Rapid Flaw Detection in Wind Turbine Blade Assemblies Using Phased Array Ultrasonics

Wind Turbine Blade Workshop

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Sandia National Labs

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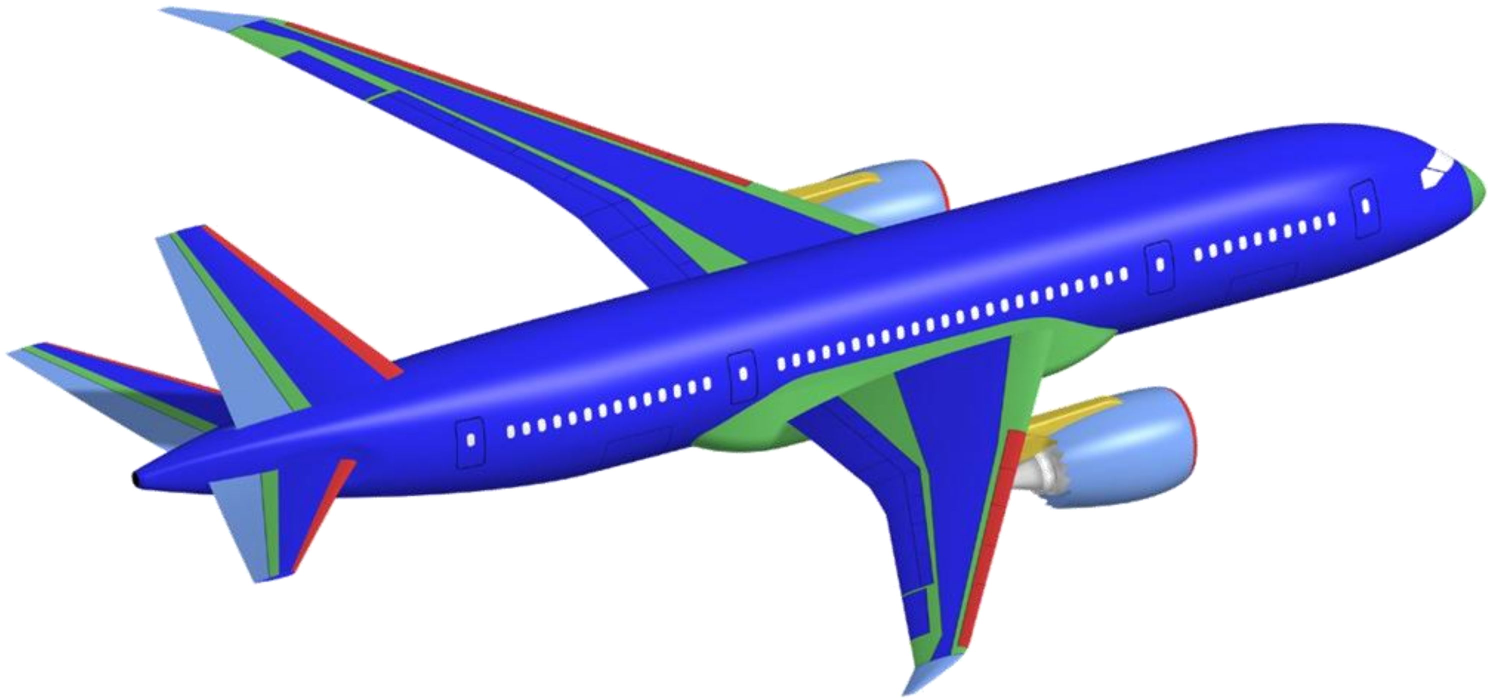
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

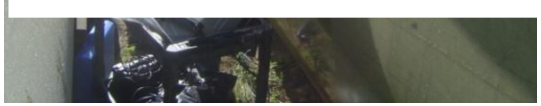
Blade Reliability Collaborative
Advanced Manufacturing Initiative
Objectives

Create the ability for manufacturers to determine the quality of their product before it leaves the factory

- **Dev… ins… ne bla…**
- **Pla… nce and met… ues**
- **Pro… detect unc…**



FAA Airworthiness Assurance Center operated by Sandia Labs



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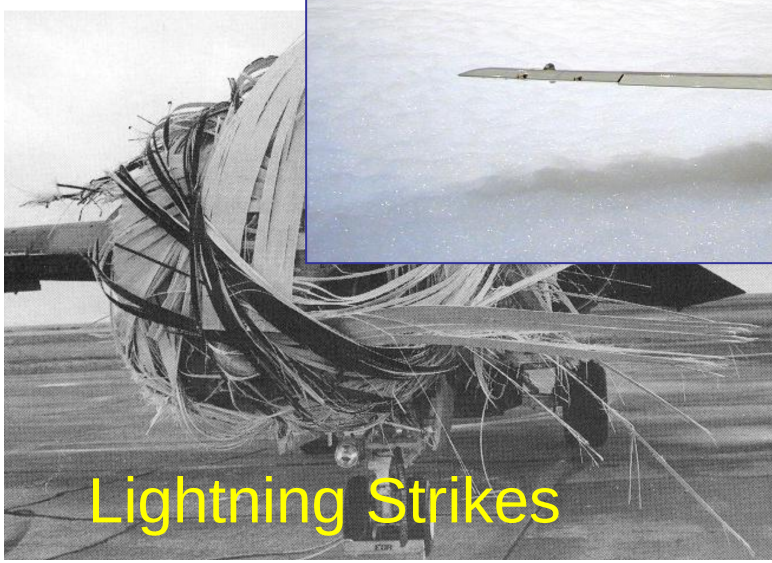
Jackstands

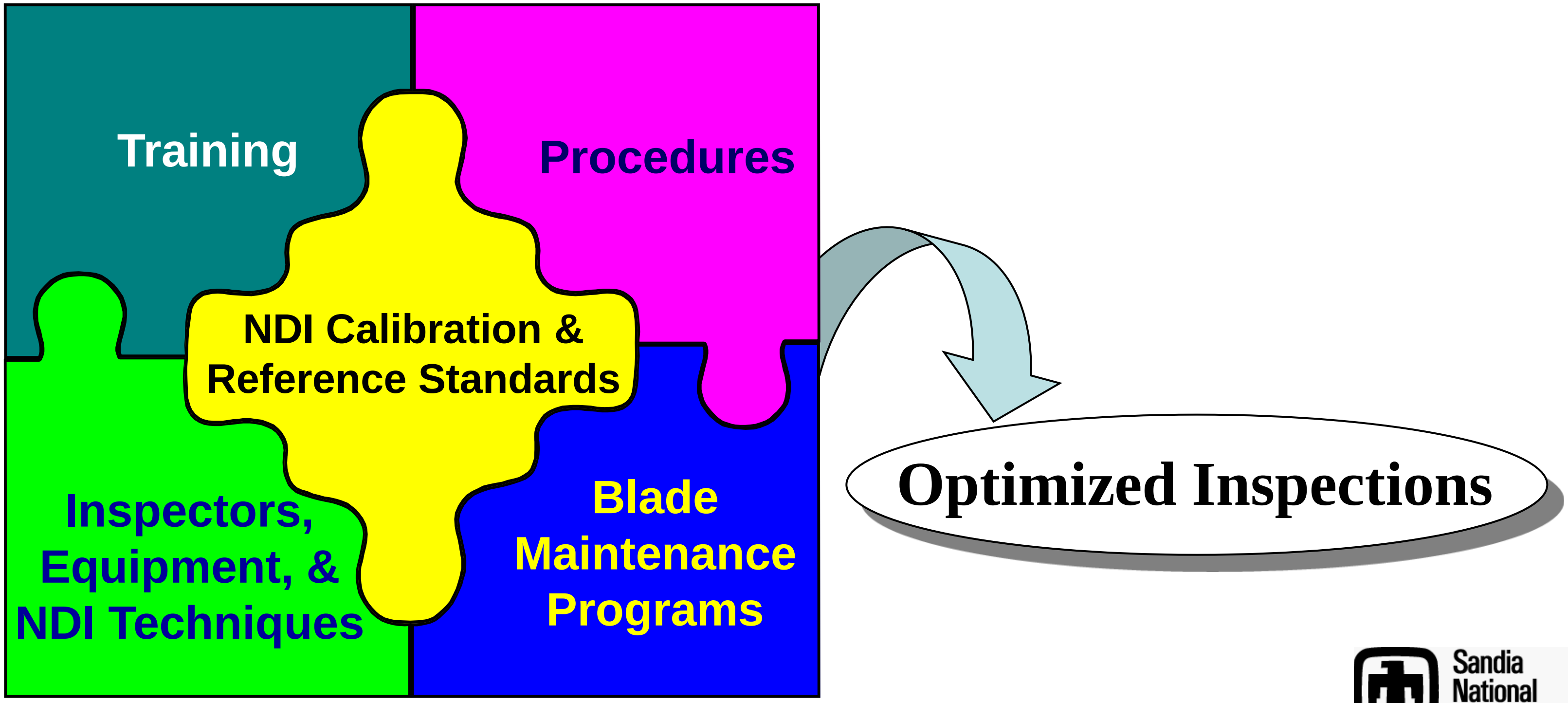

d Handling
t Damage


Lightning Strikes

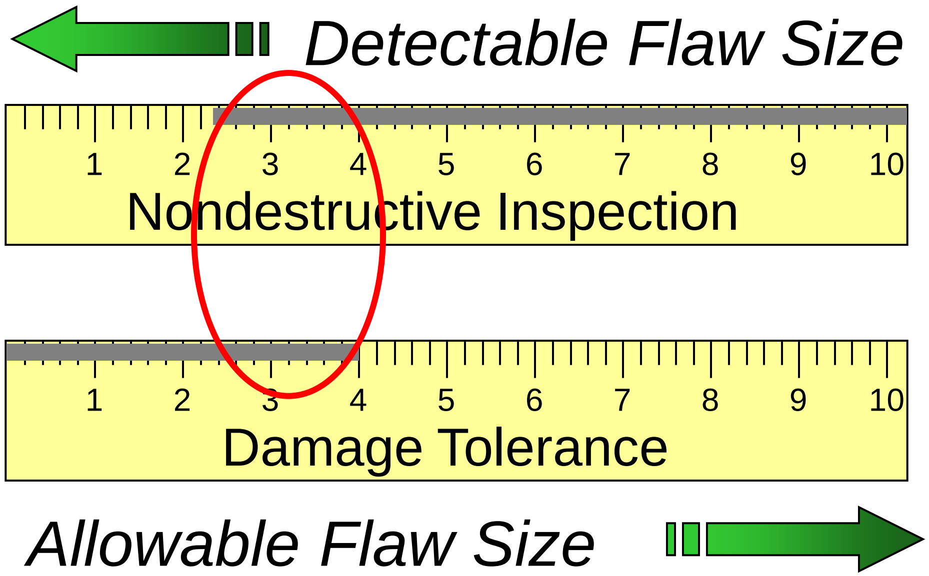

Bird Strikes

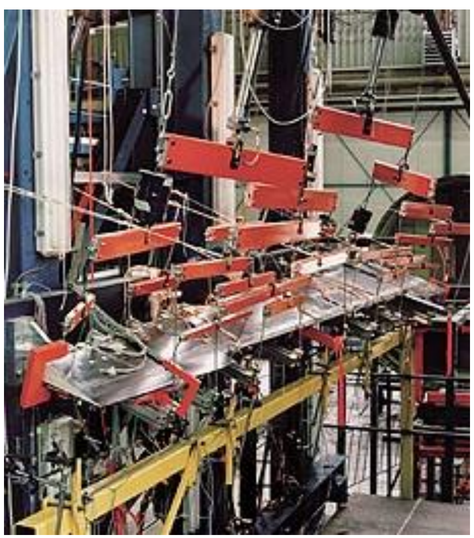
Program Thrusts to Improve Wind NDI

- Use of NDI reference standards to form sound basis of comparison & ensure proper equipment set-up
- Use of material property & calibration curves (attenuation, velocity)
- Human factors – adjust procedures, automate, streamline
- Improved flaw detection:
  - Advanced NDI – max signal-to-noise; image-based; sensitivity
  - Hybrid inspection approach - stack multiple methods which address array of flaw types (data fusion)

