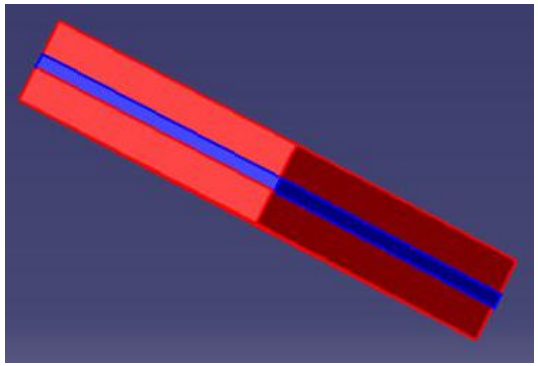
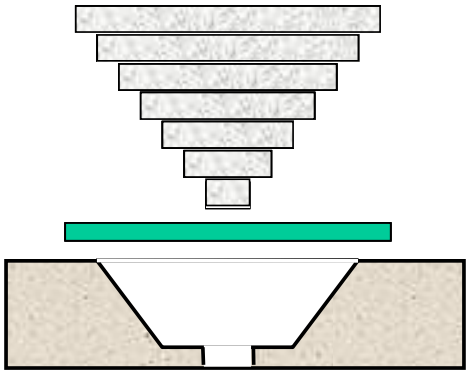
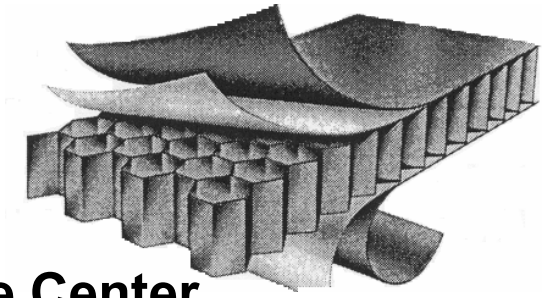
Improving In-Service Inspection of Composite Structures

CACRC Inspection Task Group Update
Application of Advanced NDI to Composite NDI







Dennis Roach
Sandia National Labs
FAA Airworthiness Assurance Center

FAA Hughes Technical Center

Sandia National Laboratories

ITG Team Participants

CACRC Inspection Task Group Members:

John Hewitt – Airbus (Co-chair)
Jim Hofer - Boeing
Jeff Kollgaard – Boeing
Kirk Rackow - Sandia Labs AANC
Dennis Roach - Sandia Labs AANC (Co-chair)
Glae McDonald - US Airways
Darrell Thornton – UPS
Richard Watkins - Delta Air Lines
Bob Stevens – United Airlines
Eric Bartoletti – American Airlines
Alex Melton - Northwest Airlines
Ana Tocalino - Embraer

Dave Galella, Al Broz, Rusty Jones, Larry Ilcewicz – FAA

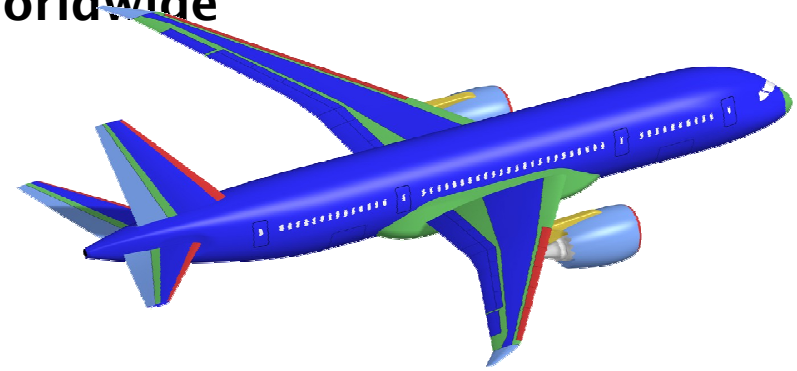
CACRC Inspection Task Group Activities

- **Industry wide NDI Reference Standards**
  - Complete (SAE ARP5506 & 5507; DOE report distributed in June 2004)
- **NDI Assessment: Honeycomb Structures**
  - Experiments completed in early 2007
  - DOT report in progress
- **NDI Assessment: Solid Laminate Structures**
  - In process (specimen fabrication completed; exp. protocols & final implementation planning remains)
- **Miscellaneous Ongoing and Planned Studies**
  - Detection and quantification of weak bonds
  - Affect of porosity, repairs & other impediments on NDI
  - As required to support main tasks
  - Can be initiated to support other task groups

Composite Inspections & Reference Standards

- Industry-wide composite reference standards developed to support damage assessment & inspection
- SAE Aerospace Recommended Practices (ARP 5605 & 5606) - adopted into Boeing and Airbus NDT Manuals
- Improve inspections of composite structures via introduction of advanced NDI methods
- Provides consistent approach to composite inspections - harmonized approach by OEMs worldwide

Optimized NDT Reference Standards



Composite Structures on Boeing 787 Aircraft

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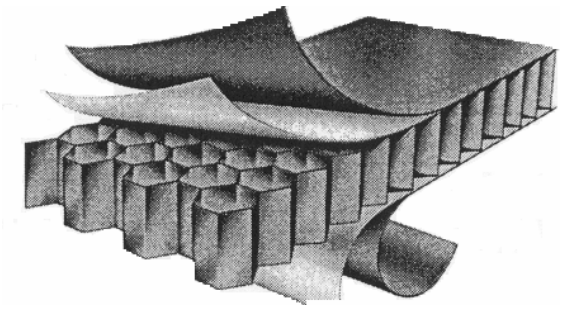
Goals of Composite Honeycomb Flaw Detection Experiments

Utilize airline inspectors to establish industry-wide performance curves that quantify:

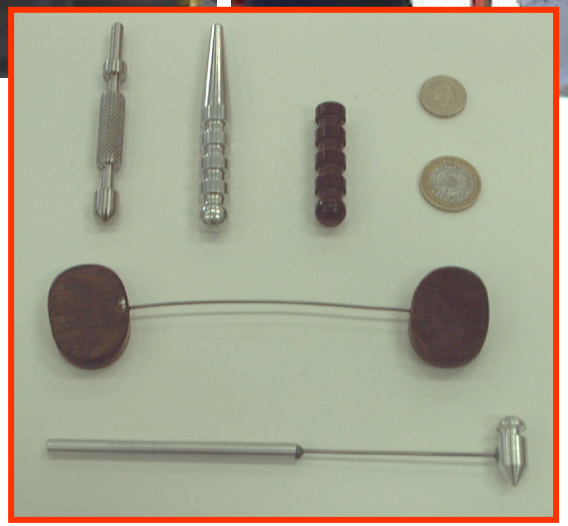
1) **how well current inspection techniques are able to reliably find flaws in composite structures**

2) **the degree of improvements possible through the integration of more advanced NDI techniques and procedures.**

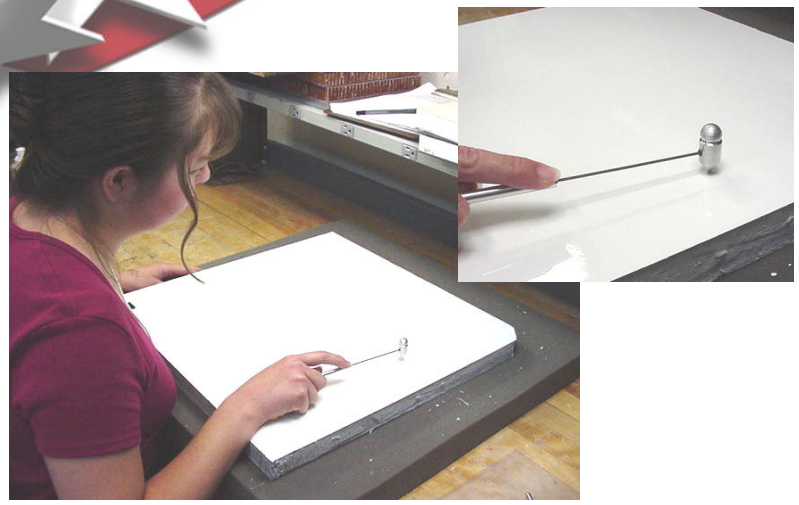
- **Statistically relevant and realistic flaw profiles**
- **Blind application of techniques to study hits, misses, false calls, and flaw sizing**



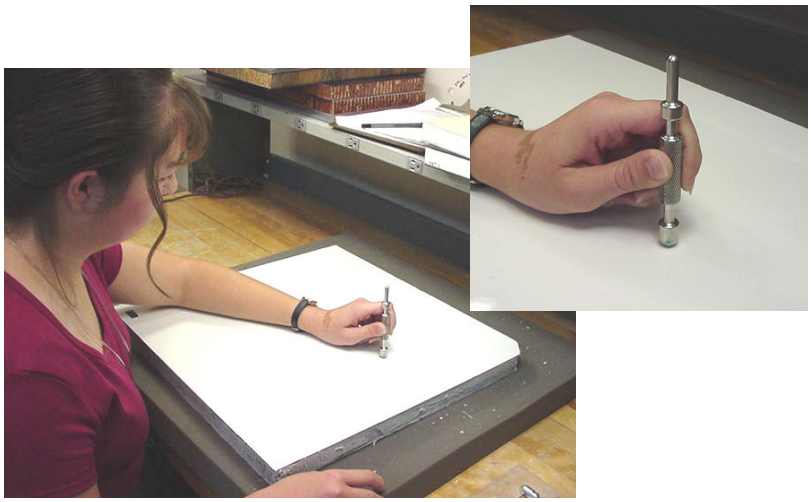
Tap Testing at Maintenance Depots



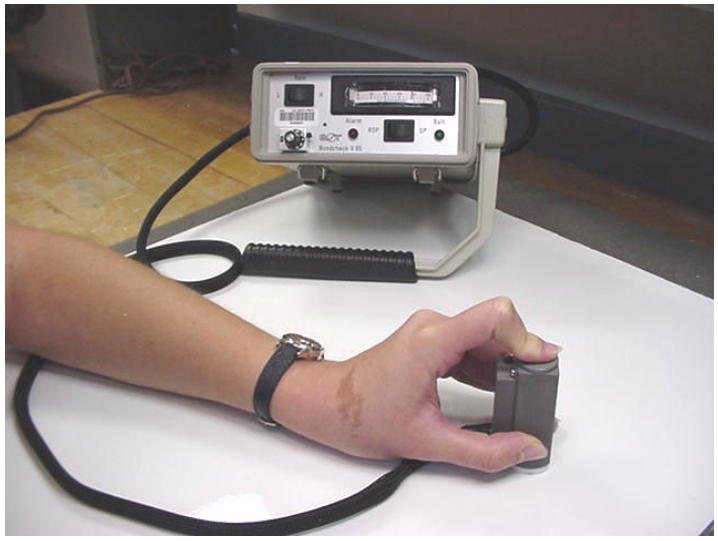
Conventional NDI Devices



Airbus Manual Tap Hammer



Boeing Manual Tap Hammer

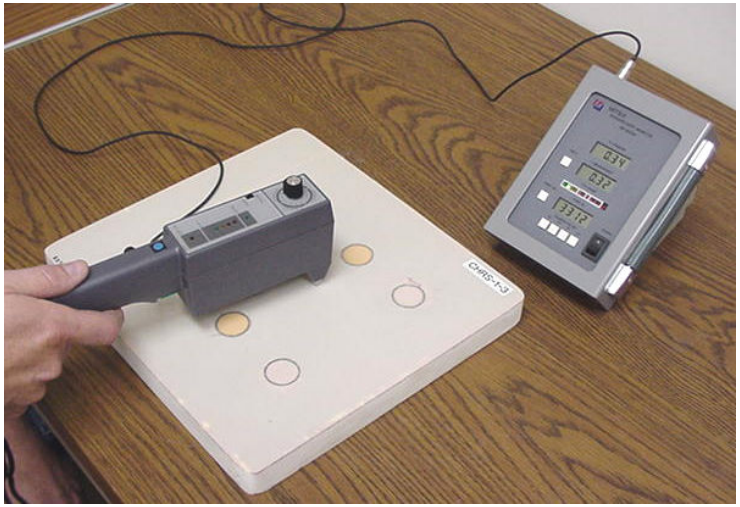


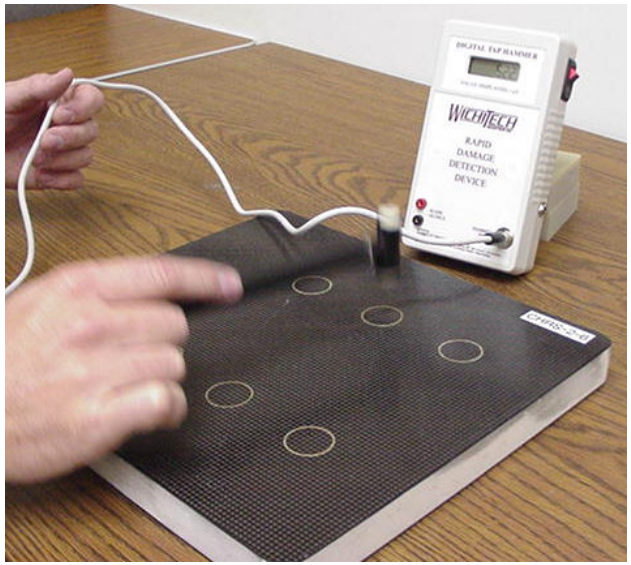
V-95 Mechanical Impedance Analysis

S-9 Sondicator (LFBT)

