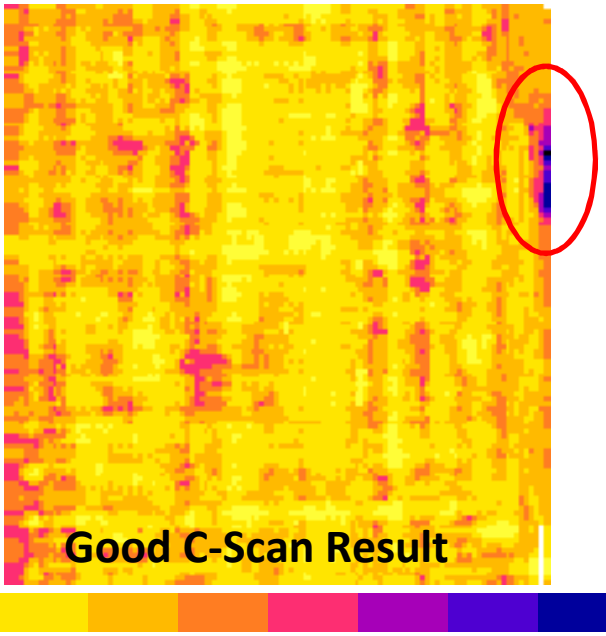


Signal return schematic of pulturded sheet interfaces shown on A-Scan



A-Scan





Several iterations of manufacturing and subsequent inspections resulted in a low porosity, inspectable product.

Conclusions

Sandia Labs is working to assess various nondestructive inspection (NDI) technologies for wind blades **in the lab, factory and in the field**

- Including ultrasonics and other technologies

- There are a large number of ultrasonic inspection options available for detection of subsurface flaws in spar cap structures.
  - Ability to customize hardware for specific needs and price range
  - Phased array and linear array probes allow for more rapid inspection when compared to single element inspection.
- Carbon spar caps can be challenging to inspect when compared to fiberglass.

- Recommended: Low frequency (0.5 to 1 MHz)
  - Phased or Linear array with 40 mm stand off
  - Soft interface that couples well with varying contours (included rolling wheels)
  - Encoder mountable

Wind Energy
Blade Reliability Collaborative (BRC)

Detection of Hidden Flaws in Composite Wind Turbine Blade Structure

Tom Rice, Dennis Roach, Stephen Neidigk,
Randy Duvall and Josh Paquette
Sandia National Labs

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

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

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

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Wind Blade NDI Probability of Detection Experiment

- Blind experiment: type, location and size of flaws are not know by inspector
- Statistically relevant flaw distribution – Probability of Detection (POD)
- Used to analytically determine the performance of NDI techniques – hits, misses, false-calls, flaw sizing, human factors, procedures

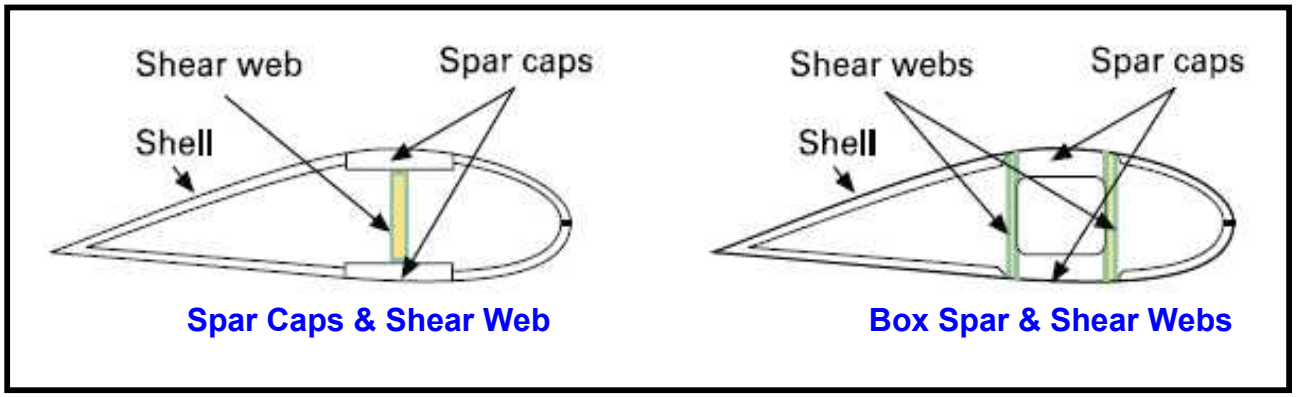
Experimental Design Parameters

- Representative design and manufacturing
- Various parts of blade such as spar cap, bonded joints, leading and trailing edge
- Statistically valid POD (number, size of flaws and inspection area)
- Random flaw location
- Two days to perform experiment
- Deployment