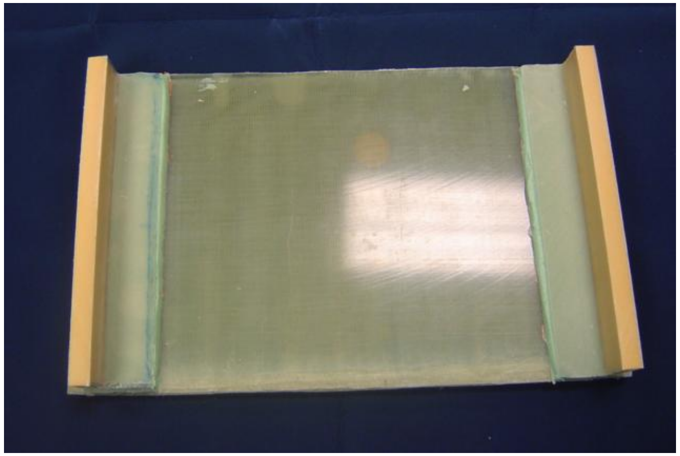


Required Relationship Between Structural Integrity and Inspection Sensitivity

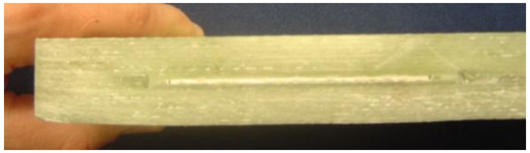




Engineered Flaws in NDI Feedback Specimens
Shear Web & Foam Core Specimens

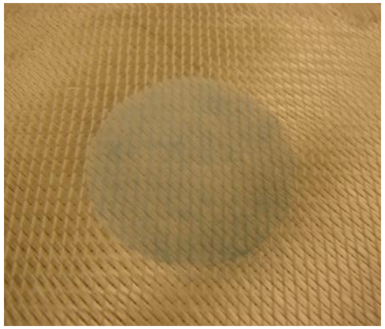


Shear Web/Spar with Disbonds and Delaminations

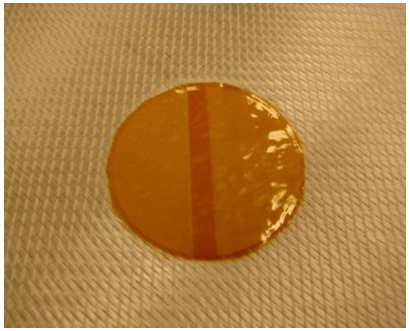


Dry fabric areas

Grease



Mold Release



Pillow Insert

Materials inserted into multiple layers

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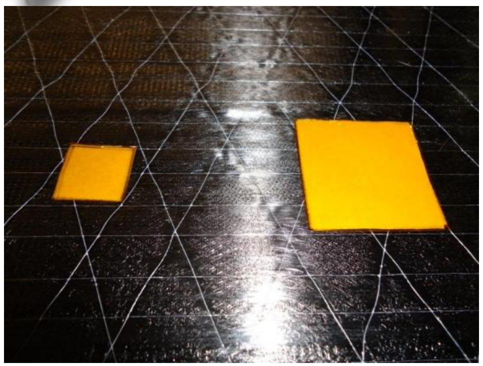
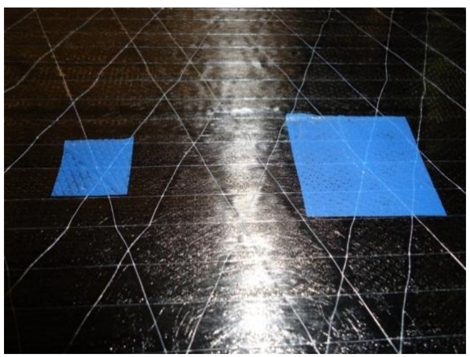
Samples of Different Flaw Types Engineered into Carbon NDI Ref Standards



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

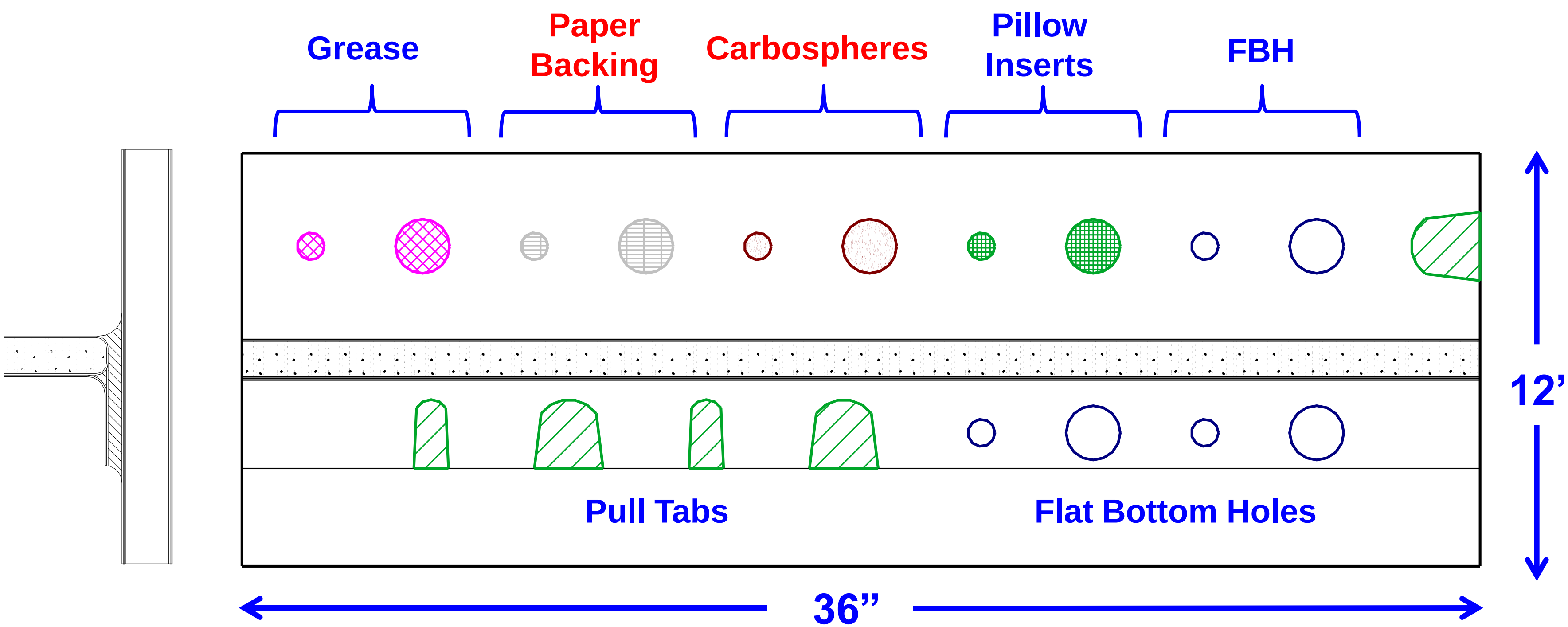
Adhesive Void

Fiberglass FOD

Carbon NDI Reference Standards

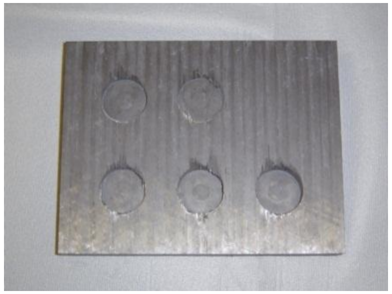
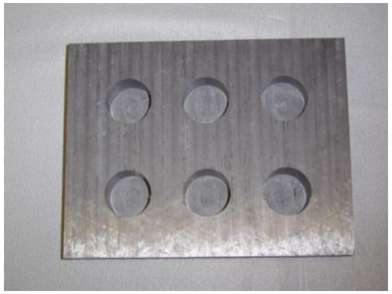
- Pre-Preg Carbon Material
- Up to ~ 2" thick
- Quality assurance cannot visually inspect through carbon
- Greater need for NDI during manufacturing