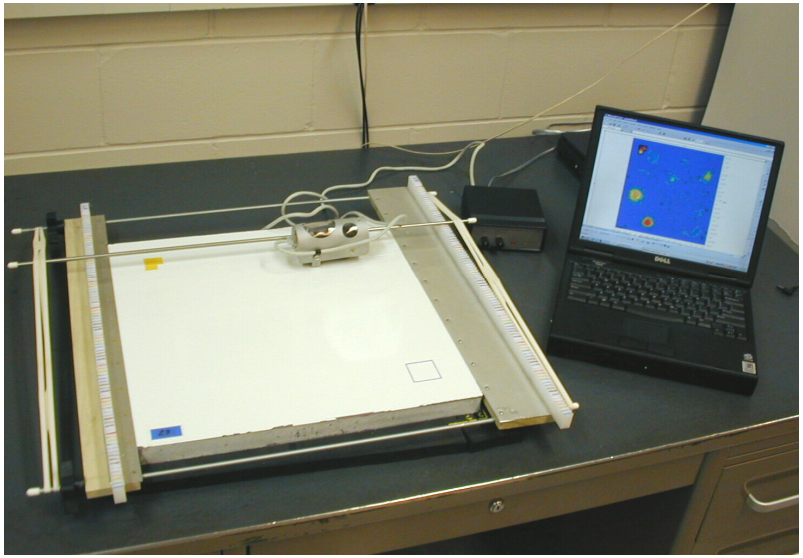
Automated Tap Test Devices

Mitsui Woodpecker with Digital Readout





Wichitech Digital Tap Hammer



CATT Instrumented Tap Test System

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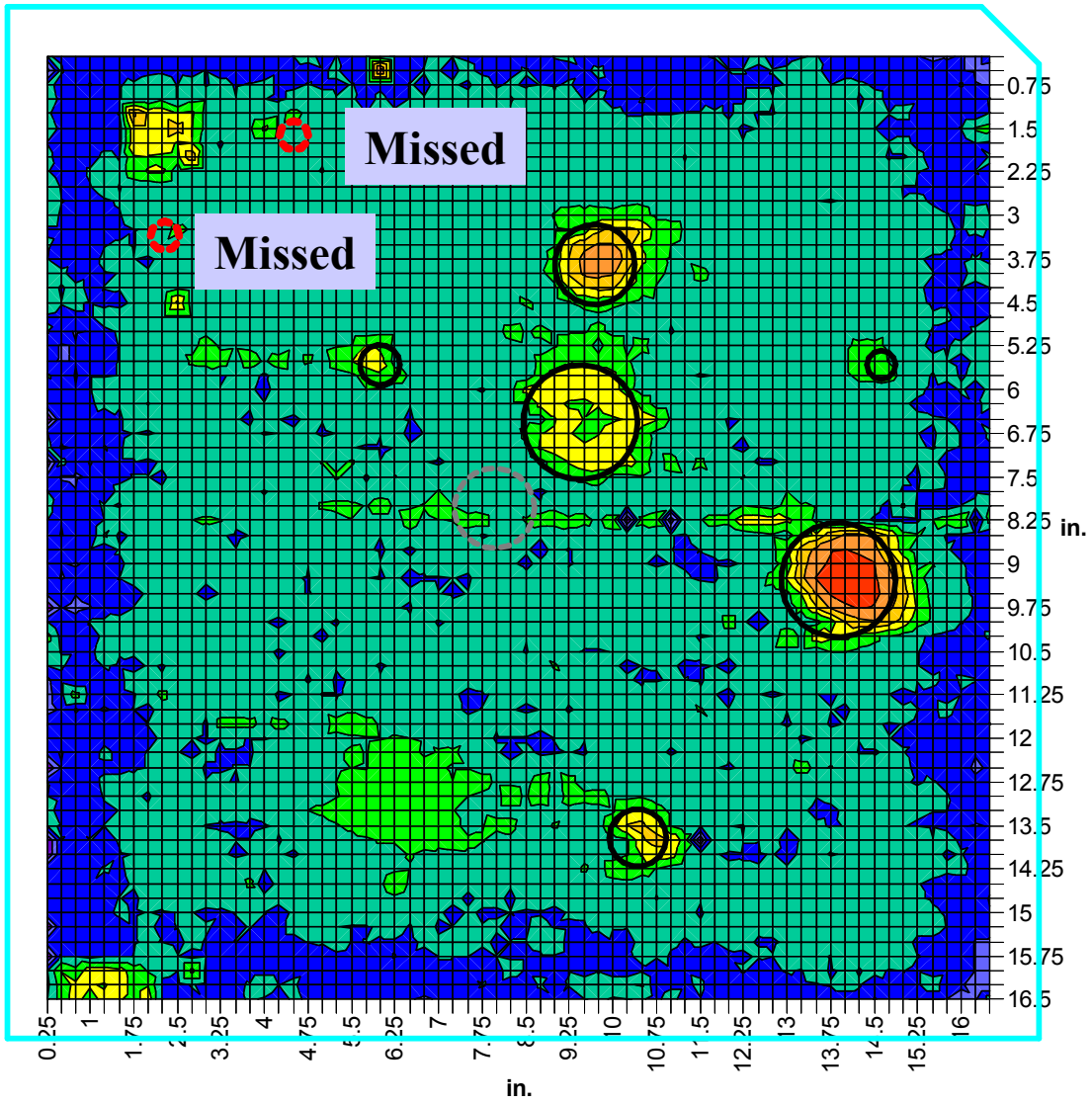
CATT Results on 6 Ply Fiberglass



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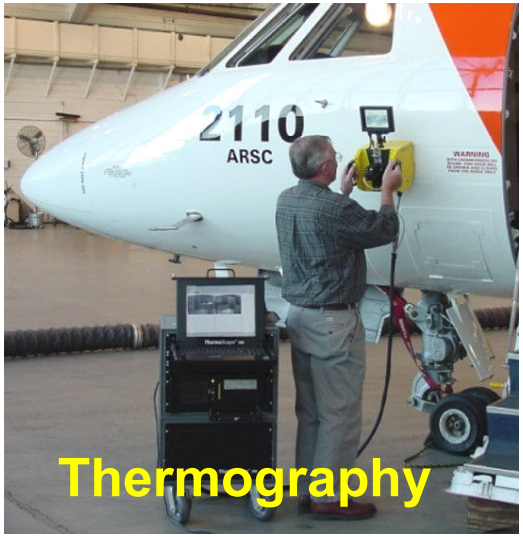
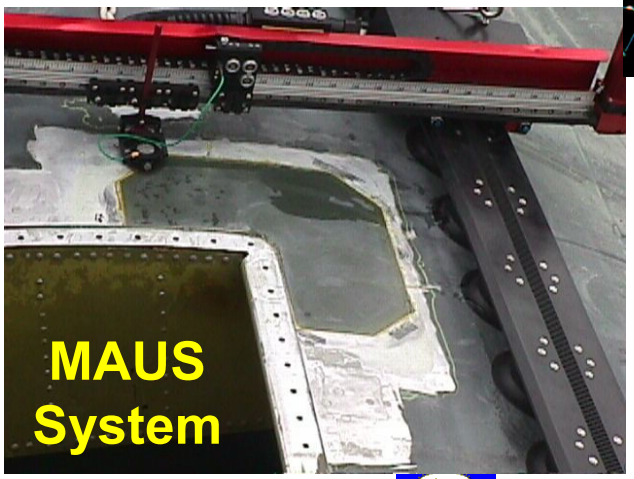
Wide Area and C-Scan Inspection Methods





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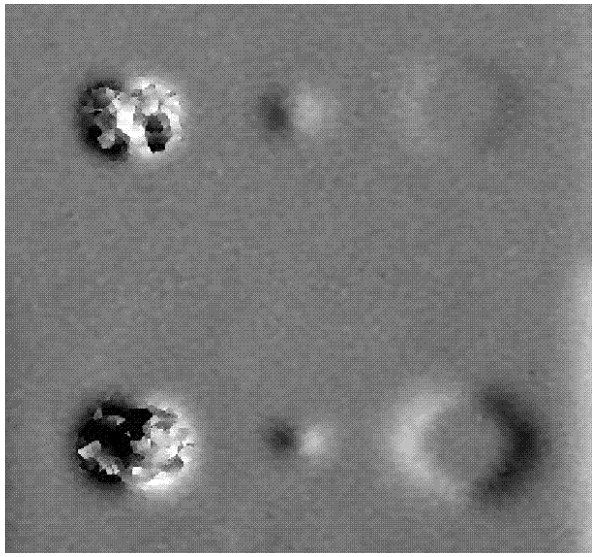
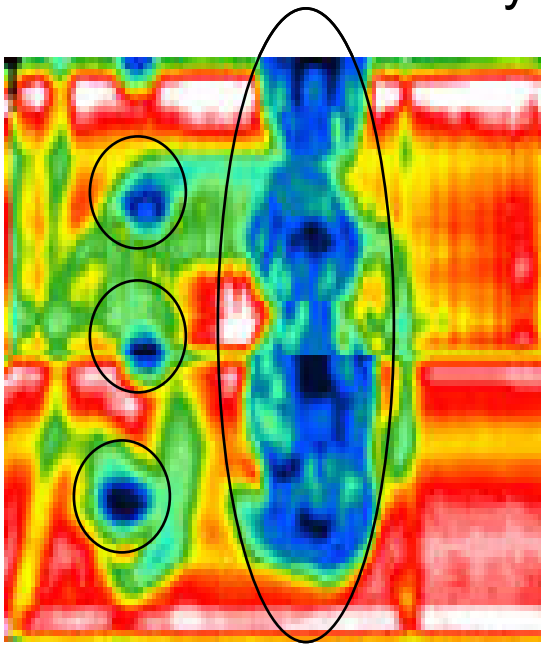
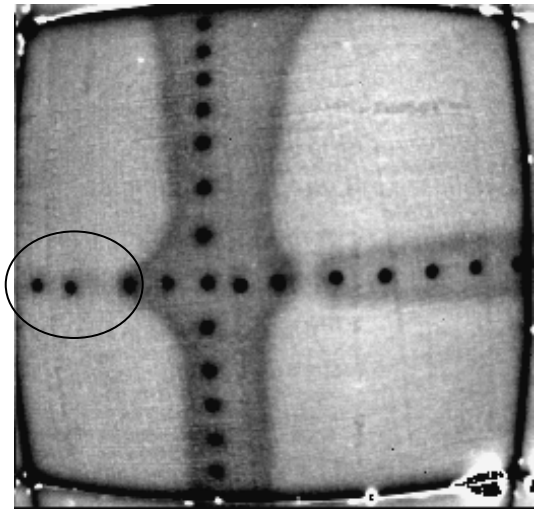
Shearography (LTI) Image

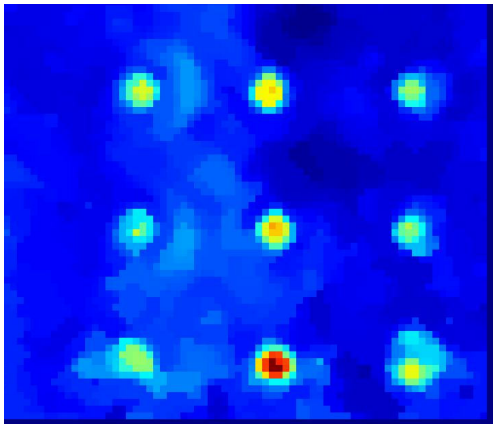


Ultrasonic Wheel Array

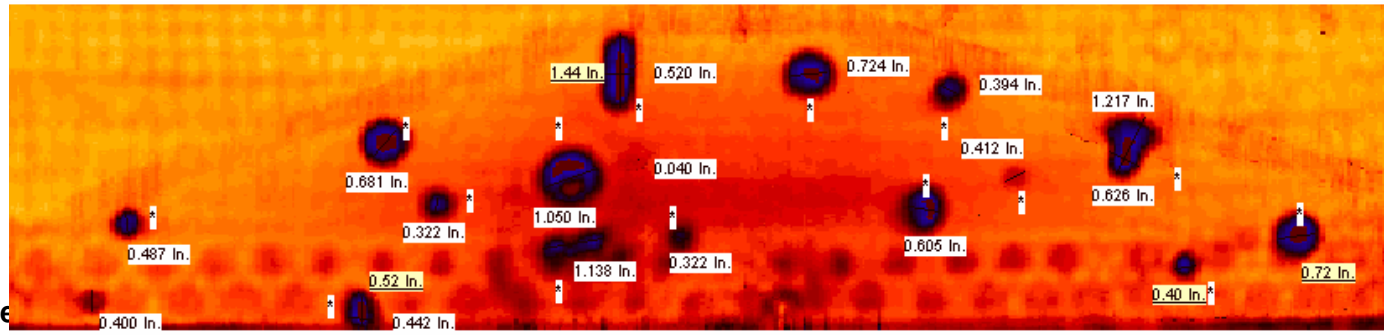


Thermography (TWI) Image





SAM Image



MAUS Image

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Implementation of Honeycomb Flaw Detection Experiment