Fabrication Considerations

- Realistic, random flaw locations
- Portable sample set
- Range of thickness
- Material types (fiberglass, carbon and various adhesives)
- Who will manufacture

Designed to be applicable to various blade construction



Spar Caps & Shear Web

Box Spar & Shear Webs

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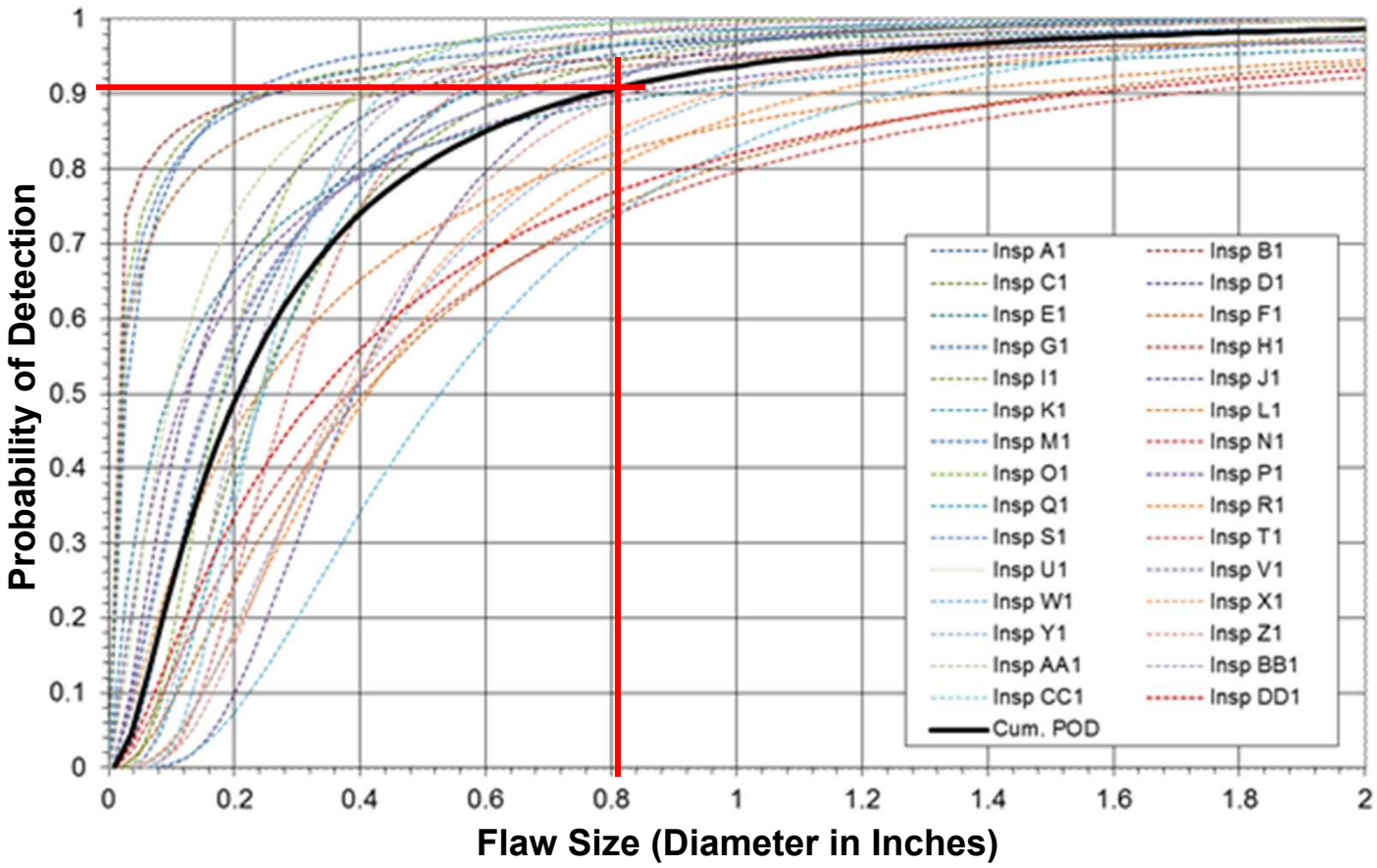
Aerospace Experiment – POD for Solid Laminat

Individual and Cumulative Comparisons



Overall:
$POD_{[90/95]}$ = 0.82" dia.