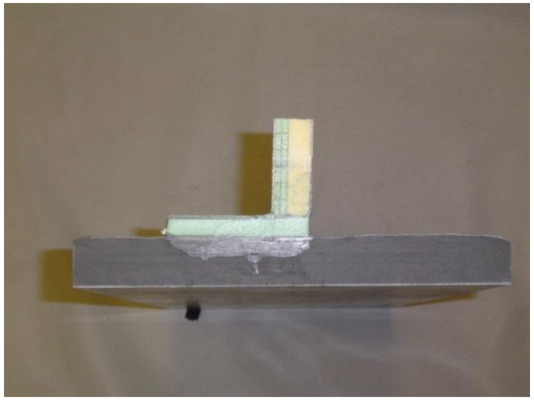
Carbon Fiber Spar Cap Assembly

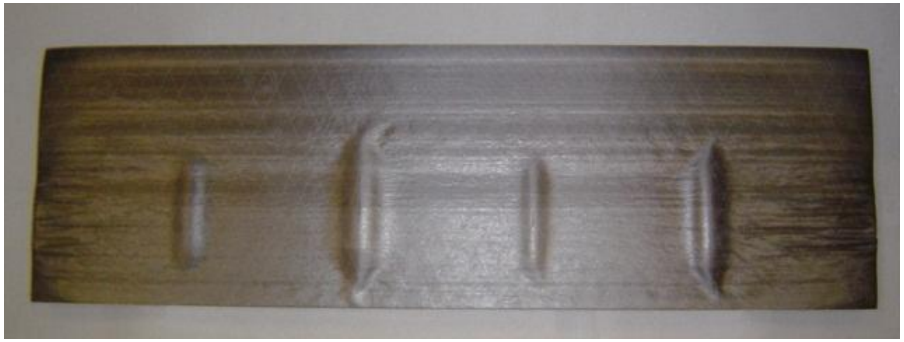


Completed NDI Reference Standards for Use at Blade Manufacturing Facilities

- 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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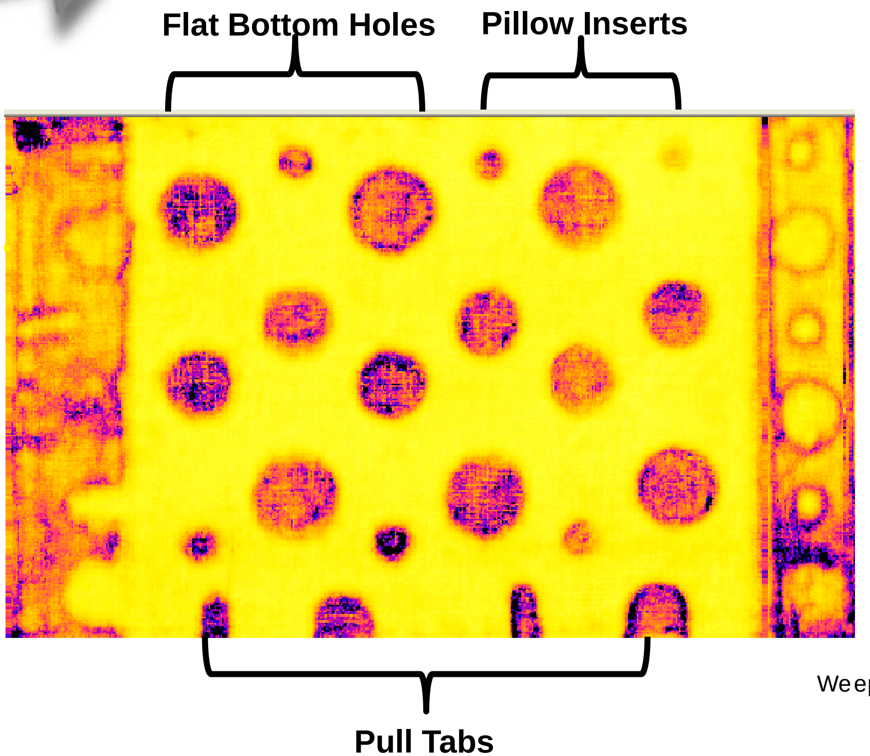
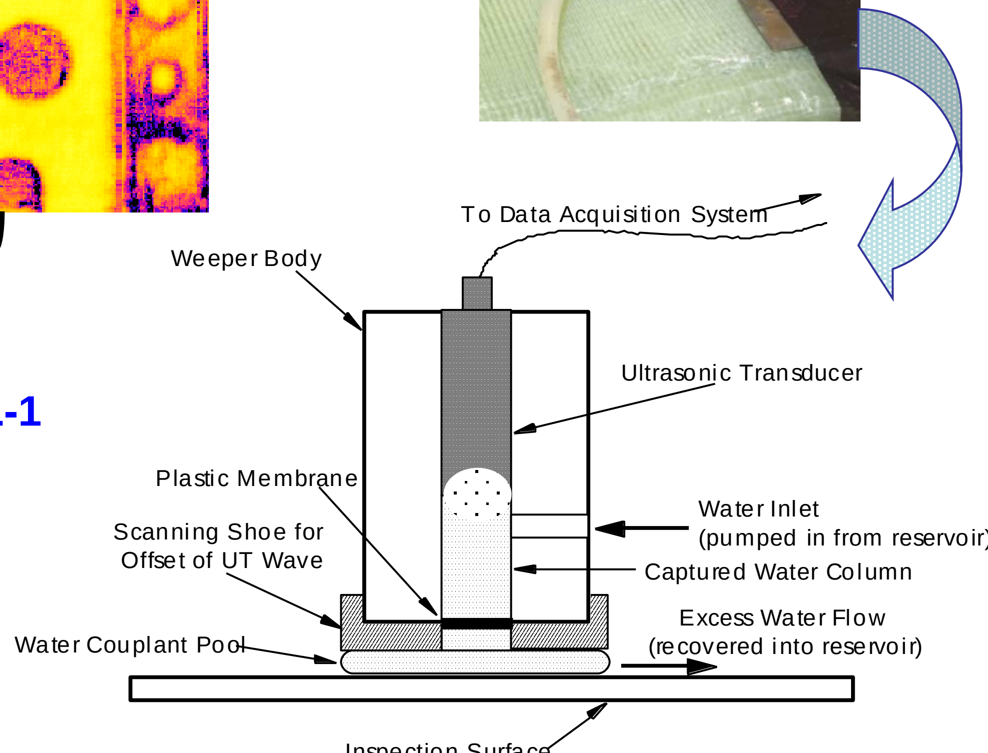
MAUS P-E UT with Focused Probe (1 MHz/2") and Adjustable Water Path



REF-STD-6-202-250-SNL-1

New "Immersion" Probe Holder Allows for Adjustable Water Path



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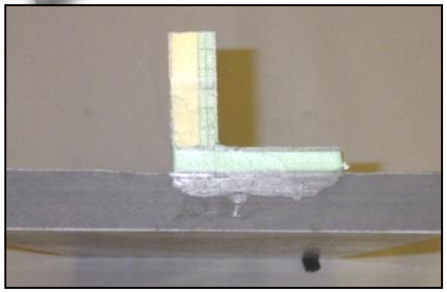
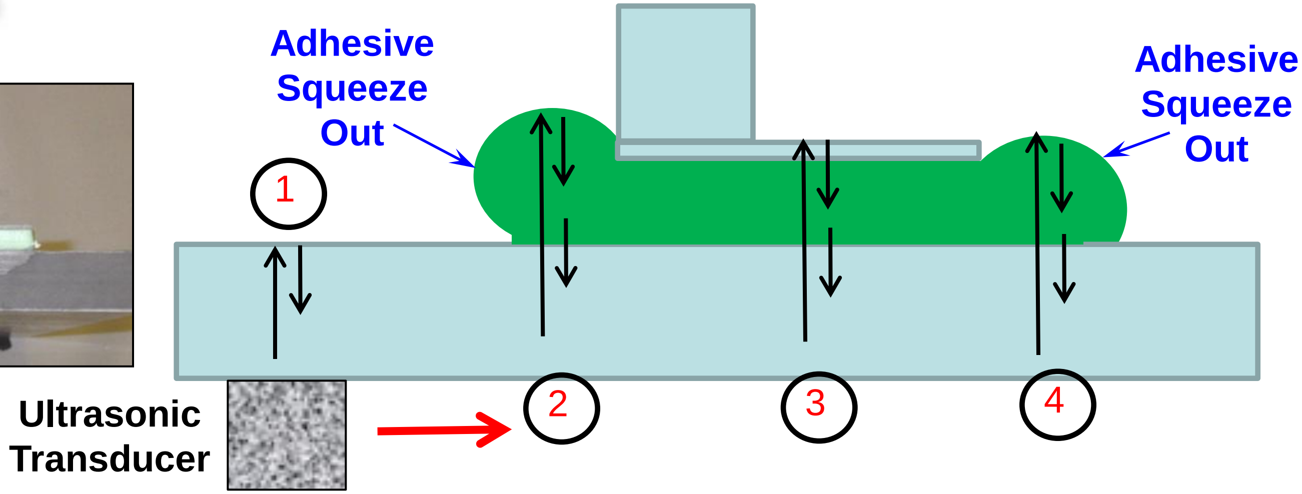
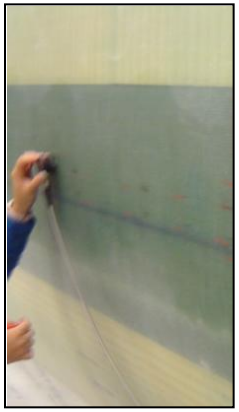
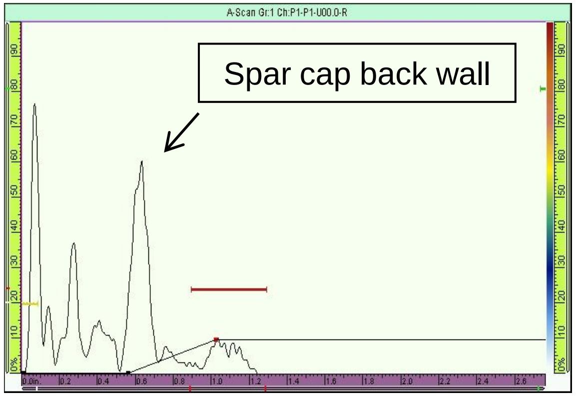
Pulse-Echo Inspection of Bond Joint