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Airlines, 3rd Party Maintenance and Adv. NDI Organizations Who Have Participated

UNITED

SR Technics

KLM Royal Dutch Airlines

BRITISH AIRWAYS

U·S AIRWAYS

AA

AIR FRANCE

Delta

FedEx

Alaska Airlines

NORTHWEST AIRLINES

AGUSTAWESTLAND

Laser UT (Lock.-Martin)
Computer Aided Tap Tester (ISU)
Microwave Scanner (Evisive)
Thermography (TWI - 2)
Laminography (Digiray)
Shearography (LTI)
Air Coupled UT (ISU)
Structural Anomaly Mapping (Honeywell)
MAUS MIA & Resonance Scanner (Boeing)
Digital Radiography (Digiray)
Phased Array Ultrasonics (NDT Sol'ns)
Acoustography (Imperium)
Terahertz (GMA)

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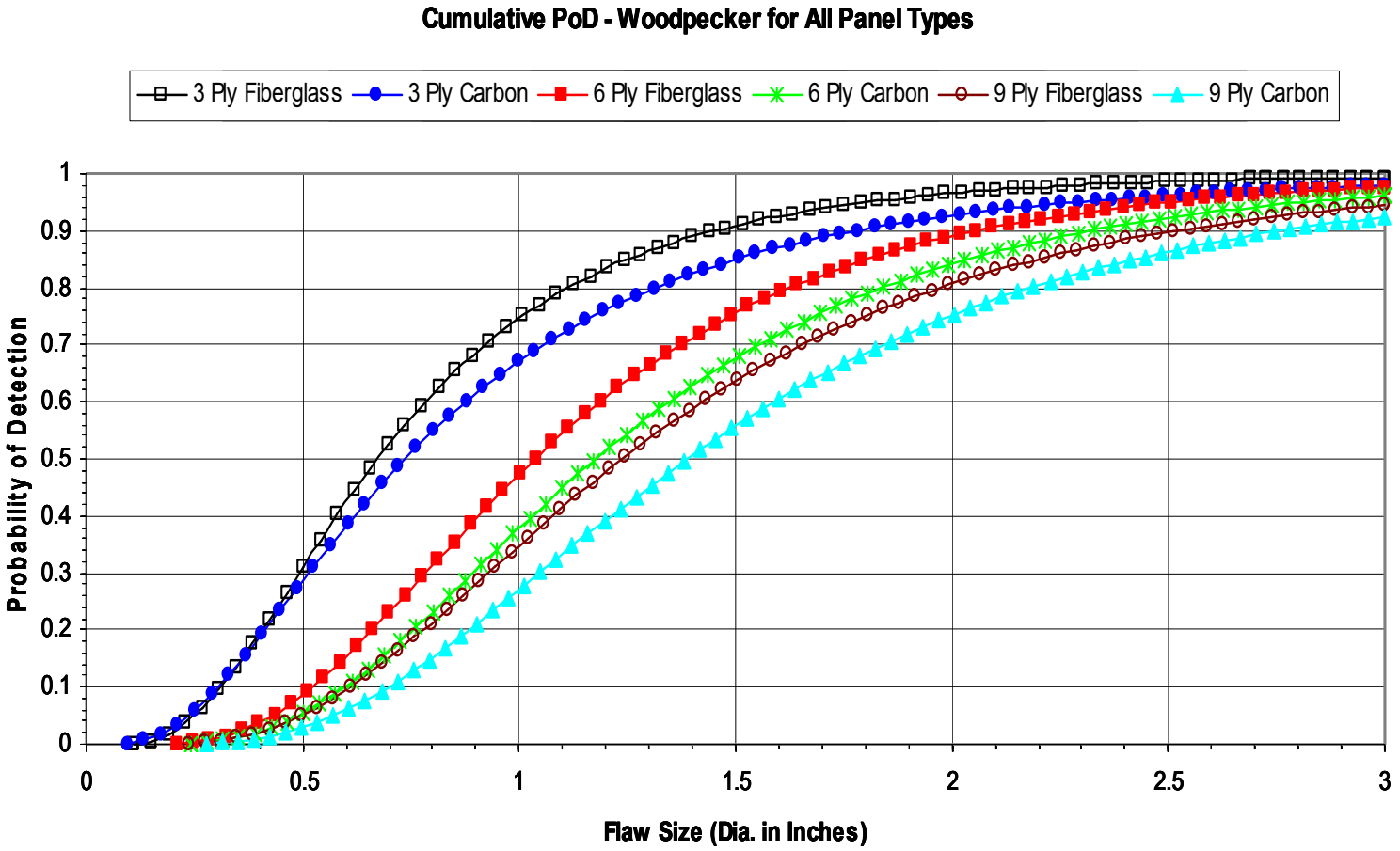
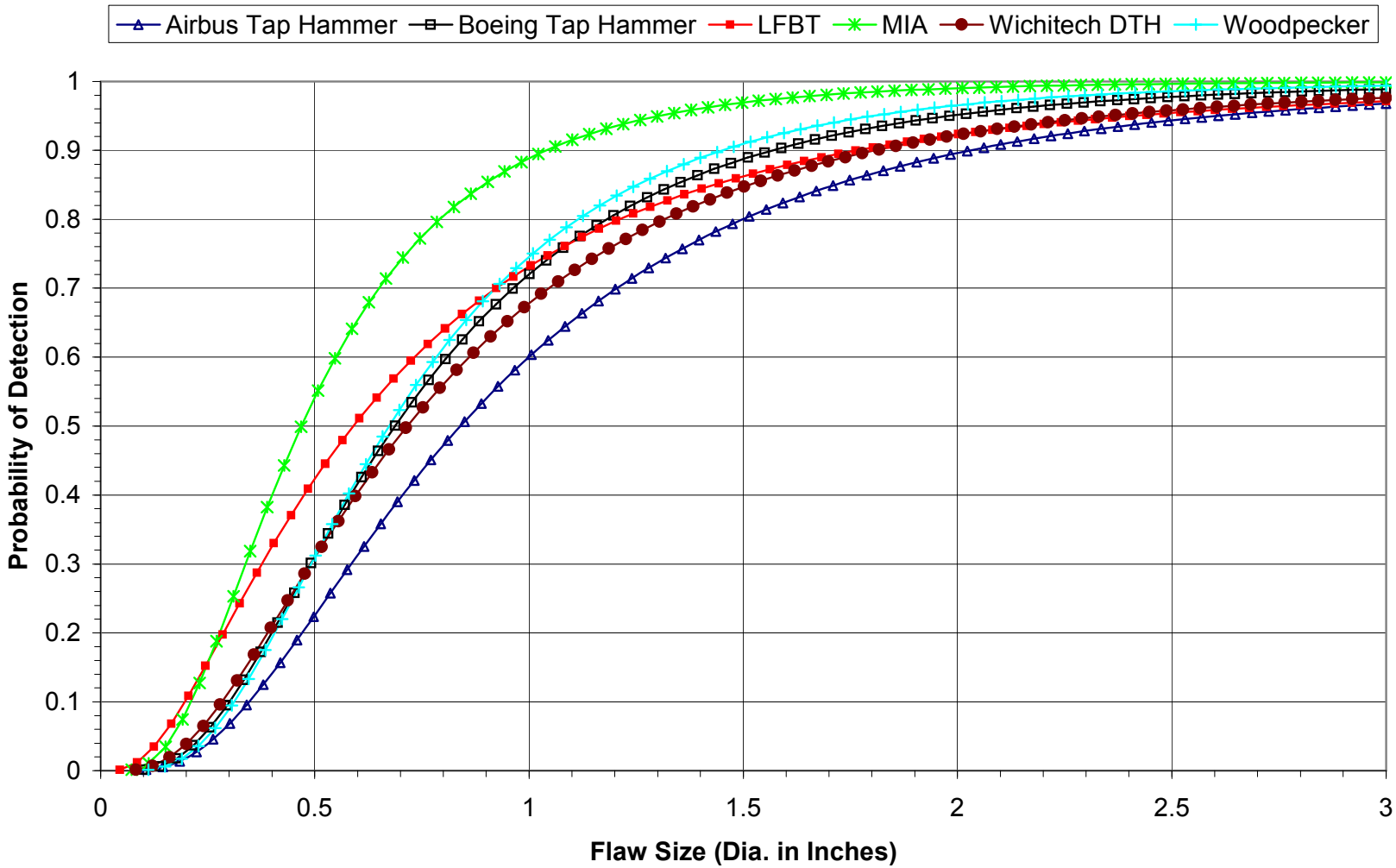
Performance of Single Device (Woodpecker) Over Range of Test Specimen Types



Performance of Multiple Devices for A Single Type of Test Specimen

Cumulative PoD of All Conventional NDI Devices for 3 Ply Fiberglass



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Conclusions – Composite Honeycomb NDI

How are we doing? – Flaw Detection with Conventional NDI

- 90% POD is not achieved for 1” dia. flaws; at 9 plies it exceeds 2” dia.
- Human factors issues (time, attention to detail, proper deployment)
- Some inspectors marked grids on panel to aid in coverage of inspection area – most inspectors had good coverage; some followed random pattern (find small flaws but miss large ones)
- Overall, MIA mode worked well (reliability, repeatability, ease of use)

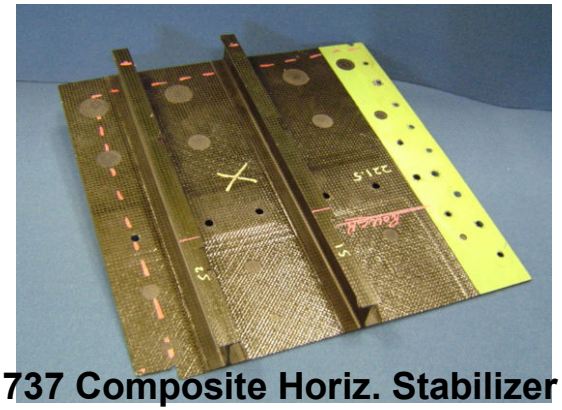
How can advanced NDI help? – Flaw Detection with More Sophisticated NDI

- Improvement in flaw detection ranged from 66% to 72%
- Automated deployment & data presentation/analysis reduces many human factors concerns (100% coverage; flaw recognition on images)
- Allow for more rapid inspections
- MAUS, Thermography (sizing), Shearography all performed well

An Experiment to Assess Flaw Detection Performance in Composite Laminate Structures

Purpose

- Determine in-service flaw detection capabilities: 1) conventional NDT methods vs. 2) improvements through use of advanced NDT.
- Optimize laminate inspection procedures.
- Compare results from hand-held devices with results from scanning systems (focus on A-scan vs. C-scan and human factors issues in large area coverage).
- Provide additional information on laminate inspections for the "Composite Repair NDT/NDI Handbook" (ARP 5089).



737 Composite Horiz. Stabilizer

A380 Section 19

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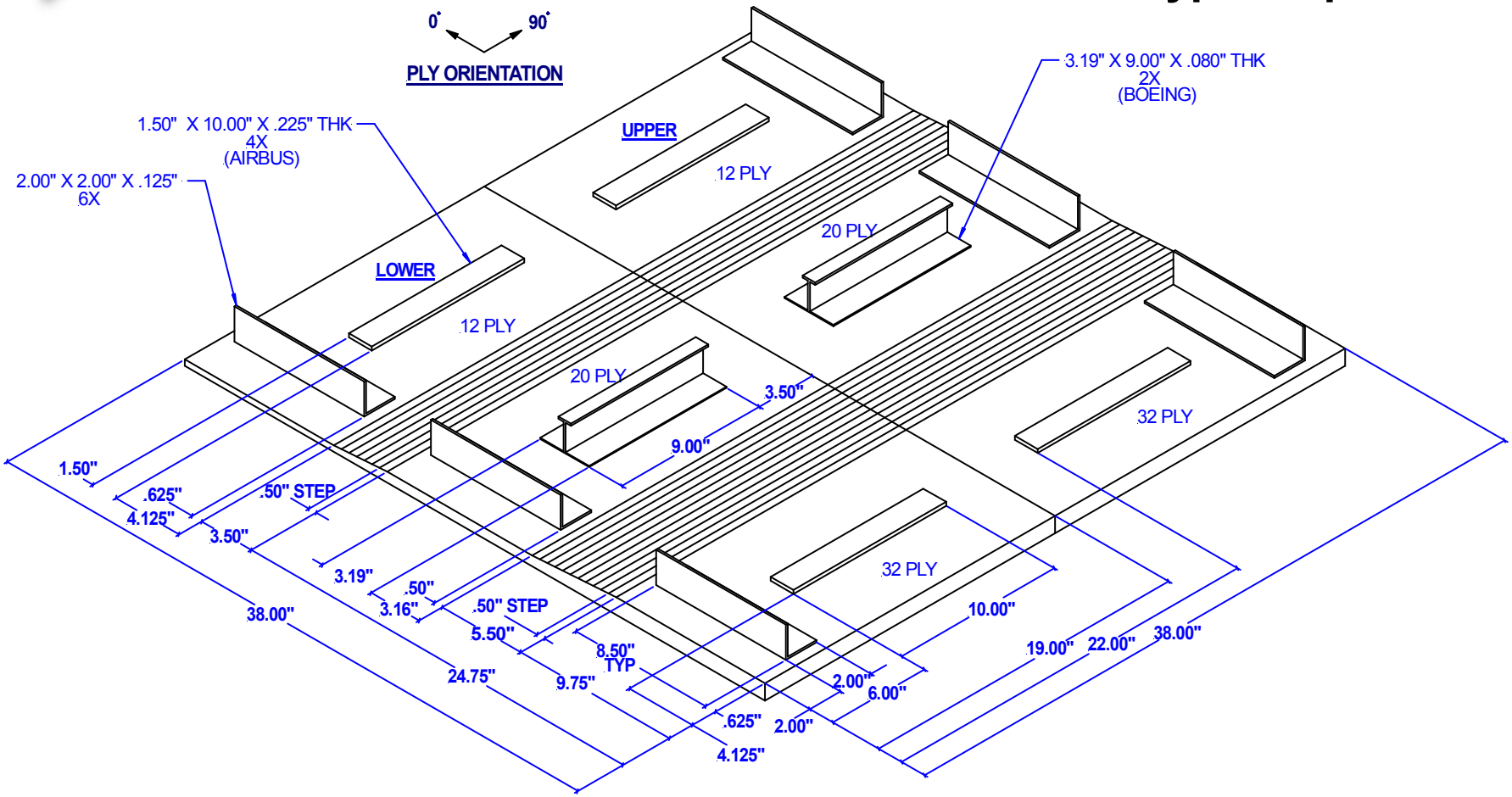
Specimen Set - Flaw Detection in Solid Laminate Composites