What improvements will advanced NDI provide?

False Calls: Constant thickness = 0.8/inspector
Complex Geometry = 0.3/inspector
12 ft.² inspection area

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Wind Blade Probability of Detection Experiment

What We Need

- Qualified Inspectors
  - Wind blade manufacturing companies
  - Blade service companies
  - Wind farms
  - NDI equipment development labs
- 2-2½ days of your time

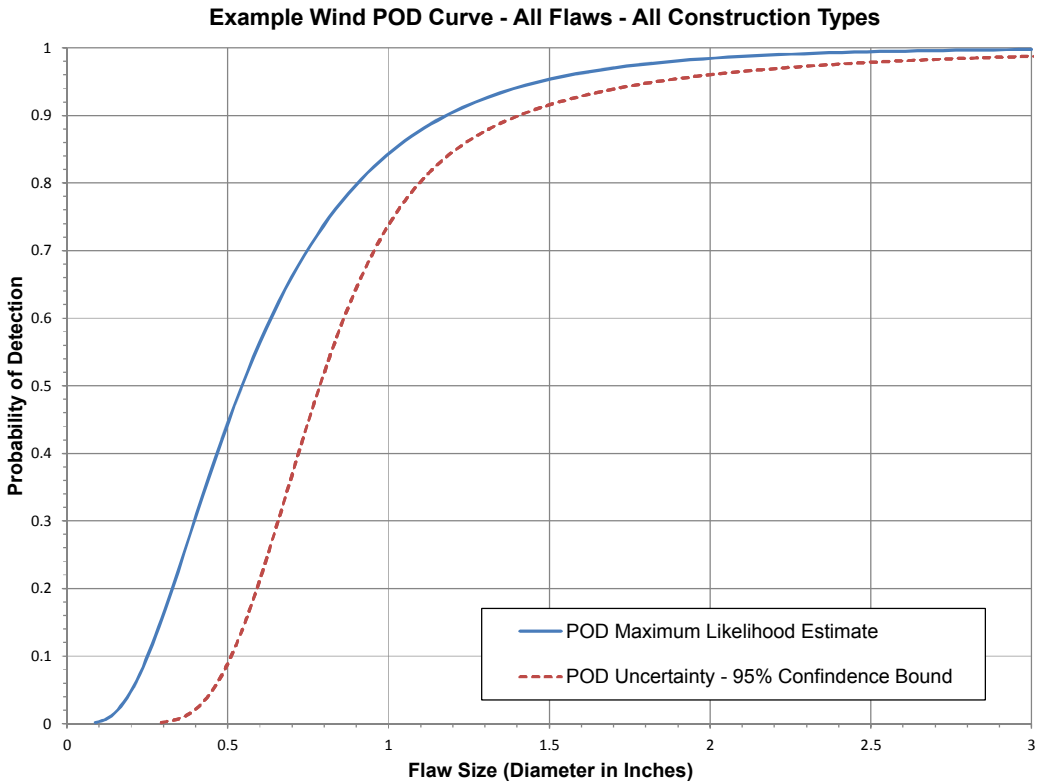
How Does This Benefit You?

- Training perspective, inspections on representative blade structure
- Inspector will receive feedback on how they performed
  - PoD Value, smallest flaw size detectable with 95% confidence
  - Number of flaws detected
  - Number of flaws missed
  - Number of false calls, if any
  - Flaw sizing
  - Location and type of flaws missed

Wind POD Experiment is UNDERWAY

Completed fabrication of 11 POD Specimens

- 11 POD specimens with spar cap and shear web geometry
- Thickness ranges from 8 Plies (0.45” thick laminate, 0.85” thick with adhesive bond line) to 32 Plies (1.80” thick laminate, 2.20” thick with adhesive bond line)
- All panels painted with wind turbine blade paint (match inspection surface)



Wind Blade Probability of Detection Experiment

If you are interested in participating in this experiment or have other questions, please contact me using the following:

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Stephen Neidigk
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