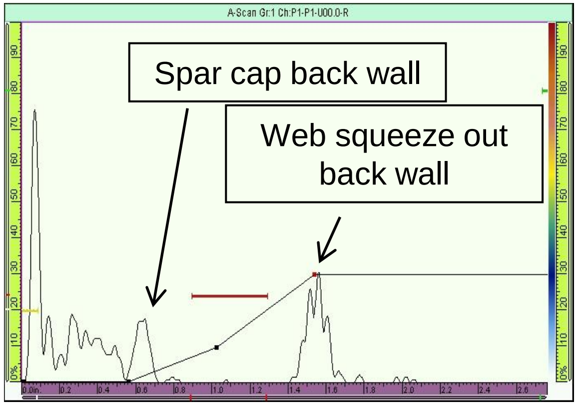




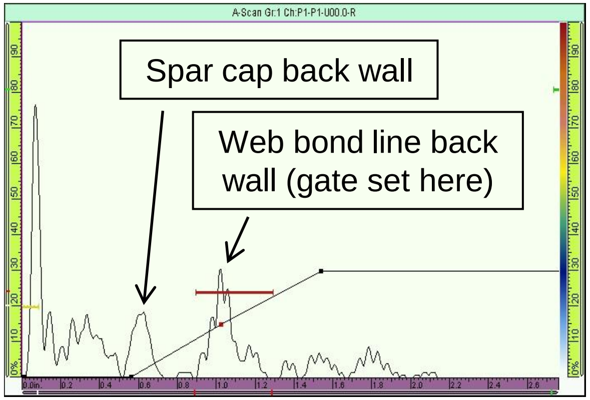




Spar Cap - 1

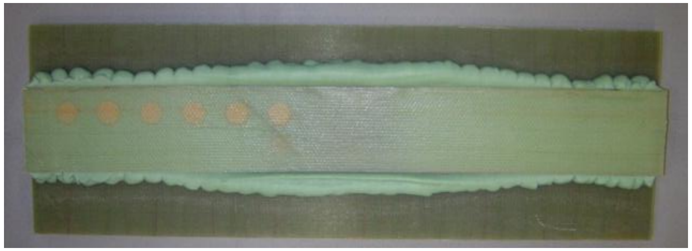


Web Squeeze Out- & 2 4



Web Bond Line- 3

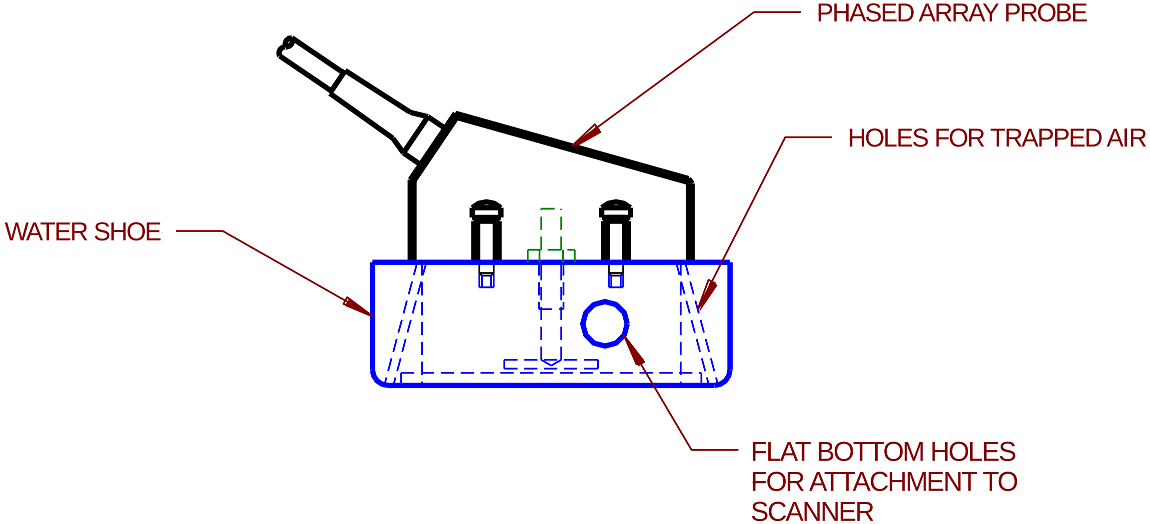
A-Scan Signals



Phased Array UT Using Water Shoe

Advantages of using water shoe:

- **Better/cleaner scanning signal response (less noise) which results in a better signal-to-noise ratio for flaw detection**
- **Better coupling - no signal dropout and easier clean-up than couplant**
- **Easier to deploy over scanned surface**



Challenges – Requires custom contour, cannot tolerate thick foam seal at base, difficult to maintain seal when deploying vertically

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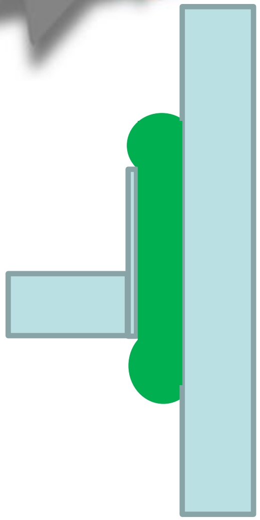
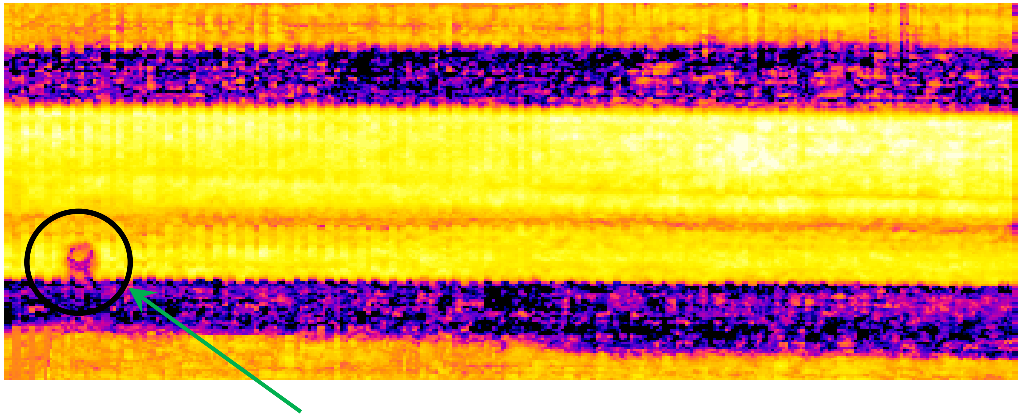
On-Blade Bond Line Testing with Phased Array UT Scanning



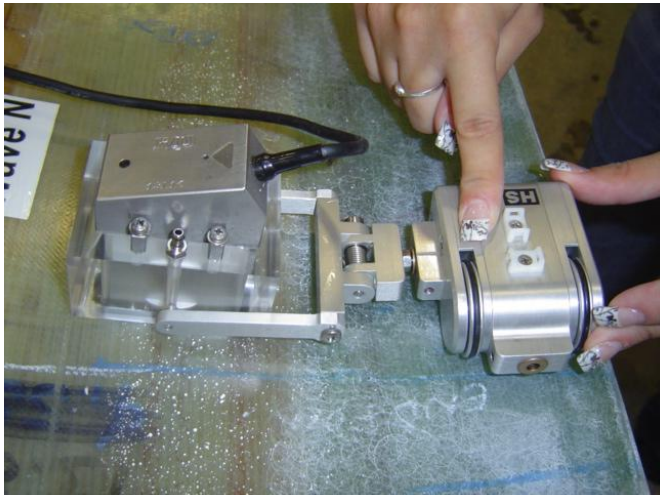


Anomaly in Bond Line

Phased Array Inspection

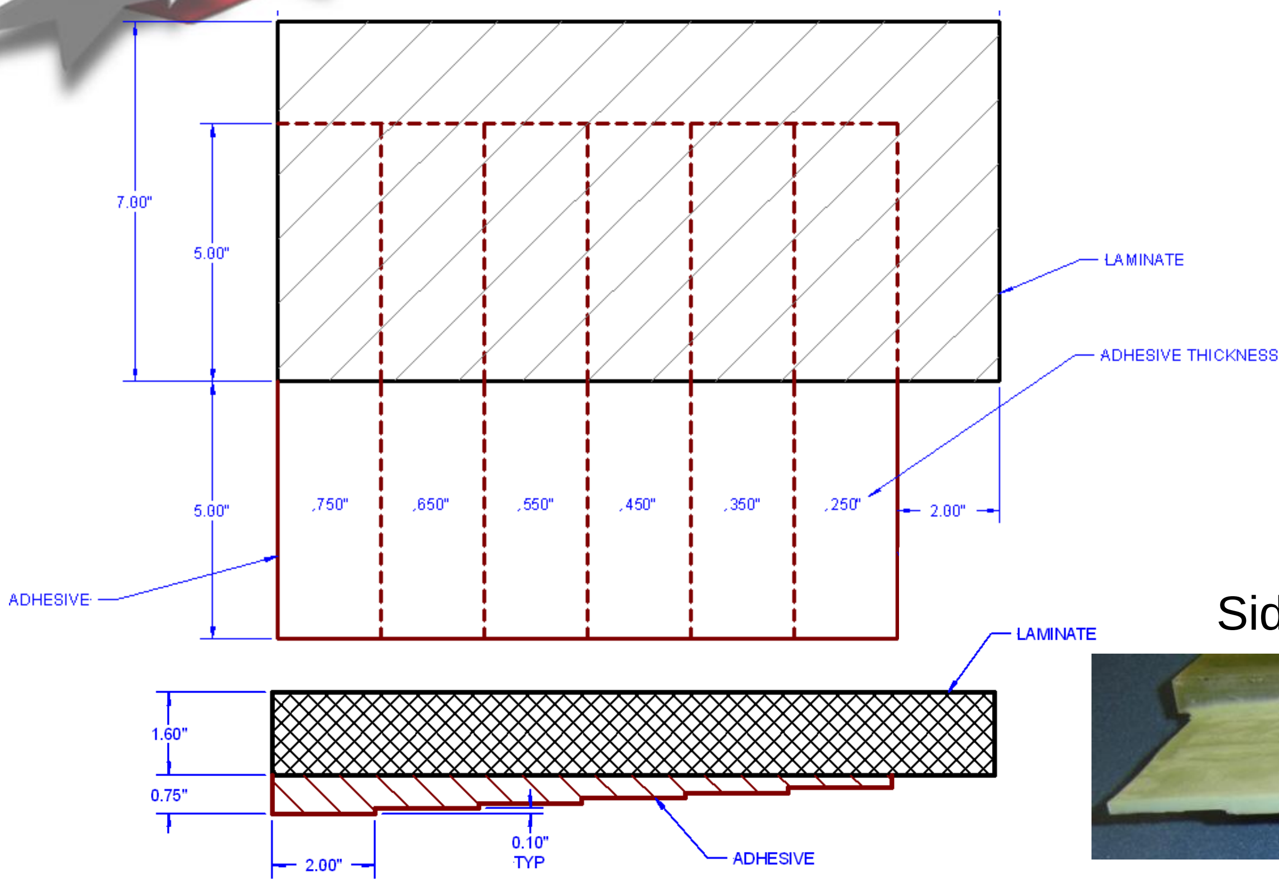
Inspections must address all field deployment issues:

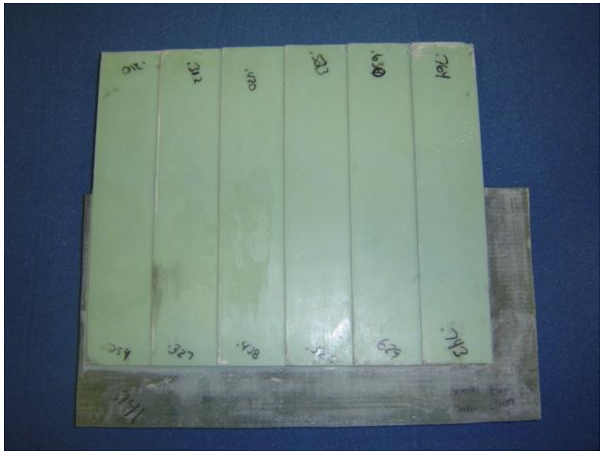
- Vertical and horizontal inspection surfaces
- Hand scan vs. attachable scanner
- Signal coupling – water flow, air bubbles
- Wide range of thicknesses (gate adjustments)
- Quantitative information
- Ease and rate of inspection