Thickness Range:
12 – 64 plies

Thick Laminate With Simple Taper

Type 2 Specimen



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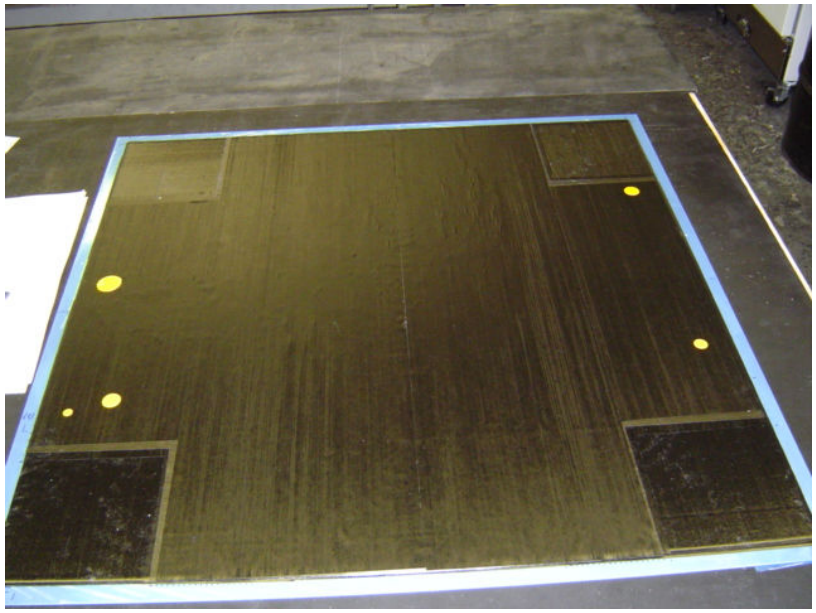
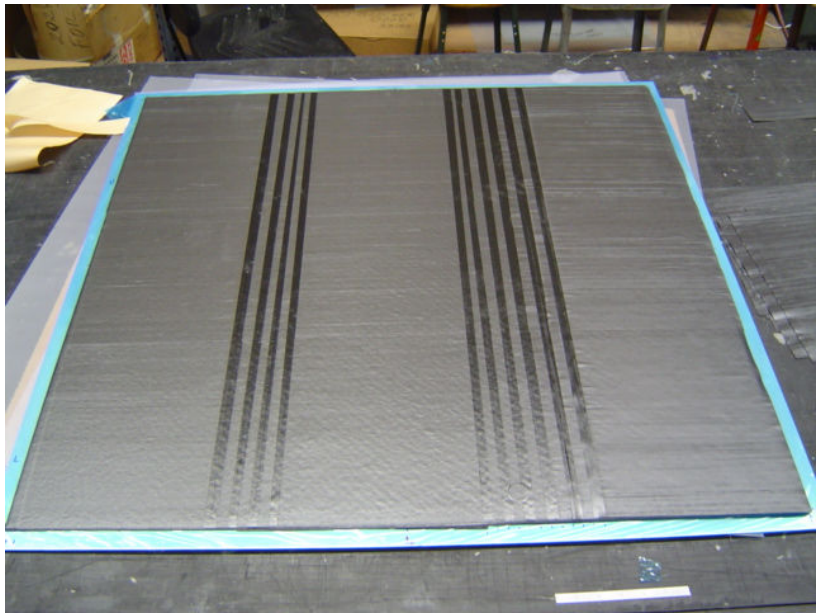
Composite Laminate Fabrication





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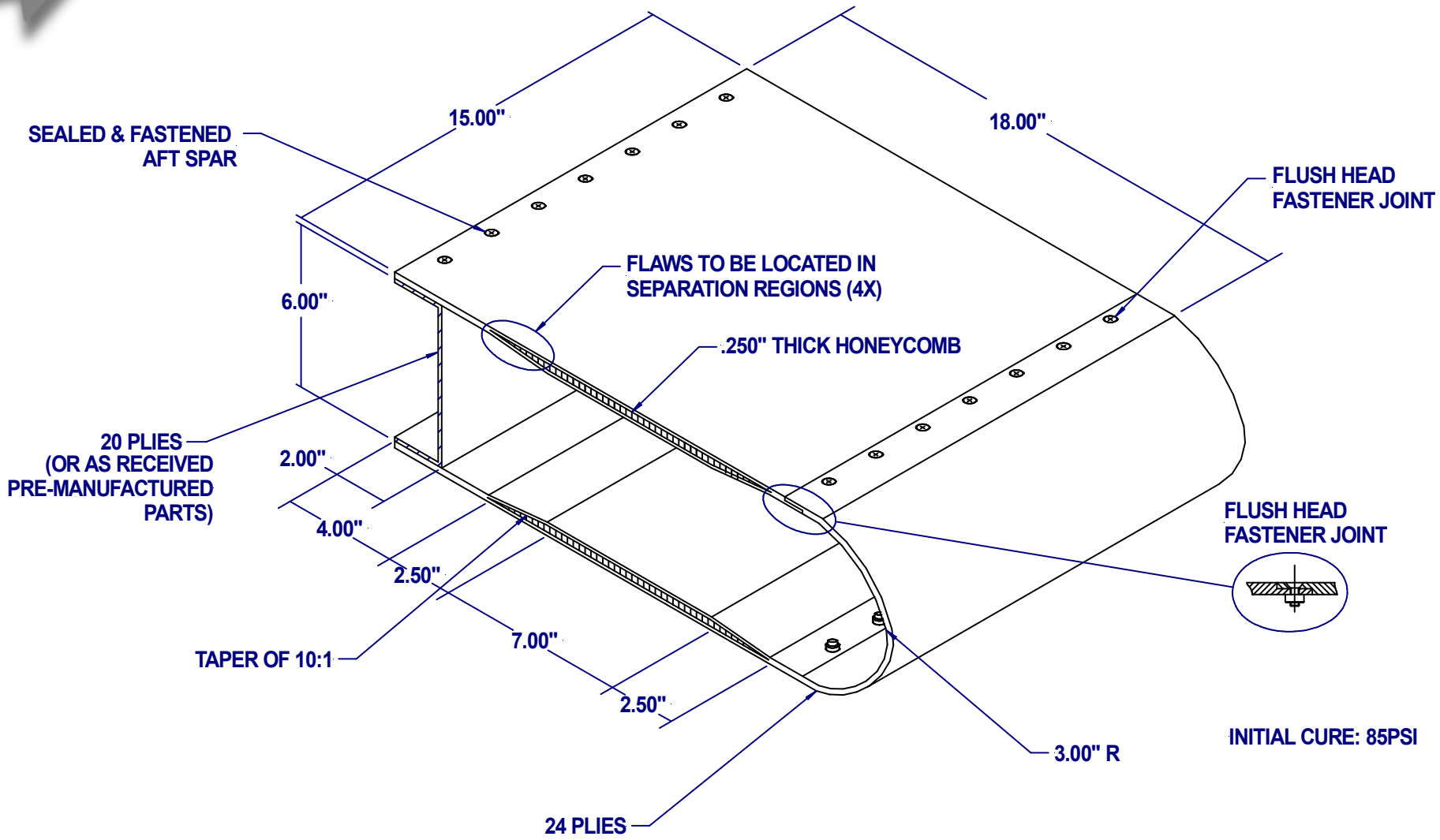
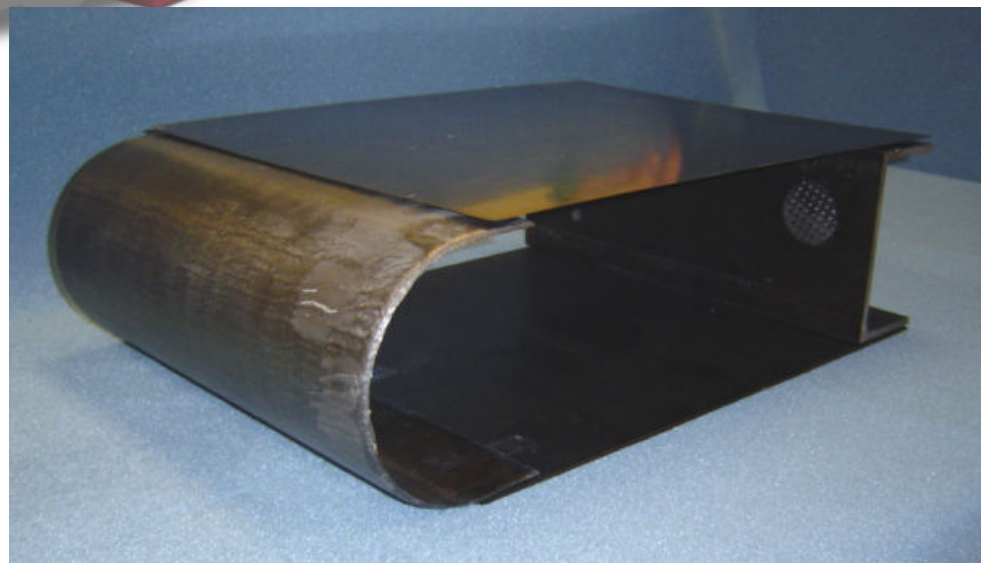
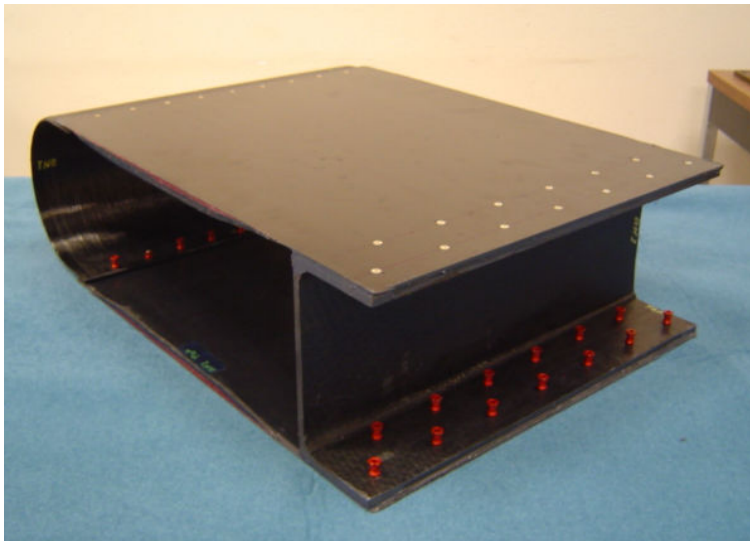
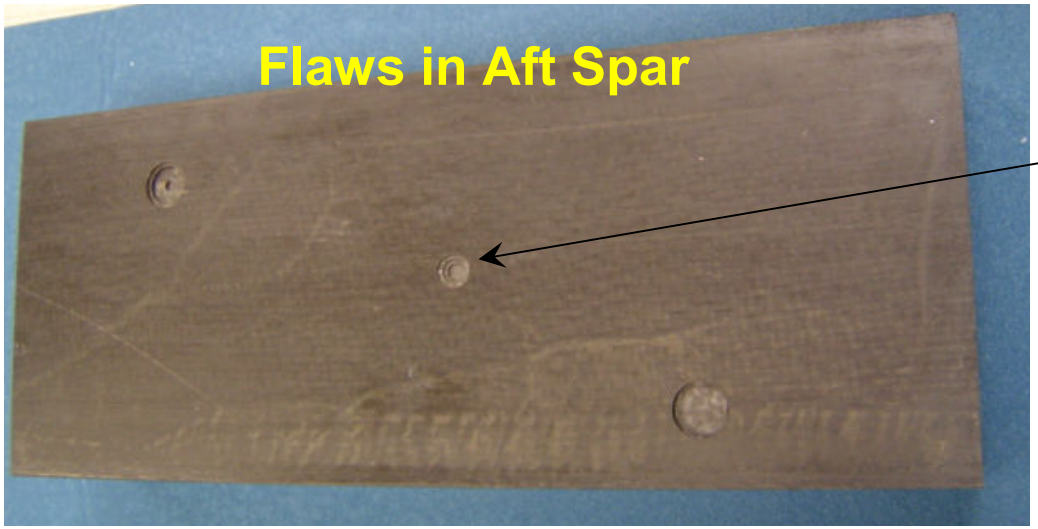
Contoured Test Panel with Honeycomb