Use of Position Encoder

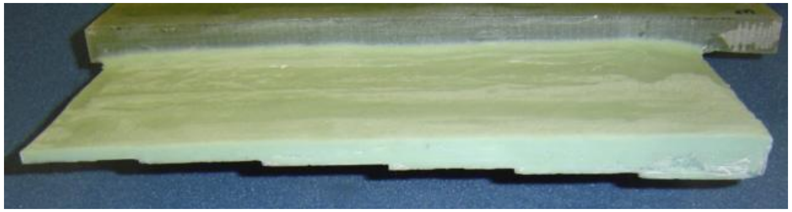
NDI Ref Std – Adhesive Step Wedge

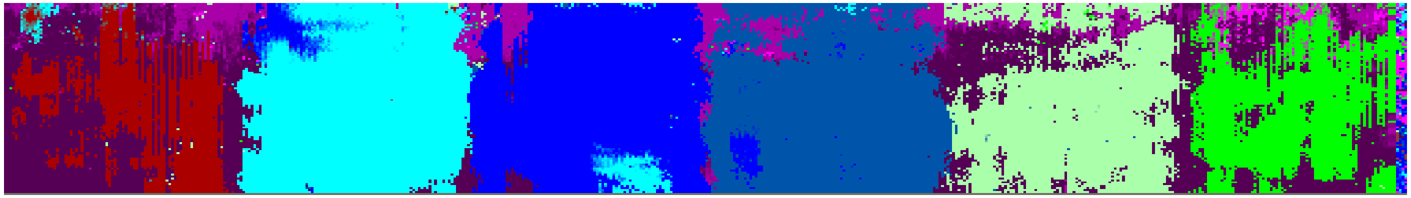




Bottom View

Side View - Adhesive Area





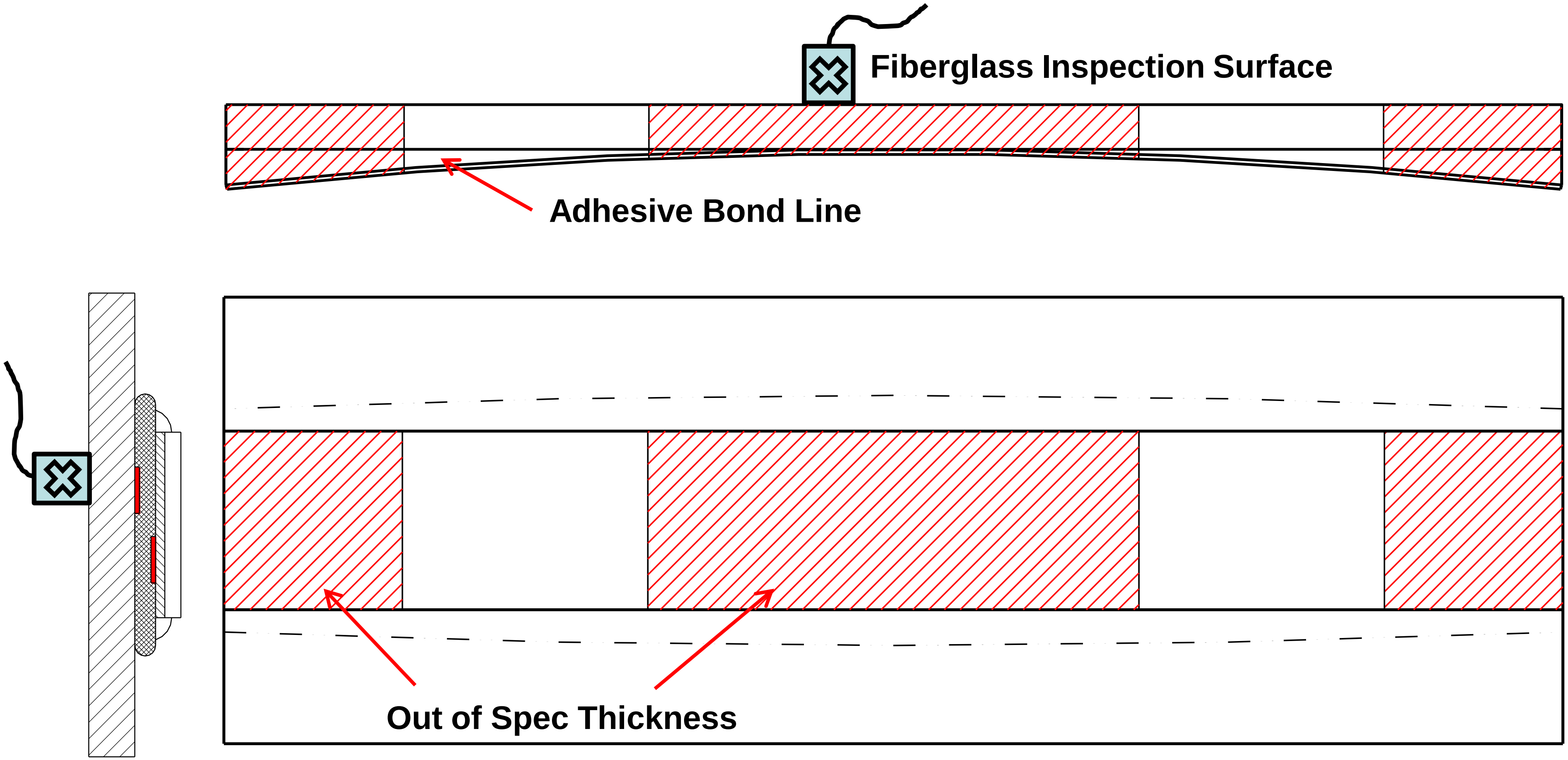
(1.01) (1.07) (1.18) (1.26) (1.37) (1.48)

Thin → Thick

UT C-Scan Using Time of Flight

Adhesive Wedge NDI Reference Standard

Goal: Develop and assess methods to rapidly inspect/quantify bond line thickness

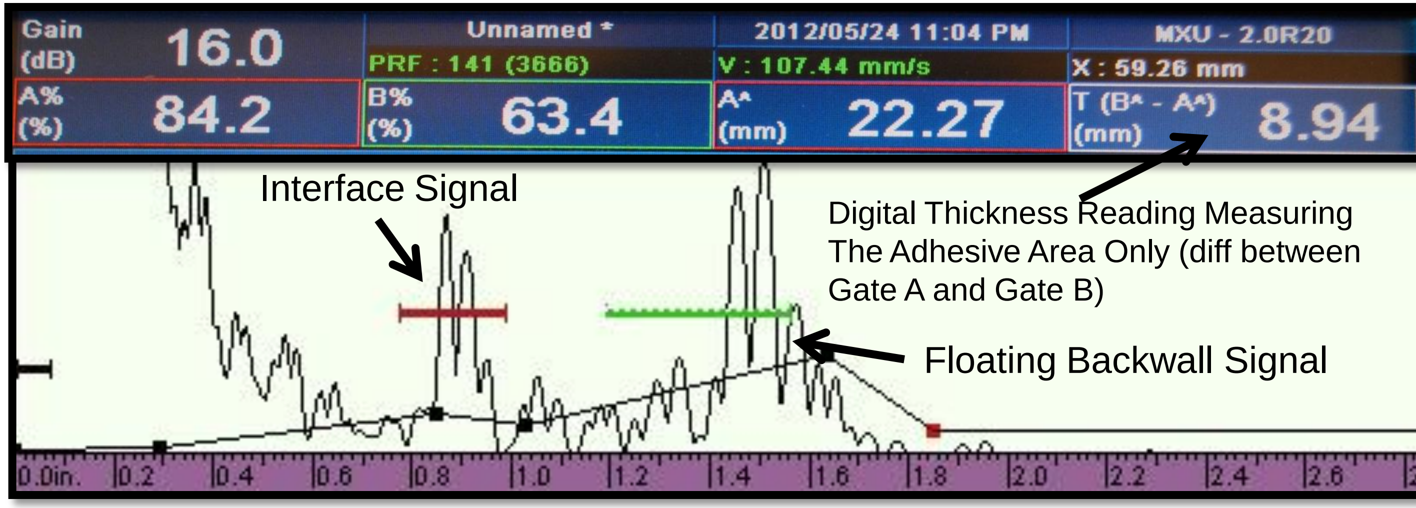


Tapered Adhesive Wedge

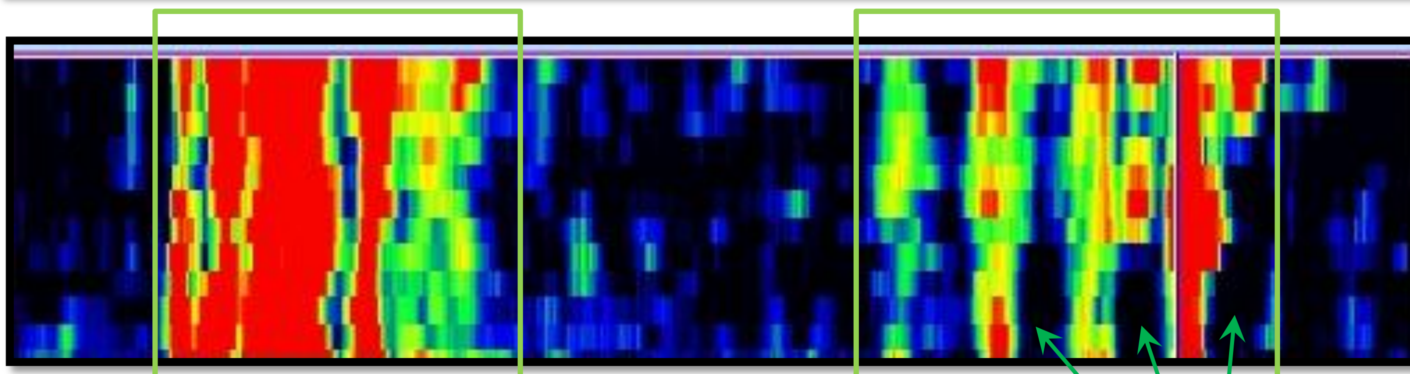
Adhesive Thickness Measurements with Phased Array UT

Omniscan UT Device 1.5L16 (1.5 MHZ) Phased Array Water Box REF-STD-F6-086-TW-A

Use of Dual Gates to Quantify Bond Thickness

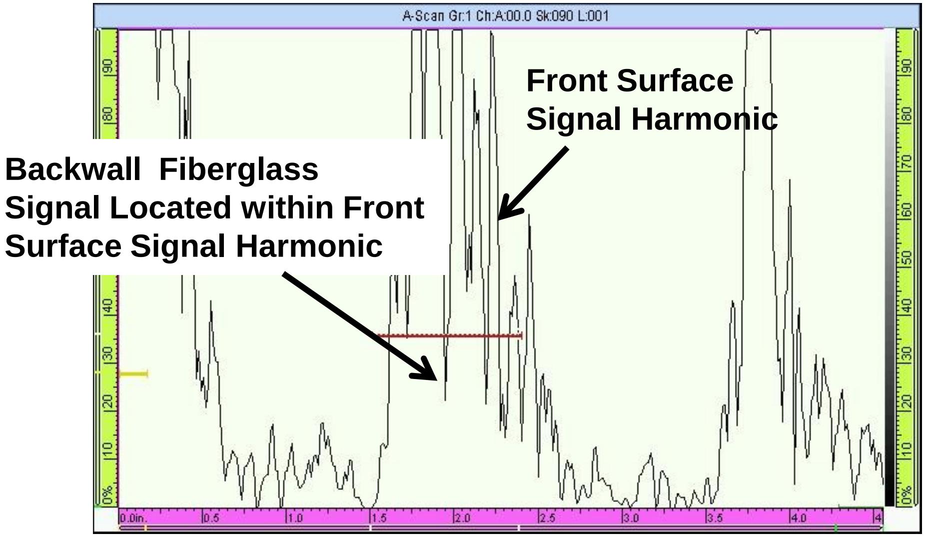


Amplitude C-Scan Produced by Green (B) Gate Set Across Proper Bond Line Thickness

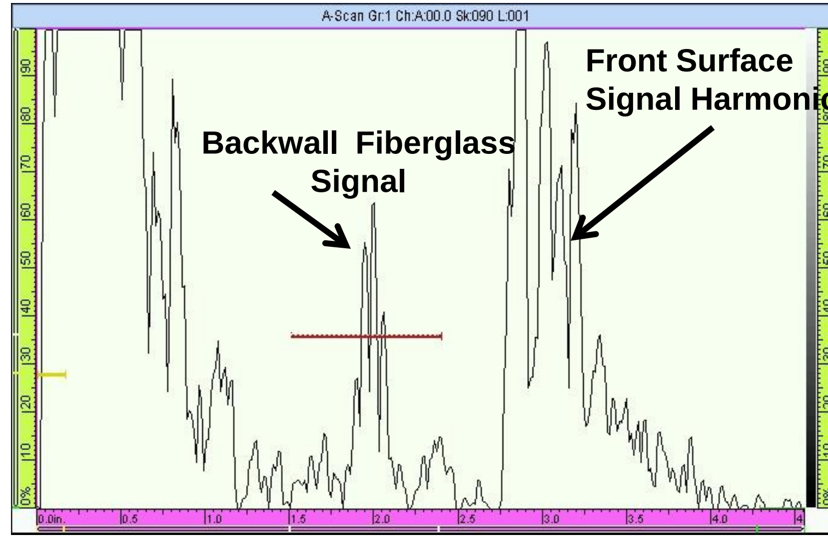


Design of Delay Lines to Avoid Signal Interference

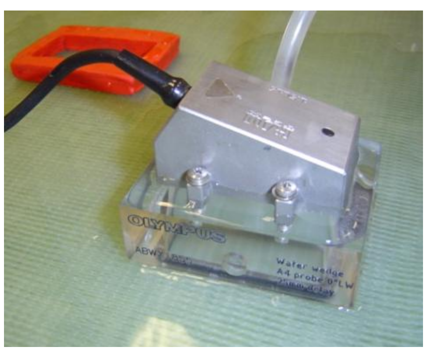
Water Box Signal Analysis - 25mm compared to 40mm; Moves harmonic return signal outside area of interest.



25mm Delay



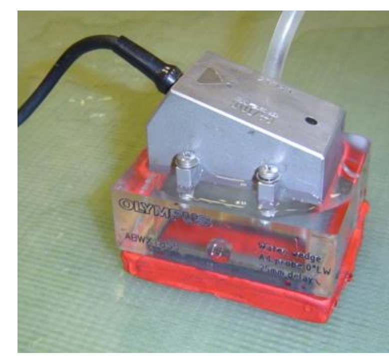
40mm Delay



1.5 MHz Phased Array UT Probe

Sandia has focused on a sealed couplant box that:

- Adjusts to slight curvature in surfaces
- Eliminates water flow to open box
- Maximizes signal strength
- Accommodates necessary standoffs for signal clarity
- Easily saves scanned images for reference using a wheel encoder



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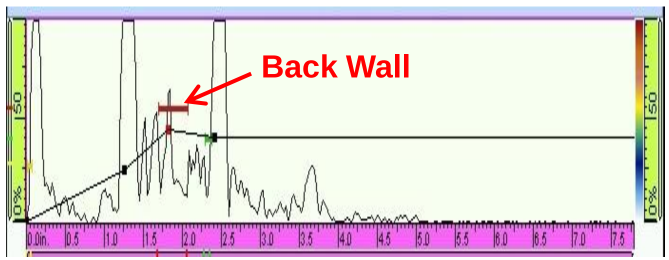
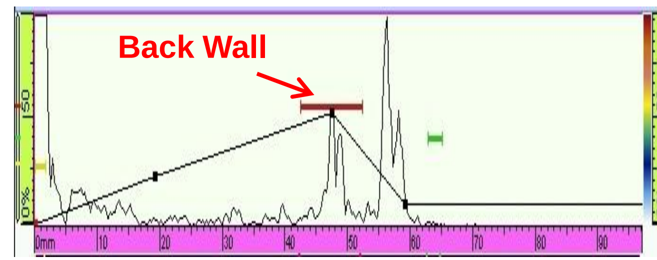
Probe Housing Development for Factory/Field Deployment

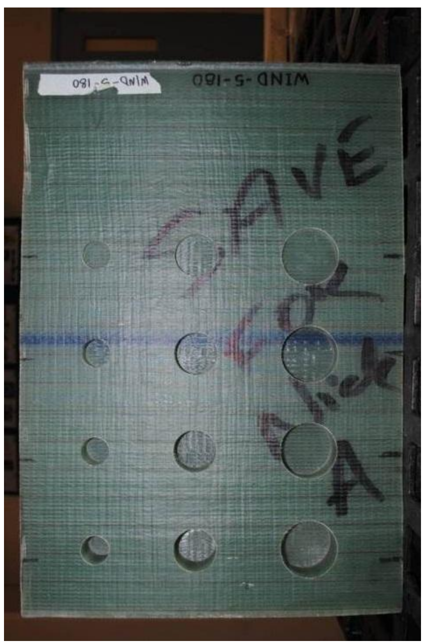
Goal is to develop a sealed water path that produces clear signal through a wide range of <u>thicknesses</u> (up to 2.5 inches) and <u>curvatures</u>

25 mm Sealed Box

40 mm Sealed Box





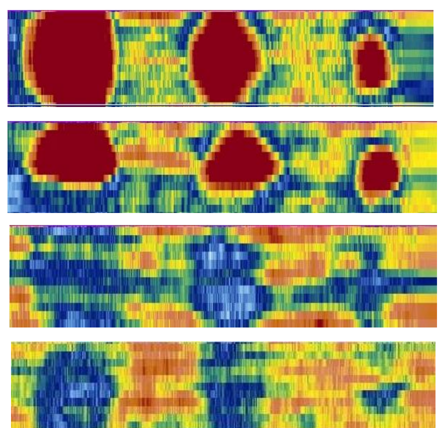


Scan 1

Scan 2

Scan 3

Scan 4

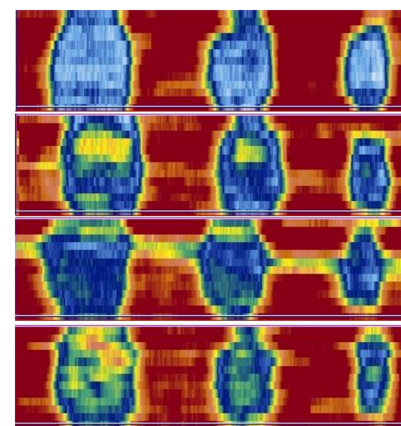


Scan 1

Scan 2

Scan 3

Scan 4



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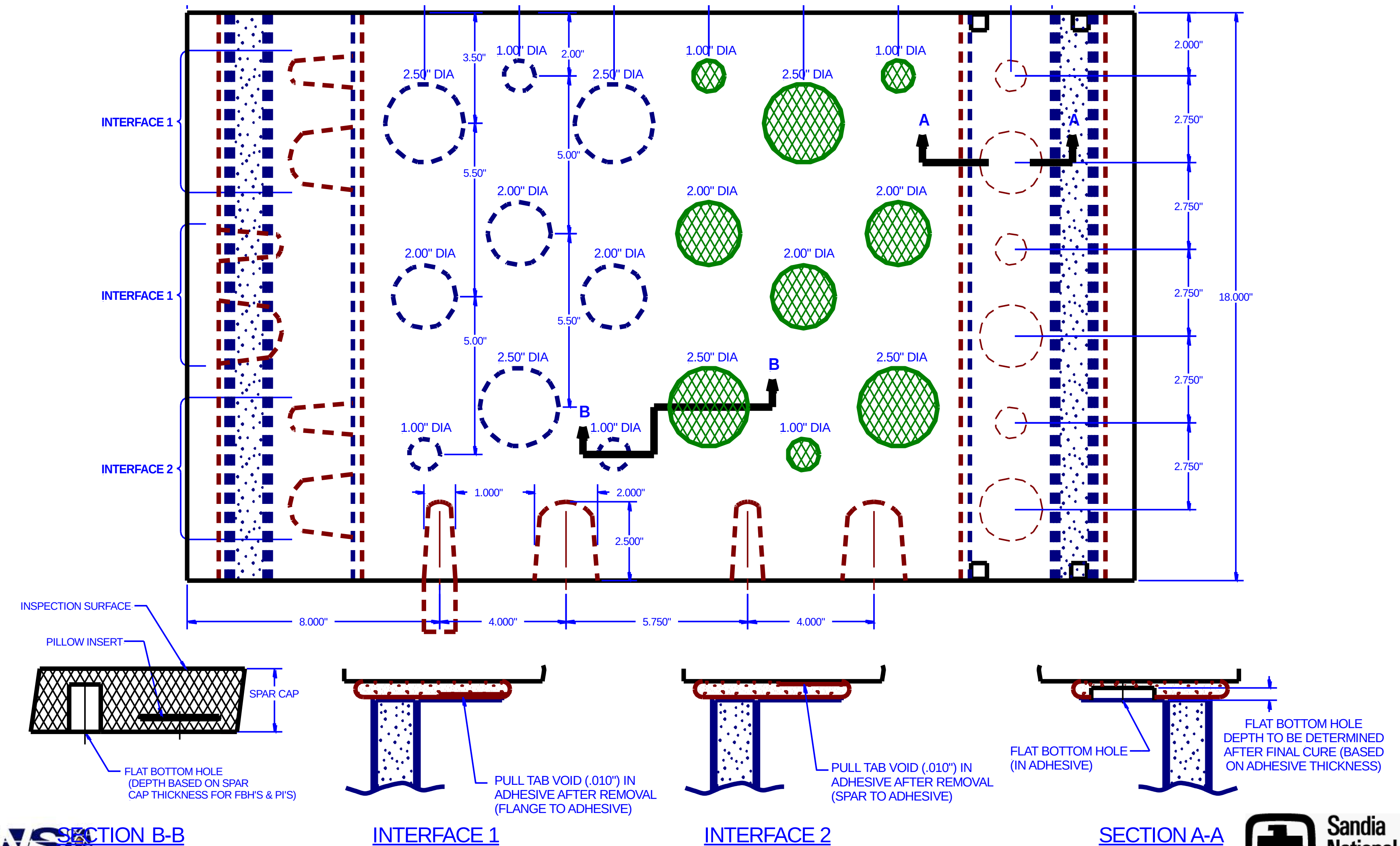
Spar Cap and Shear Web NDI Feedback Specimen No. 6