Contoured Test Panel - Fabrication



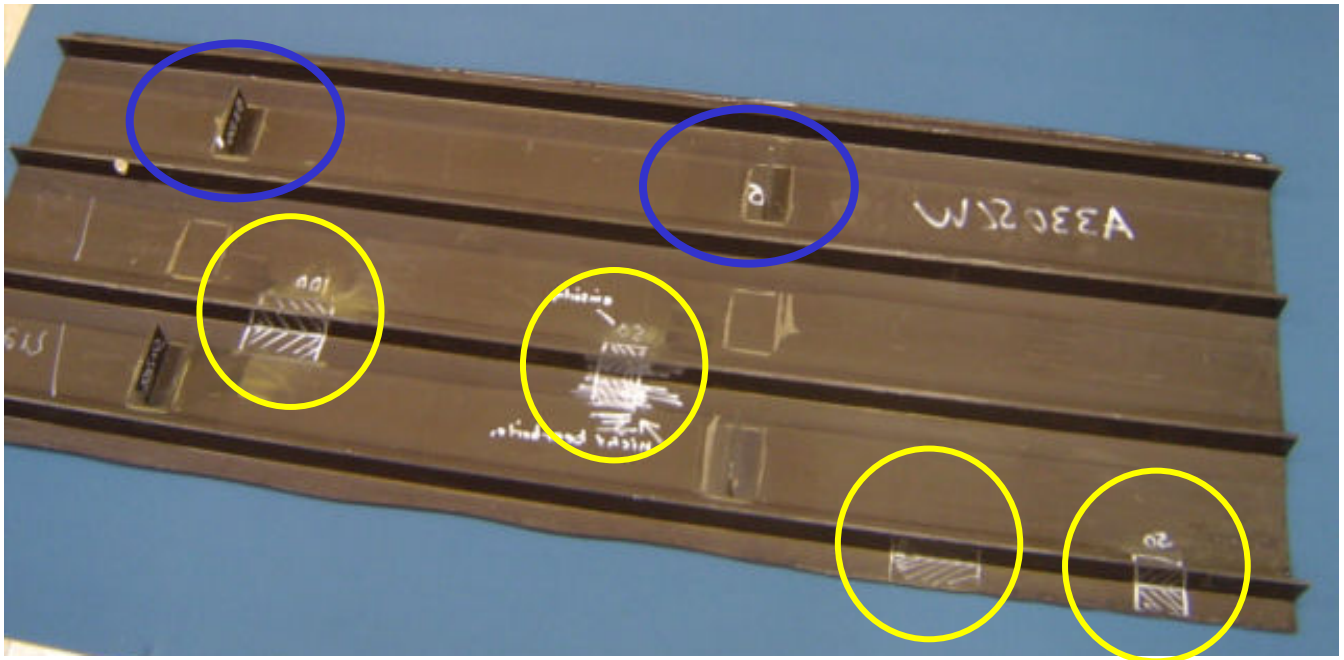




Concentric FBH to Simulate Impact Damage

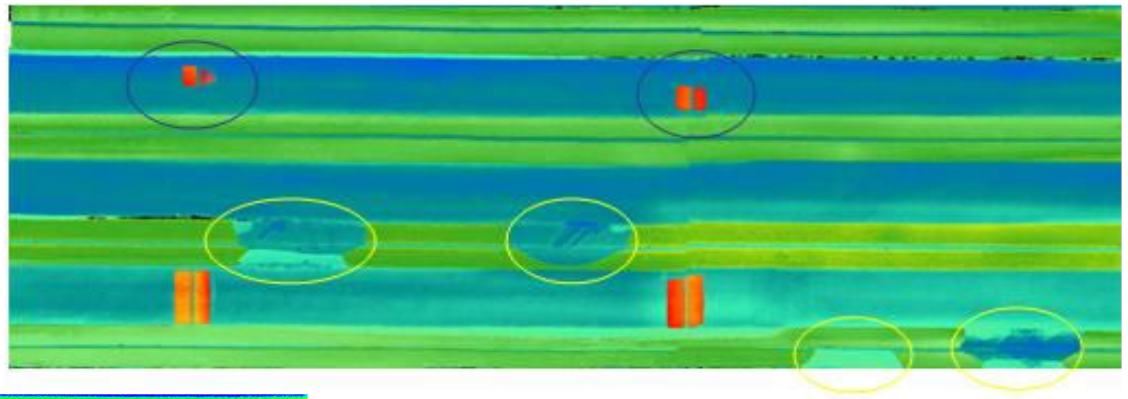
Experiment Design & Implementation

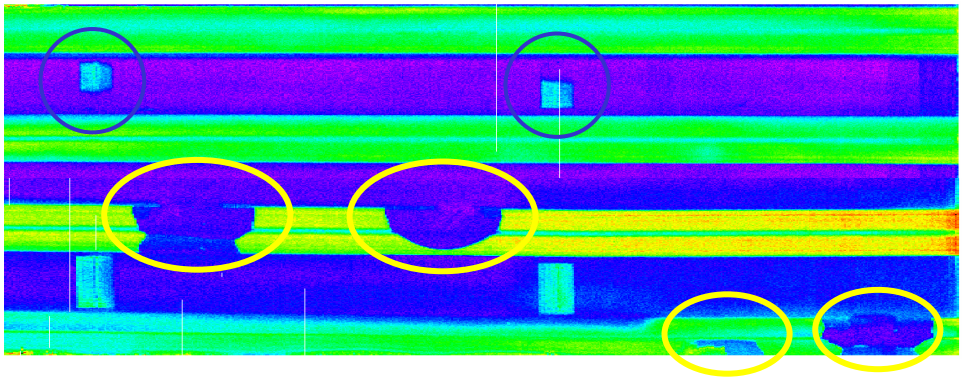
- Surface area & no. of flaws req'd (no. of specimens) vs. time for inspector to complete experiment
  - ➢ Trial inspections on simulated stabilizer by UA inspectors – 2.9 to 3.9 ft.^{2} per hour



Simulated Vertical Stabilizer with Stringers, Rib Sections and Engineered Flaws
Three stringer-to-skin disbonds (yellow)
Two rib to-skin-partial disbonds (blue)

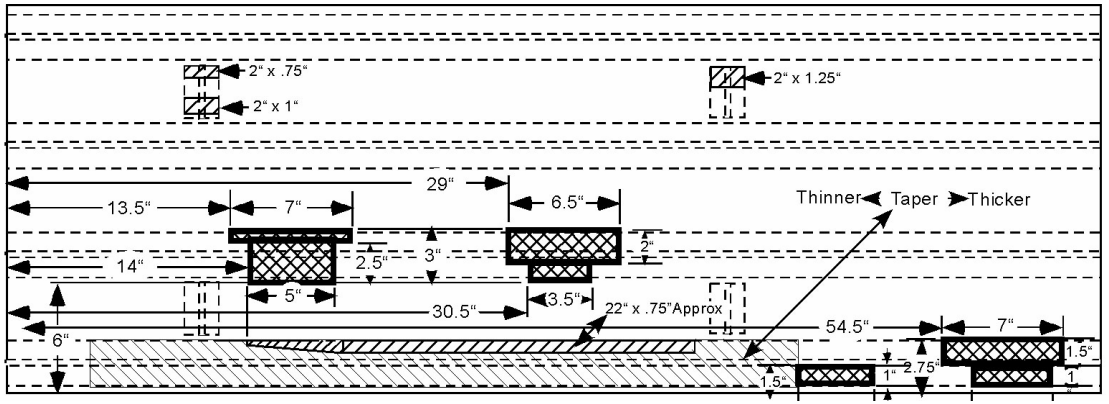
Phased Array UT Inspection of Vertical Stabilizer Specimen





MAUS – Resonance Mode

United Airlines inspection with hand-held P-E UT



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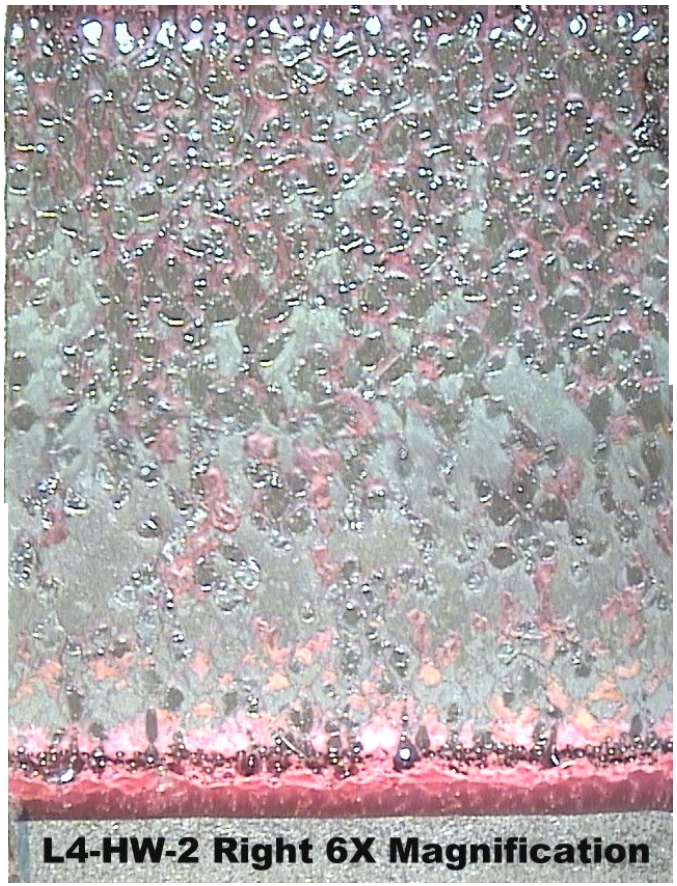
Enhanced Inspection Methods to Characterize Bonded Joints: Moving Beyond Flaw Detection to Quantify Adhesive Strength

- Process control alone may not ensure satisfactory bond strength
- Must consider joint degradation - environmental effects of moisture, aging, stress, fatigue
- Method must be a stiffness-based technique and/or able to assess material properties
- Wave transmission modes may be sensitive to in-plane displacements (interfacial changes)
- Requires high sensitivity (S/N) and possibly noise reduction methods to recognize small changes in bonds

Adhesive vs. Cohesive Failure

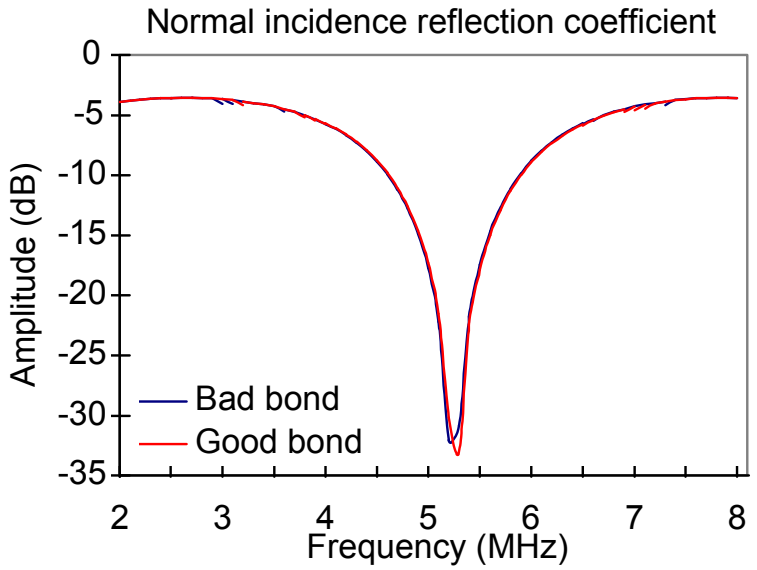
Cohesive Fracture of Adhesive Film (Option 6 silane treatment)