Thicker specimen: REF-STD-6-202-250-SNL-1



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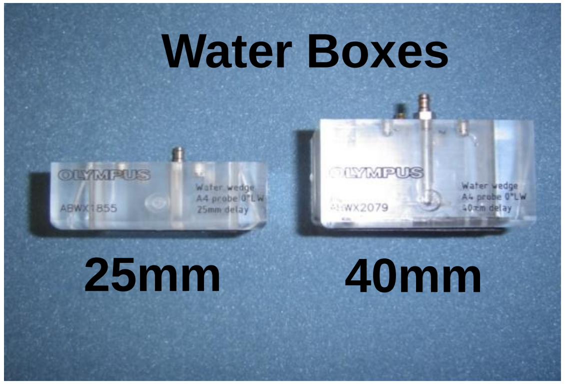
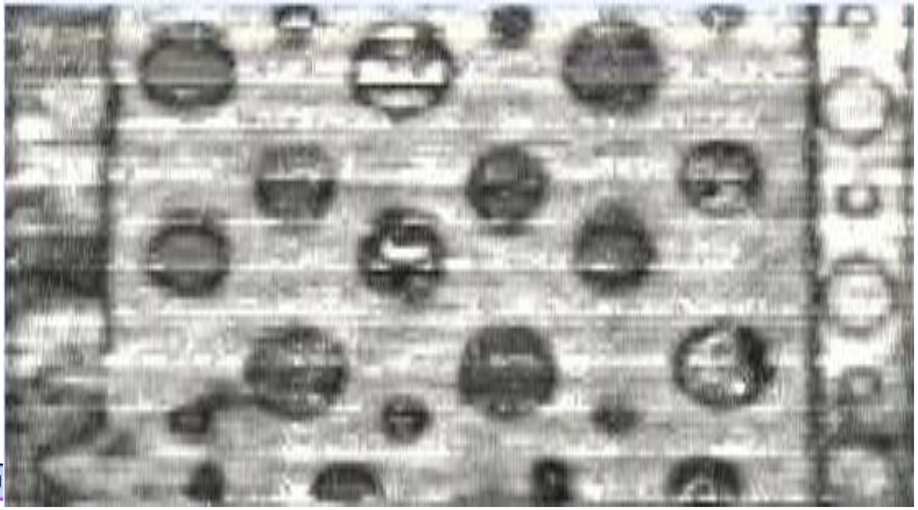
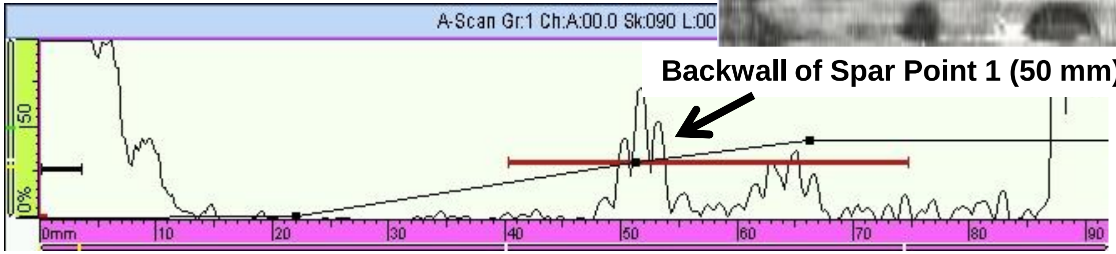
Spar Cap and Shear Web NDI Feedback Specimen No. 6

REF-STD-6-202-250-SNL-1

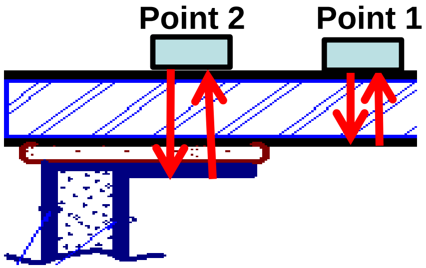
Omniscan Phased Array with 1.5 MHz & 40 mm Water Box

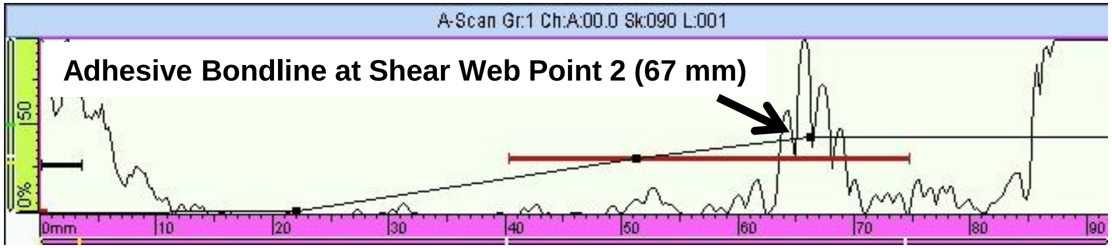






Backwall Signal From Spar Region Only

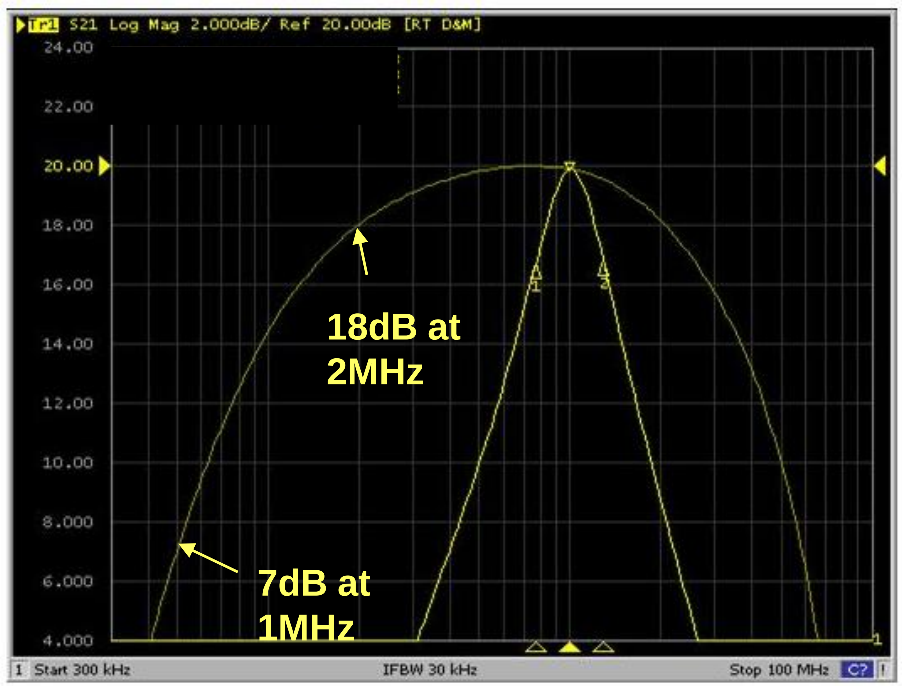




Backwall Signal From Adhesive Bondline at Shear Web

Frequency Characteristics of UT Pulser

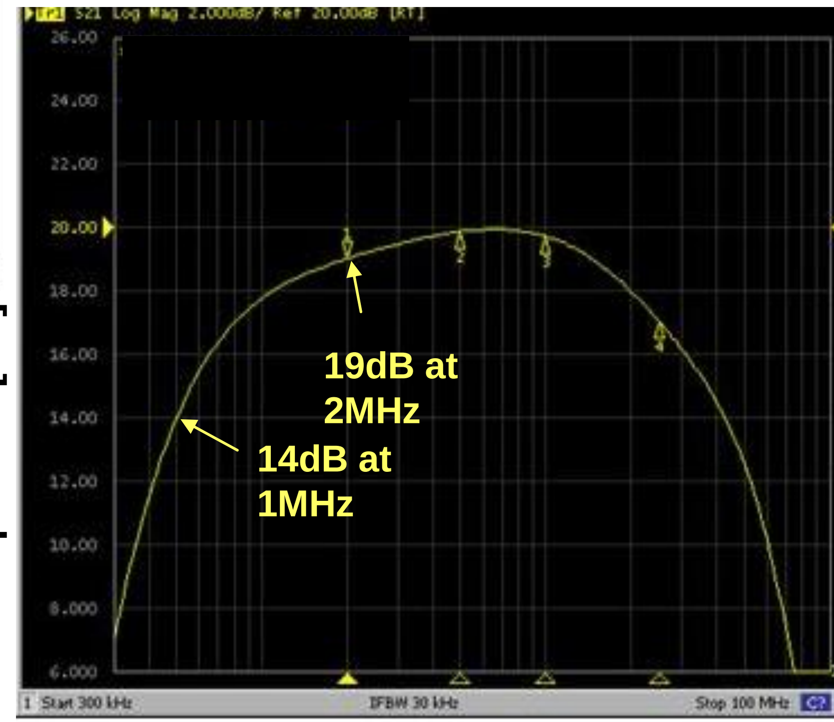
Amplitude [dB]



Frequency [dB]

Optimal excitation for depth of penetration

Amplitude [dB]



Frequency [dB]

Sandia has requested increase of pulse width to 1 micro second, which is half of 0.5MHz wave length

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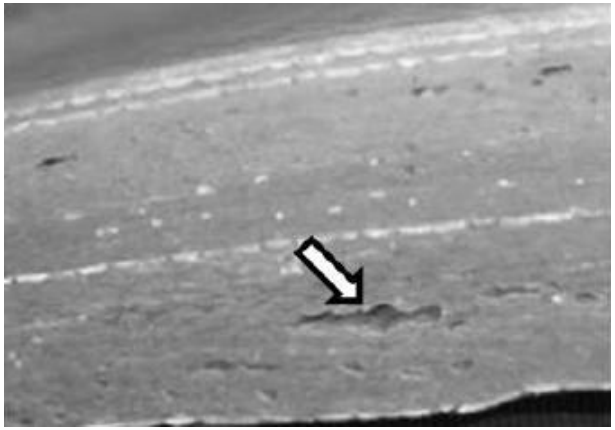
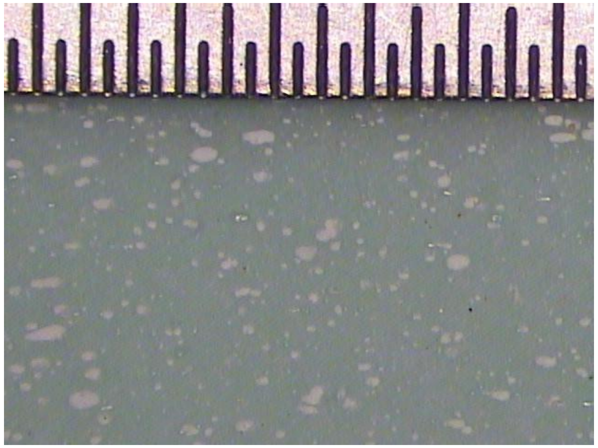
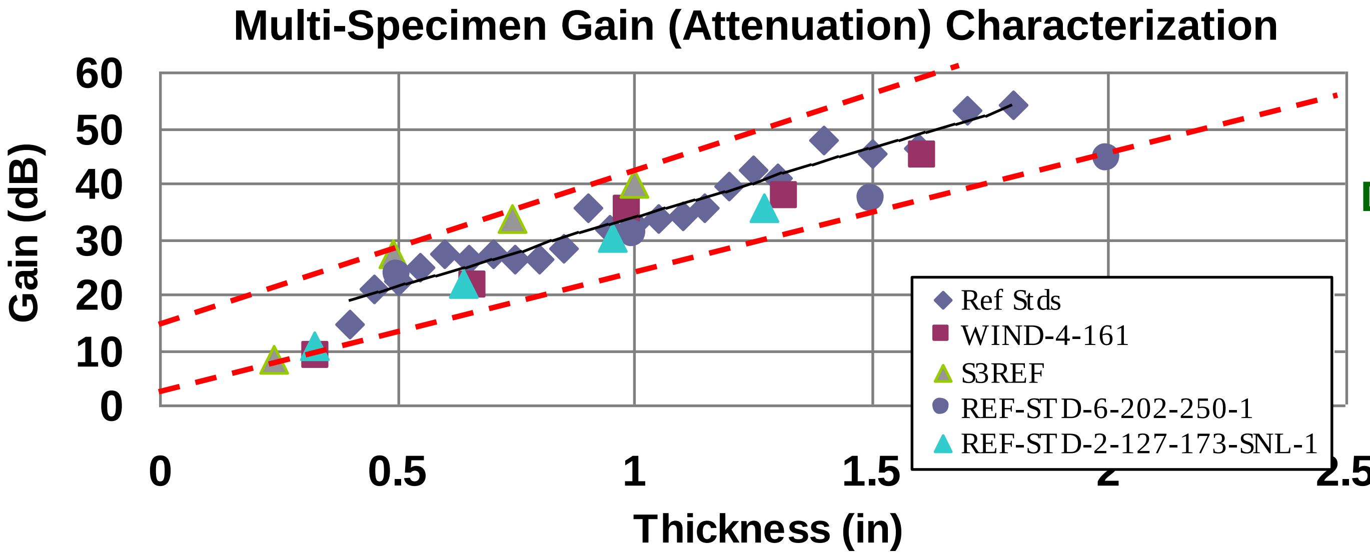
Ultrasonic Characterization of Solid Laminates and Adhesive - Porosity

Goal: work with wind blade manufacturing sites to accumulate a series of porosity measurements, along with corresponding UT attenuation and velocity and UT property measurements to generate calibration curves for use in production QA



Porosity Measurements - Optical Microscopy and Ignition Loss of Fiber/Resin





NDI Determination of Porosity Levels

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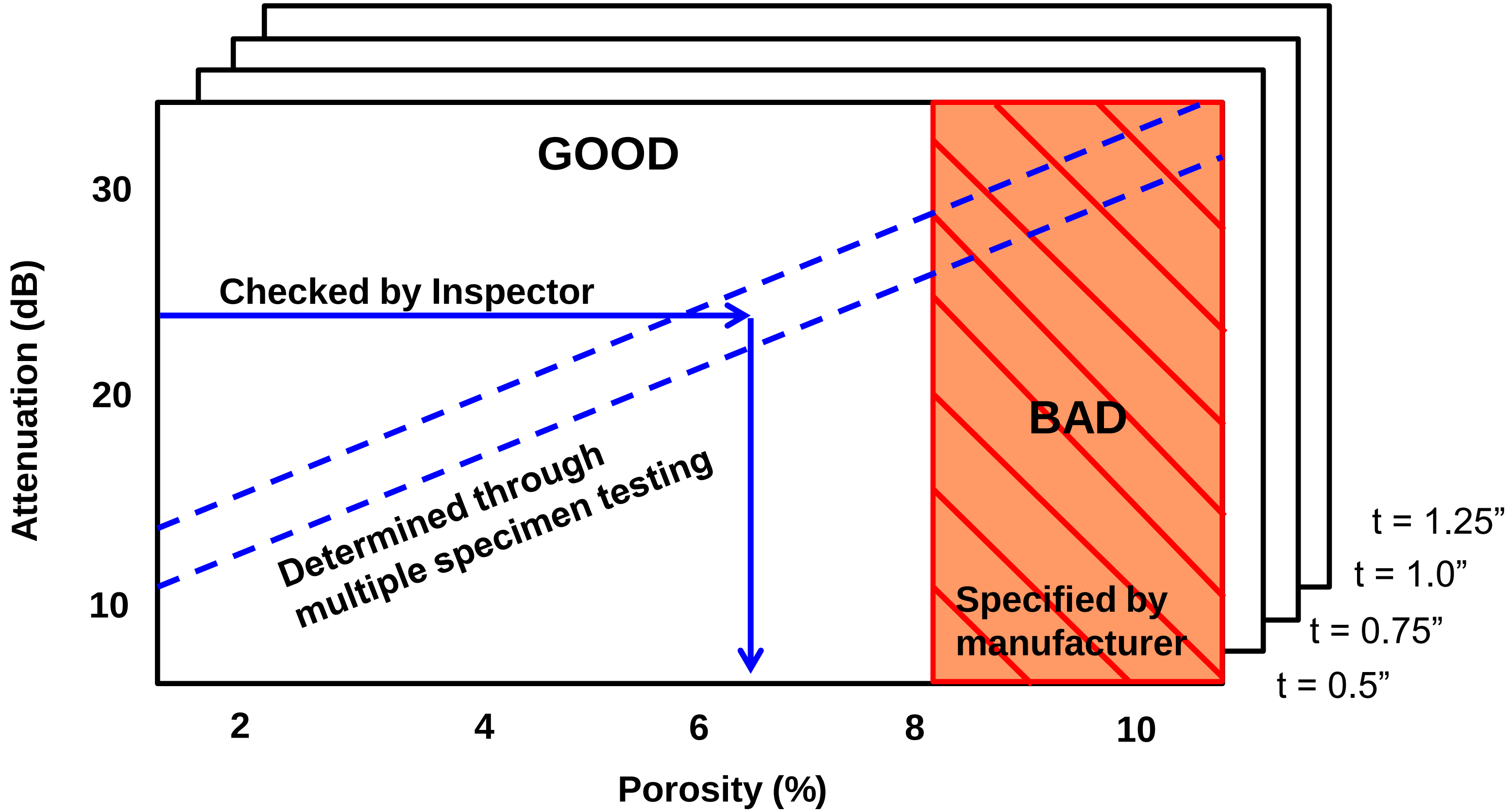
Quality Assurance Calibration Curves

How could quality assurance curves be used by inspectors to determine the quality of a blade?



Response calibration curve that can be used for QA – family of curves could produce an envelope of acceptable attenuation levels

Wind Blade Probability of Detection Experiment

- Representative blade specimens; realistic flaw types
- 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

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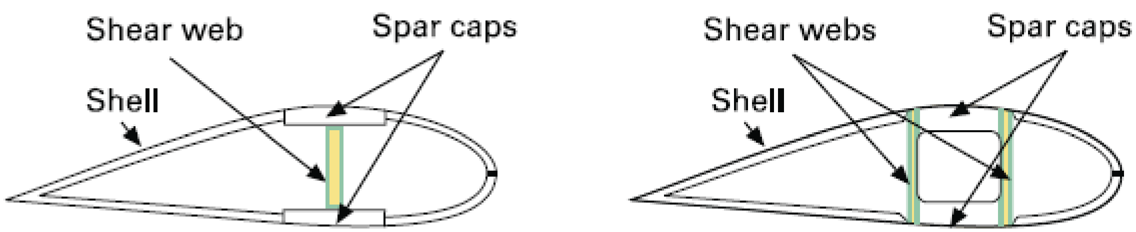

Spar Caps & Shear Web   Box Spar & Shear Webs

WINDIE – Advanced NDI Screening Activity

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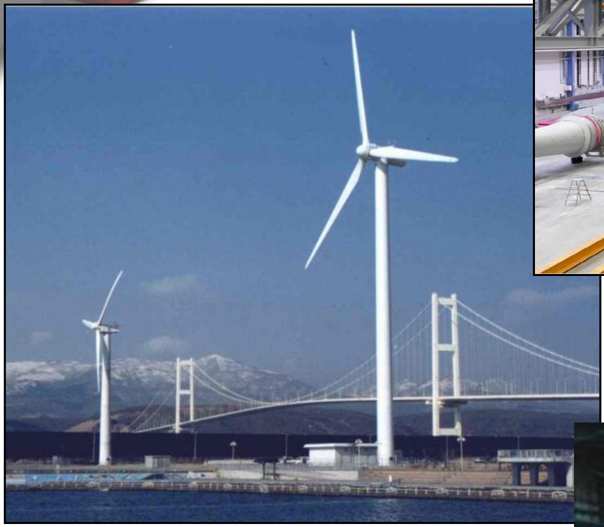
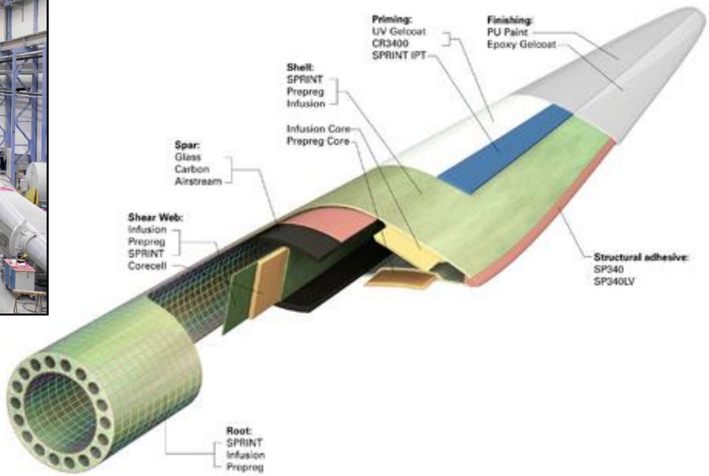
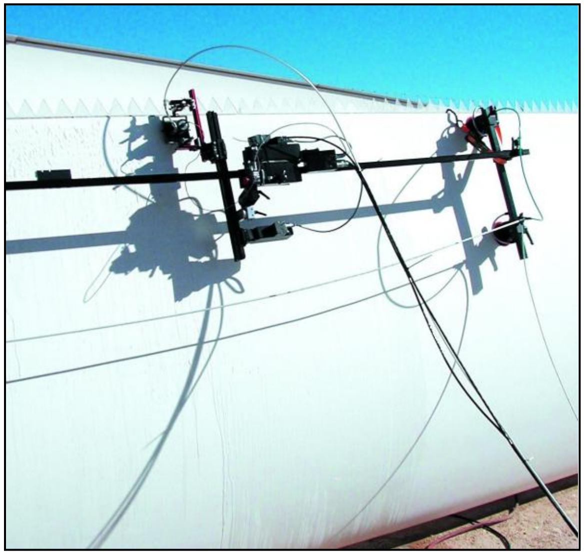
Evolution of NDI for Wind Turbine Blades

- Develop array of inspection tools to comprehensively assess blade integrity (determine needs, challenges, and NDI limitations)
- Achieve this while considering time, cost, & sensitivity issues (minimize production & maintenance costs)
- Develop NDI solutions in concert with related studies: effects of defects, field surveys, analysis, certification, standards
- Identification of impediments to be overcome and develop NDI ref stds
- NDI investigation has produced promising results thus far & may lead to hybrid approach with multiple NDI tools
- NDI to extend blade design life (??)







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