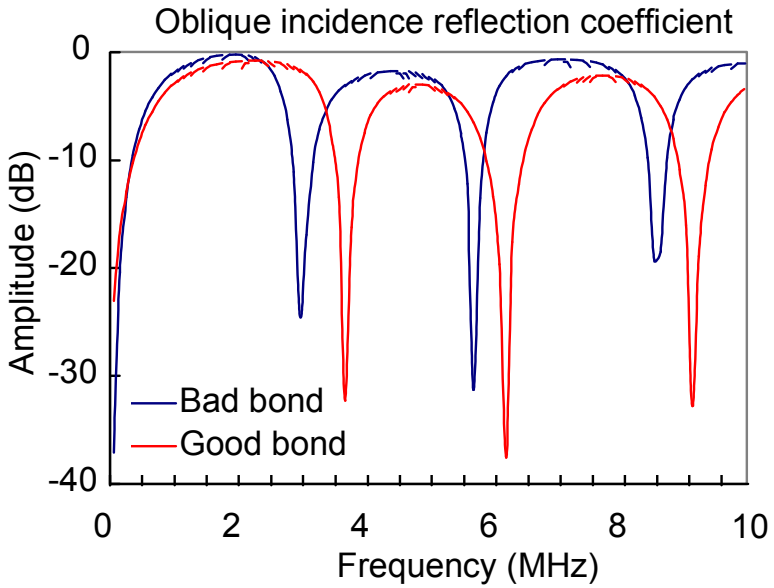
Adhesive Failure at Interface (Option 4 no chemical treatment)

Angle Beam Ultrasonic Spectroscopy (ABUS)

- **Compare received and transmitted waveforms in frequency domain; study frequency/amplitude shifts & change in damping in FRF**
- **Oblique wave (broadband UT beam) introduces shear stress in the bond line**
- **Difference between longitudinal wave and shear wave interrogation**



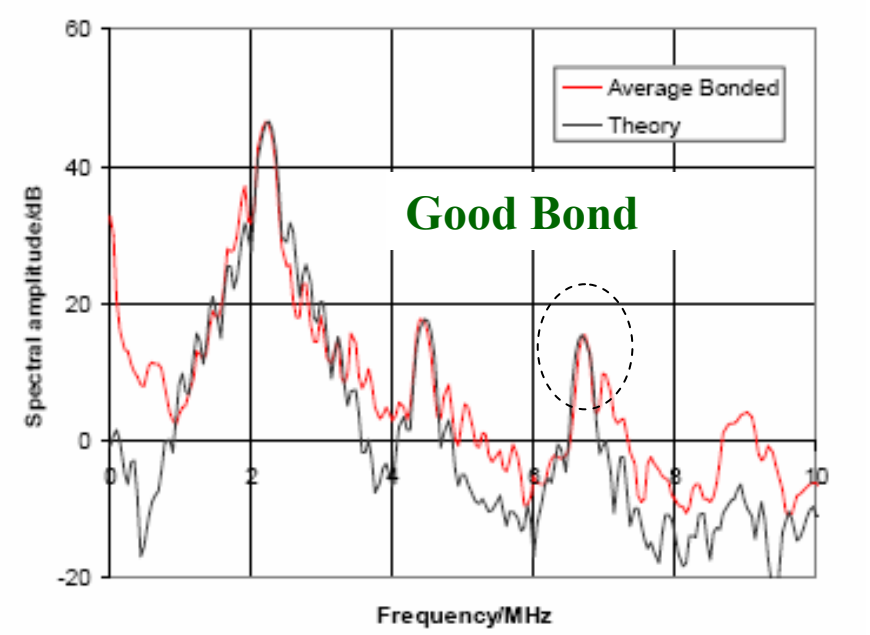
Negligible Affects on Normal Wave (?)

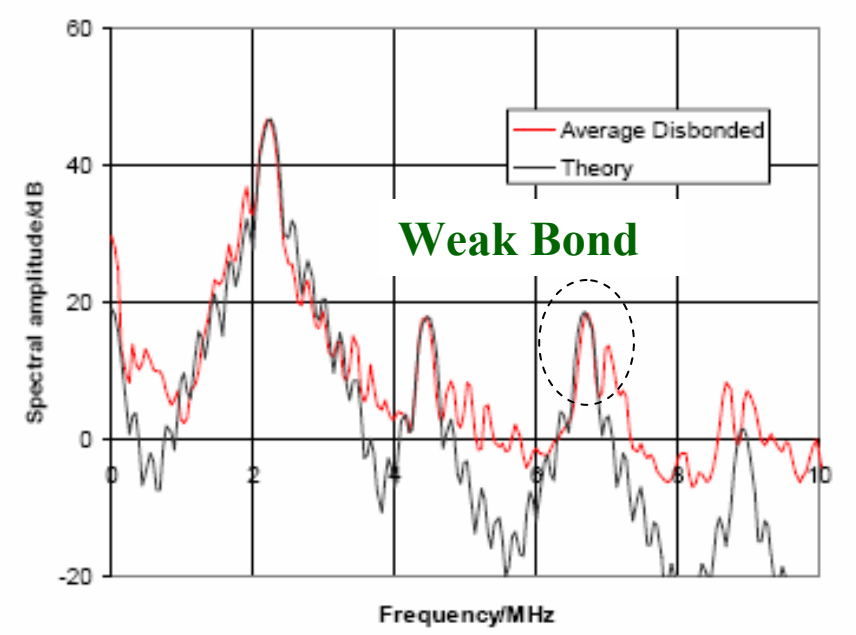


Frequency and Amplitude Shifts Differentiate Bonds

Nonlinear Ultrasonics

- Exploit contact nonlinearity in imperfect bonds
- Swept frequency or chaotic drive signals to generate unique harmonics
- Potential for introducing damage because incident energy levels must be high

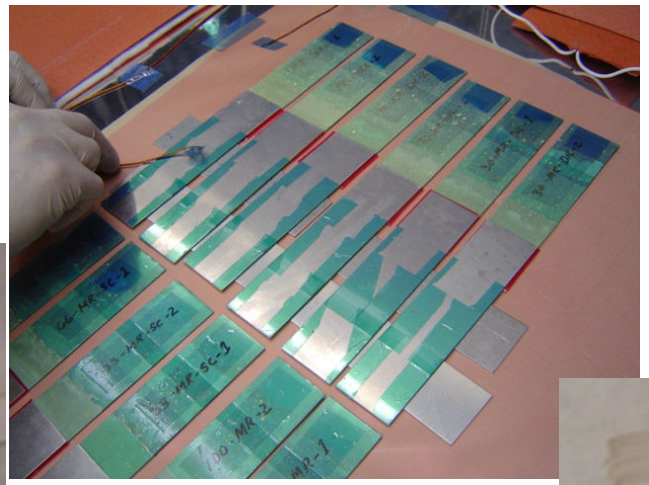


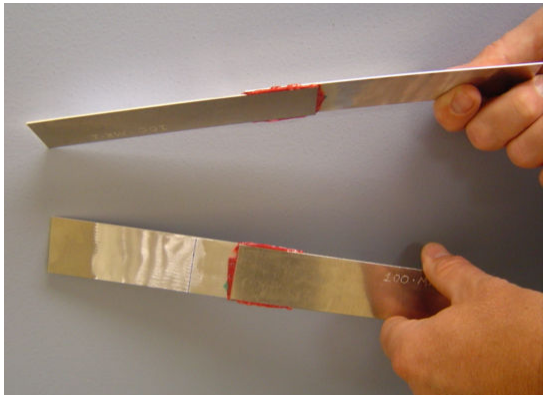


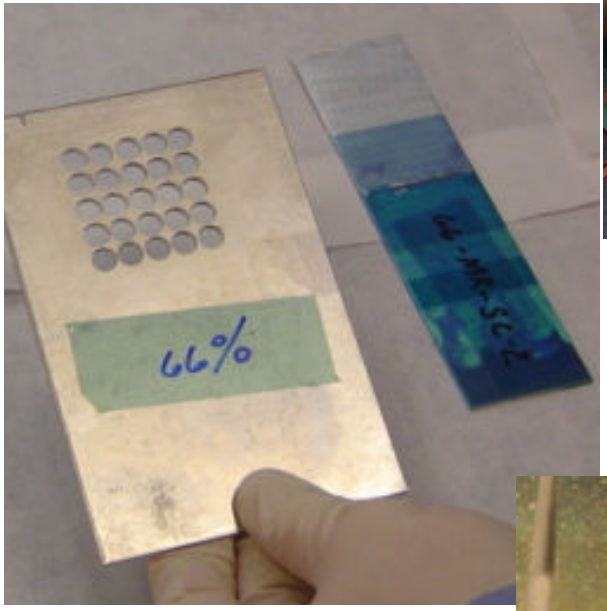
Requires high fidelity to avoid missed/false calls - signal changes may be small (low S/N)

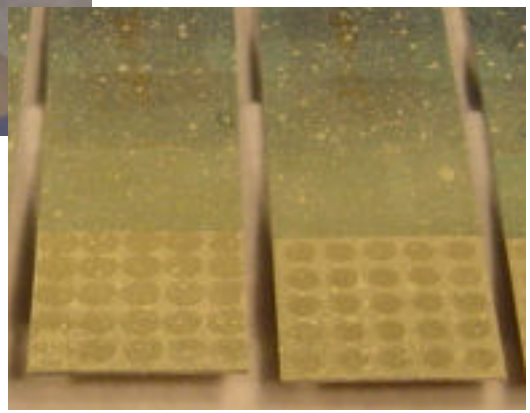
AANC Weak Bond Specimen Production

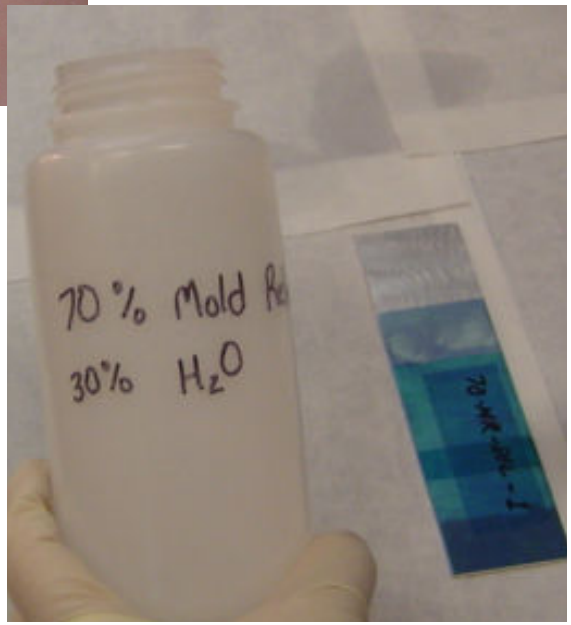
- Screened mold release
- Diluted mold release
- Poor cure



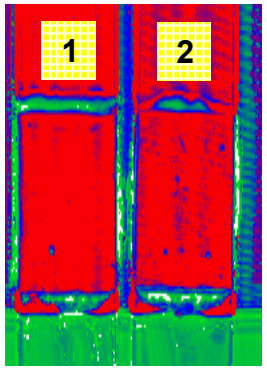




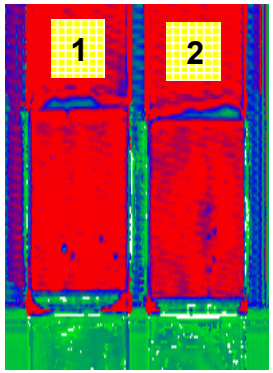




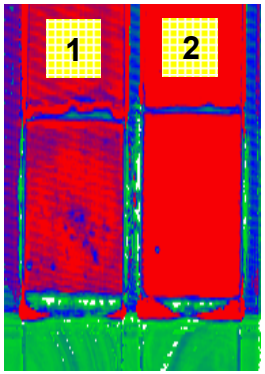
TTU of Weak Bond Specimens Show Trends



Pristine - Best



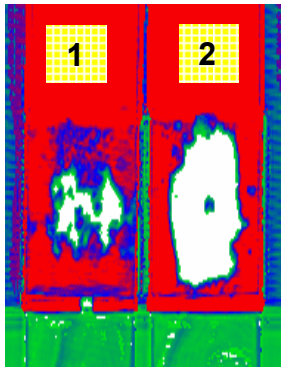
70% MR Dilution



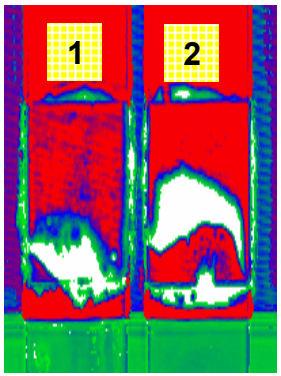
30% MR Dilution

33% MR Screen

66% MR Screen



Room Temp.

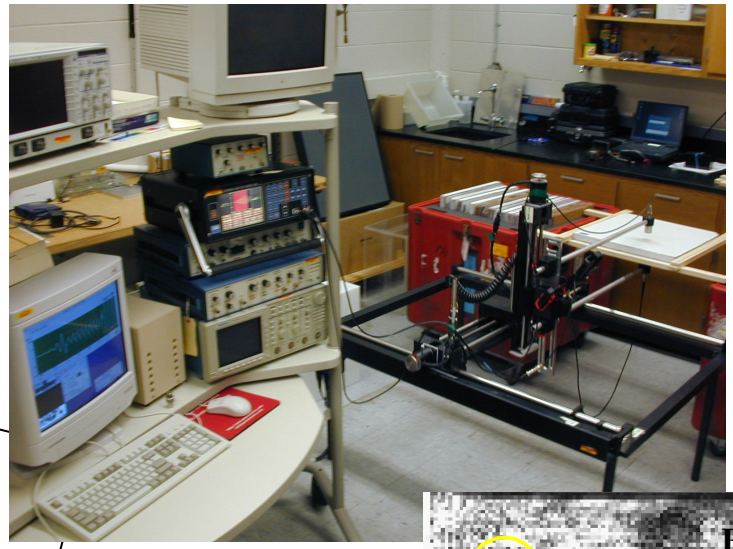


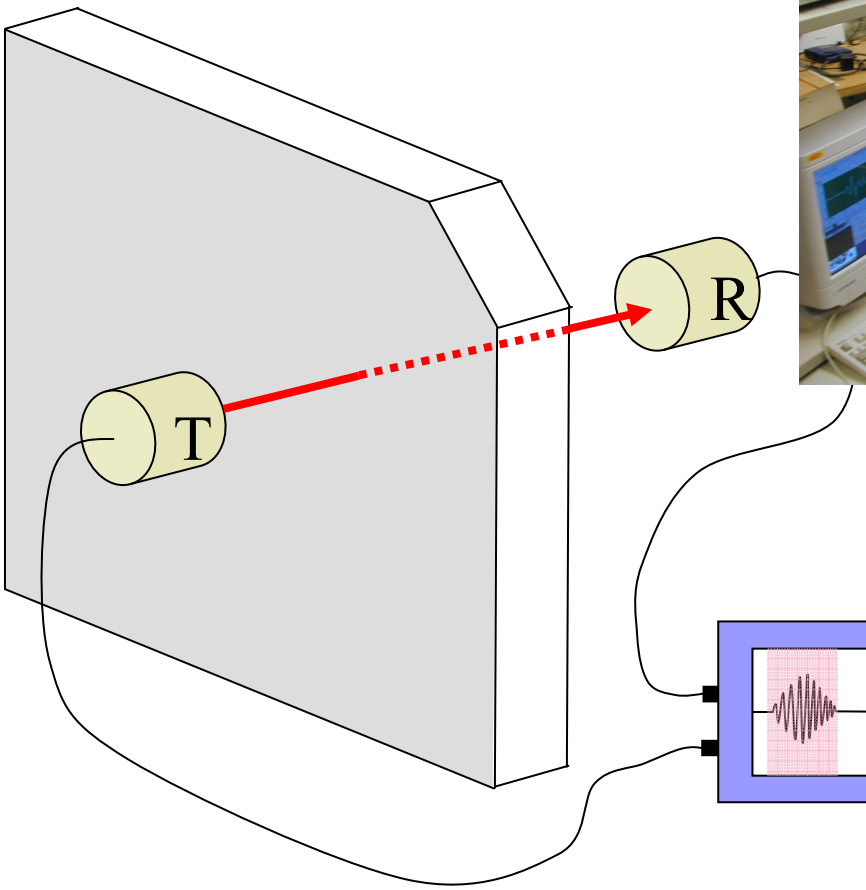
100 MR

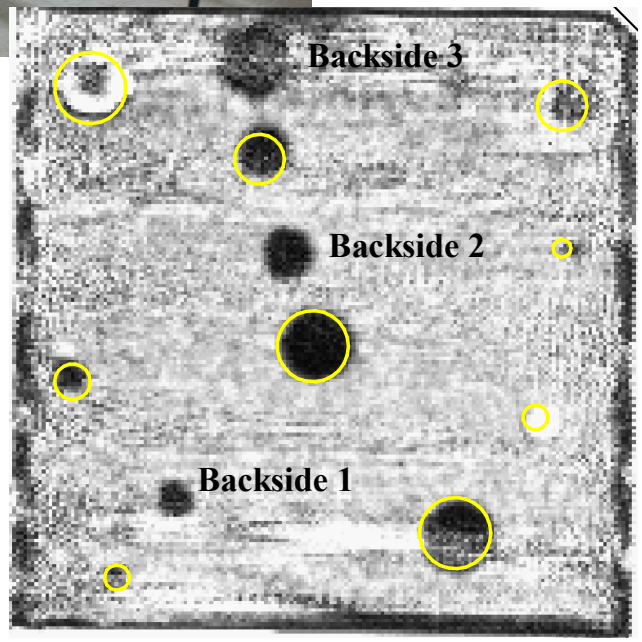
Conclusions on Weak Bond Assessments

- Understanding physics of bond integrity is key – select proper interrogation method (what do we exploit)
- One NDI method may not detect all sources of weak bonds
- Several NDI techniques show promise
- Expected low signal-to-noise ratios provide the biggest impediment; optimized excitation is important . . . .
- Ensure that inspection is truly nondestructive

Air Coupled Ultrasonics







Pixel resolution of 0.1”

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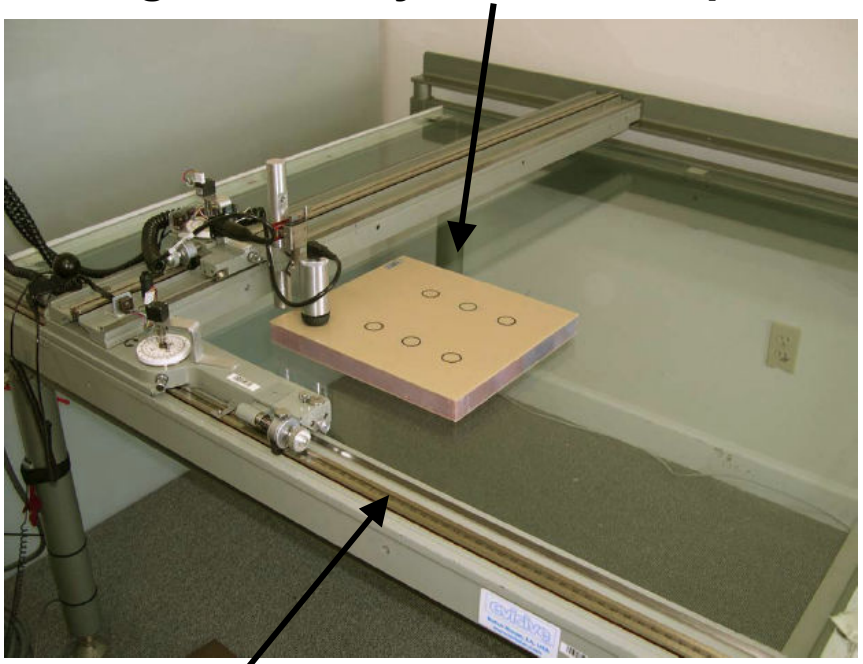
Microwave Scanning (Evisive)

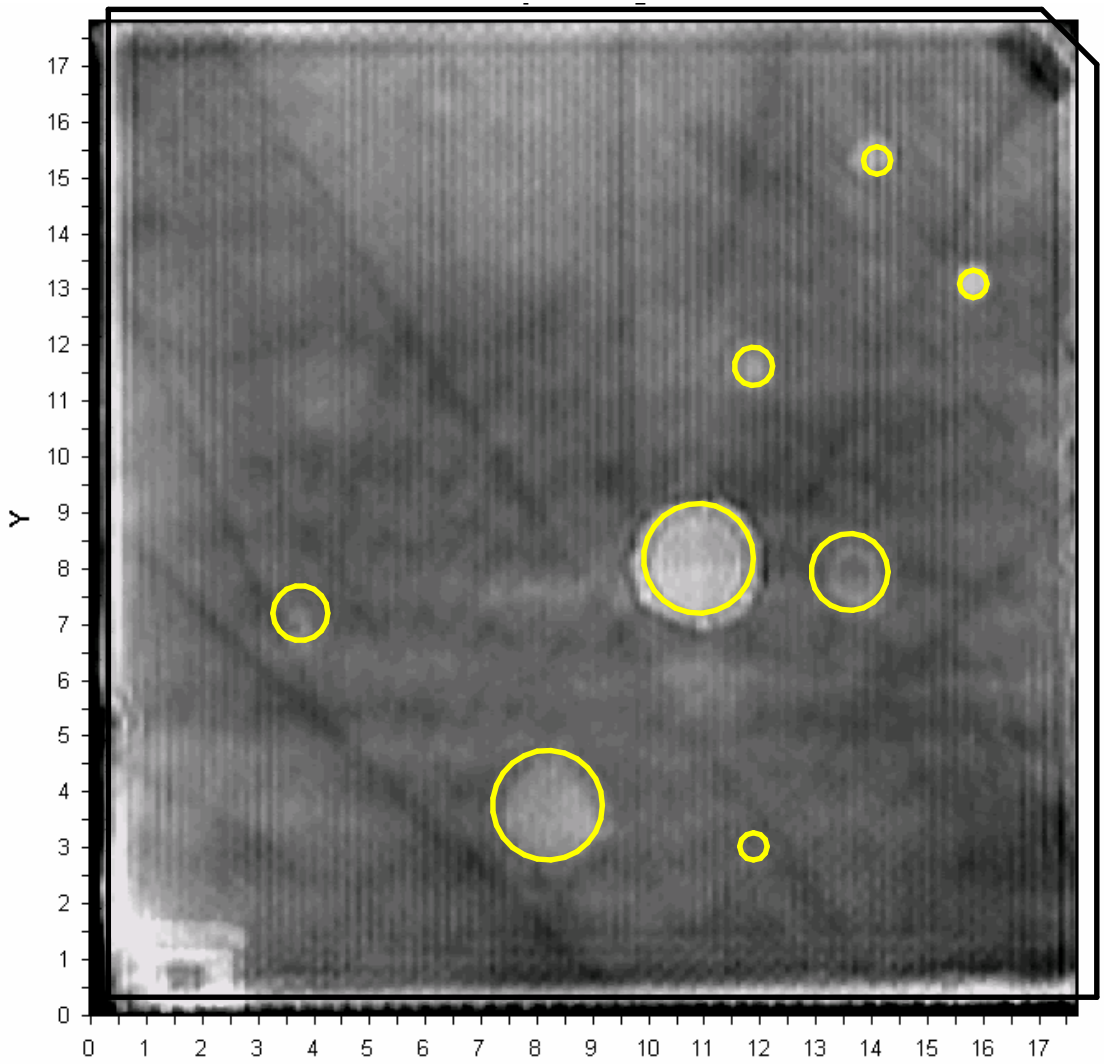
Fiberglass Honeycomb Test Specimen



Automated scan table

- Works by bathing the material in microwave energy of an essentially constant frequency
- The energy is reflected from each interface of differing dielectric constants within the specimen
- The reflected energy is superimposed, creating a signal that is acquired as an analog voltage which is digitized
- This signal is sampled at numerous discrete locations across the sample to create a 2-D image

Microwave NDI Results for 3 Ply Fiberglass Panel

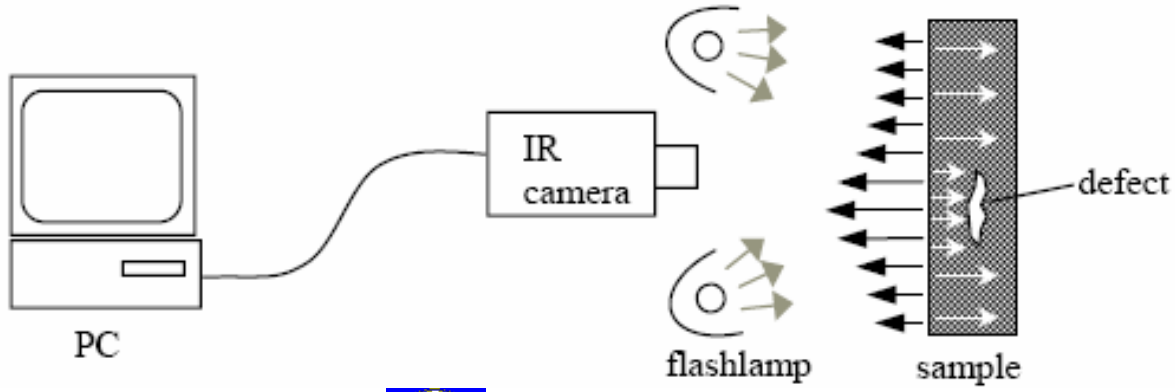


Some difficulty with carbon skin inspections

Pulsed Thermography

Flir A40 Uncooled IR Camera

- Sample surface is heated with a pulse of electromagnetic radiation from a flash lamp
- Heat from the surface diffuses into the sample and is obstructed by the presence of a subsurface defect
- The accumulated heat energy at the defect causes a transient nonuniformity in the infrared radiation



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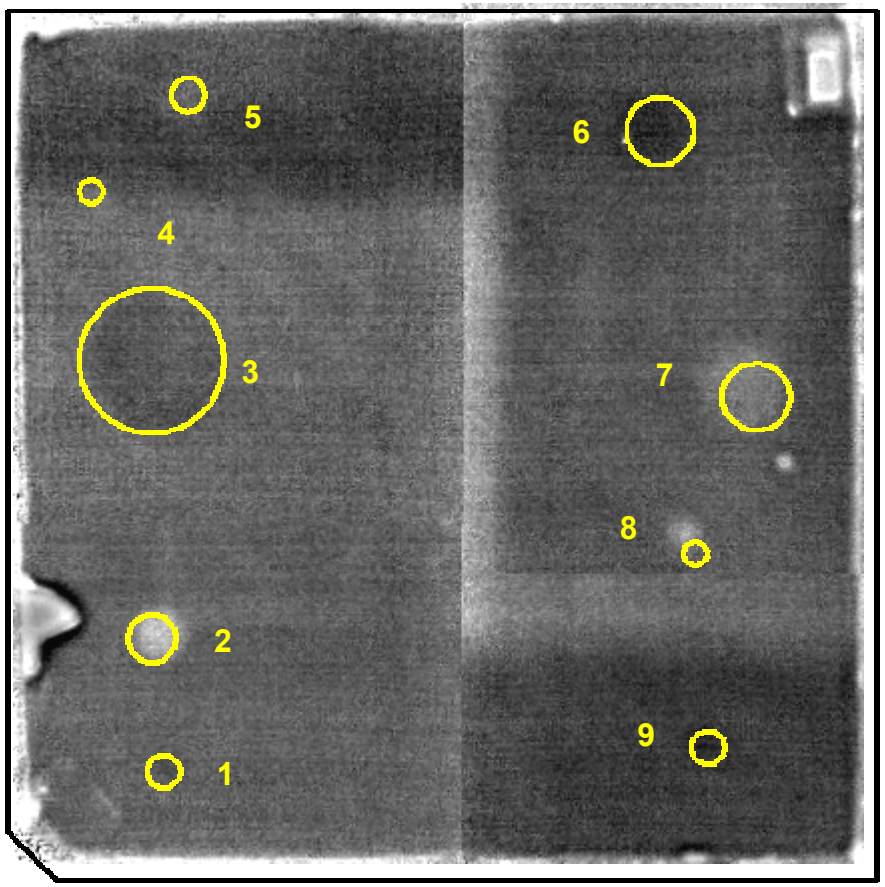
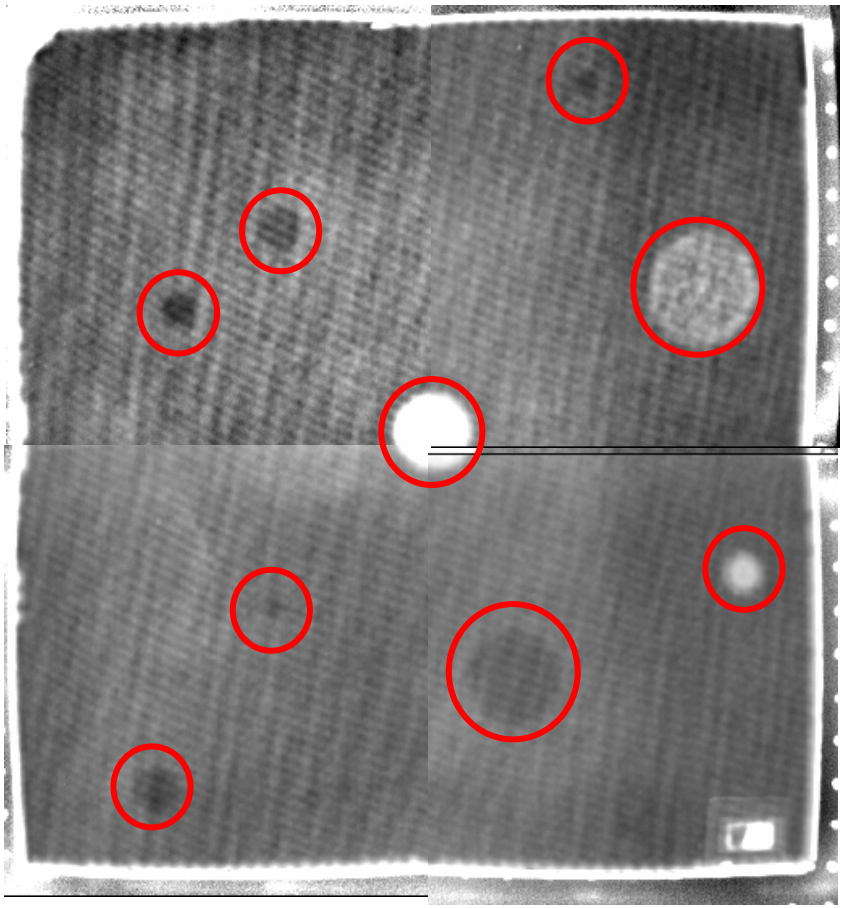
Pulsed Thermography Inspection Results for 6 Ply Panels

Carbon Skin



Fiberglass Skin



All flaws detected

Disbond Detection & Growth Monitoring with Piezoelectric Sensors

Damage Detection

Damage Identification

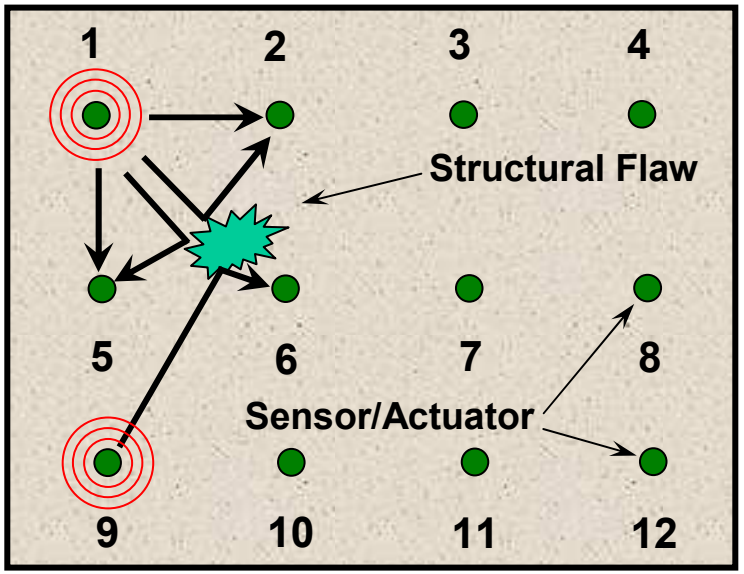
Residual Strength Evaluation

Assessment for Continued Use

Sensor Data

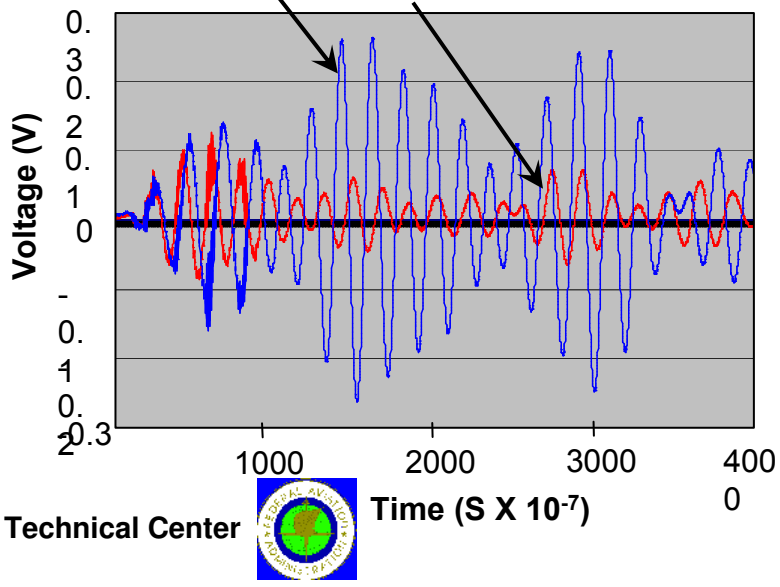
Actuation Signal

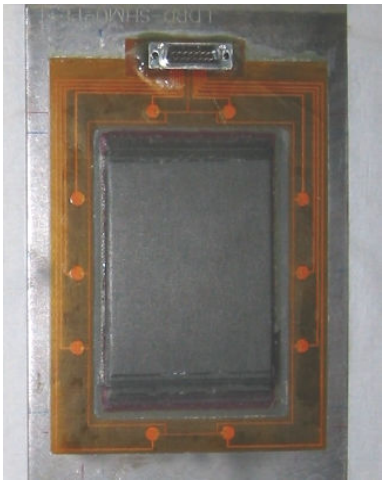
Piezoelectric Sensor Network



Blue = Signal Through Good Bondline Region

Red = Signal Through Disbond Region





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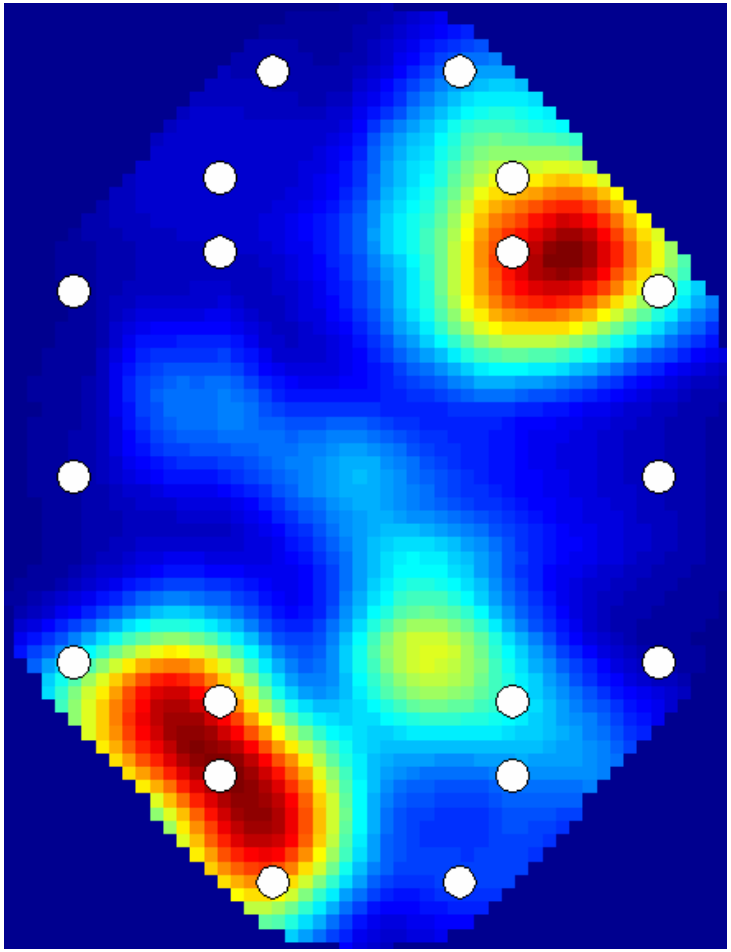
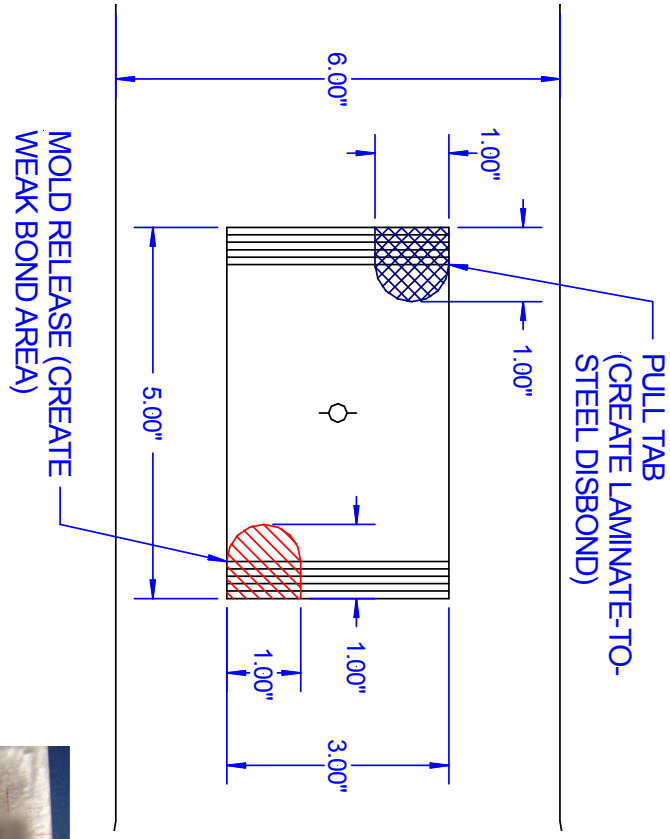
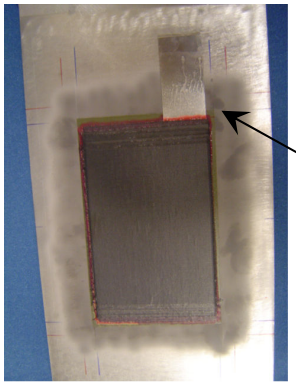
Disbond Detection & Growth Monitoring with Piezoelectric Sensors



After mold release flaw growth
(50 KHz inspection)





Pull tab flaw

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CACRC Inspection Task Group Update and Overview on Advanced NDI Methods for Composites

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