NONDESTRUCTIVE INSPECTION OF COMPOSITES USING AIR-COUPLED ULTRASOUND

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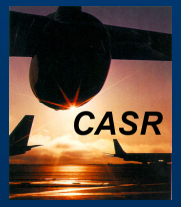
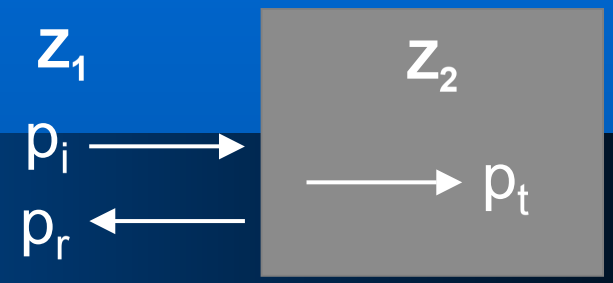


CENTER FOR NDE

Transmission and Reflection Coefficients (Energy)



$$\alpha_r = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$$

$$\alpha_r \to 1 \quad when \quad Z_2 >> Z_1 \quad or \; Z_1 >> Z_2$$

$$\alpha_t = \frac{4 Z_2 Z_1}{(Z_2 + Z_1)^2}$$

$$\alpha_t \to 0 \quad when \quad Z_2 >> Z_1 \quad or \; Z_1 >> Z_2$$

Impedance Ratios:

CFRP : Water = 3:1, CFRP : Air = 10,000: 1

From Air to Solid:

	α_t	α_r
CFRP	**0.04%**	**99.96**
Aluminum	**0.01%**	**99.99**

From Water to Solid:

	α_t	α_r
CFRP	**75%**	**25%**
Aluminum	**30%**	**70%**

Ultrasonic Attenuation in Air

5 dB/m at 120 kHz, 45 dB/m at 500 kHz, 160 dB/m at 1 MHz

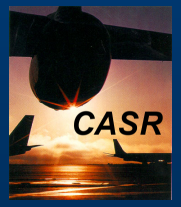
For 4” propagation distance, reduction of signal amplitude is 5% at 120 kHz, 40% at 500 kHz, and *80% at 1 MHz (not counting diffraction loss)*

Resolution of Air-Coupled Scans

The slow speed of sound in air helps to achieve reasonable resolution even at sub-megahertz frequencies.

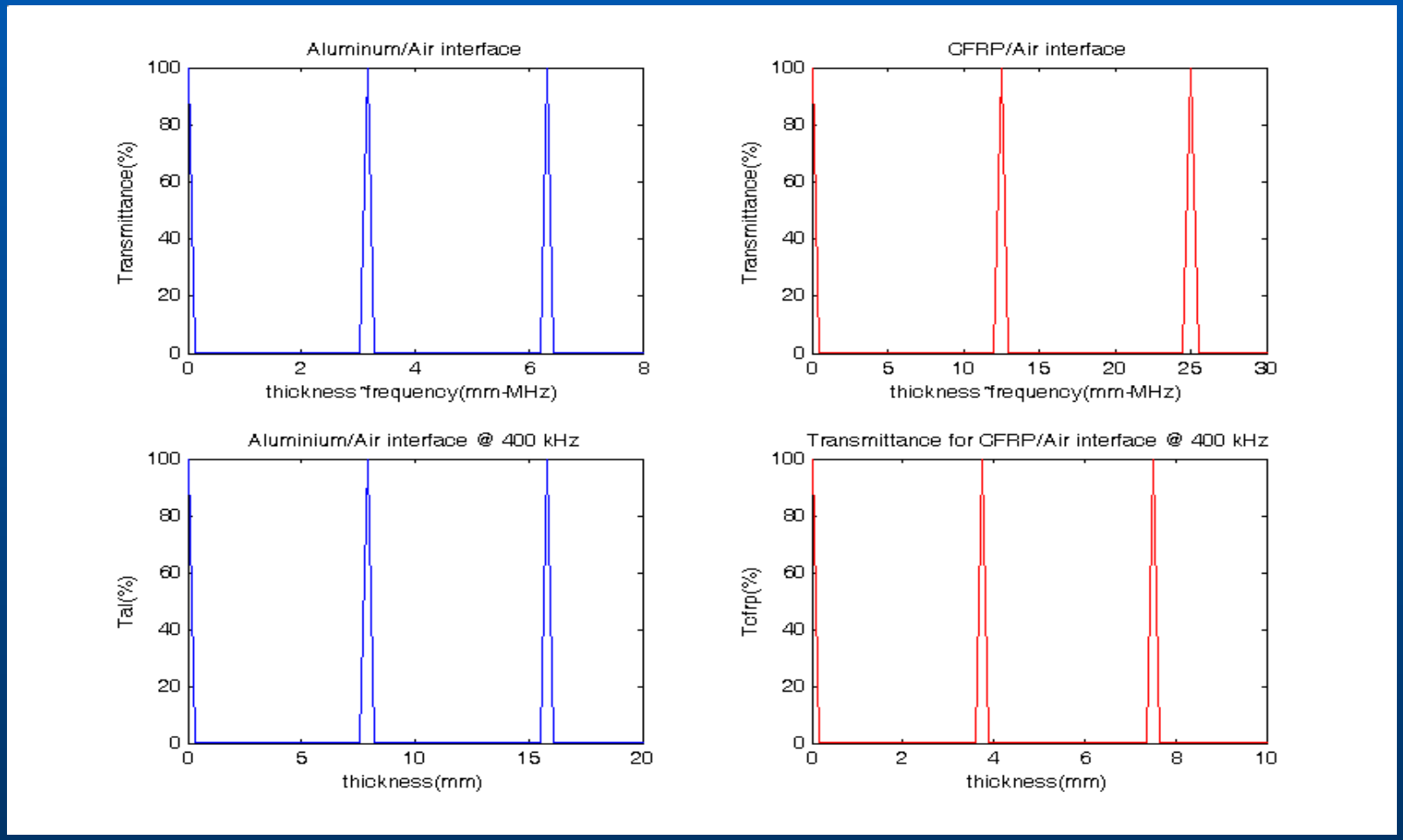
Wavelength at 120 kHz:

Aluminum	CFRP	Water	Air
2”	1”	½”	1/10”



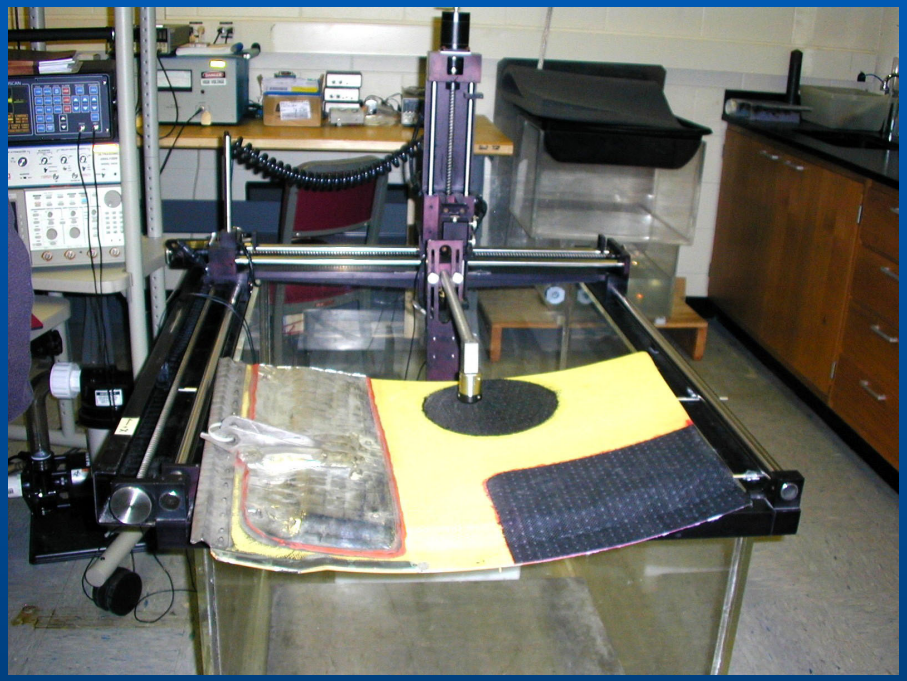
Transmission Coefficient Through a Plate

$$T = \frac{1}{\sqrt{\left(1 + \frac{1}{4}\left(m - \frac{1}{m}\right)^2 \sin^2\left(\frac{2\pi d}{\lambda}\right)\right)}}$$



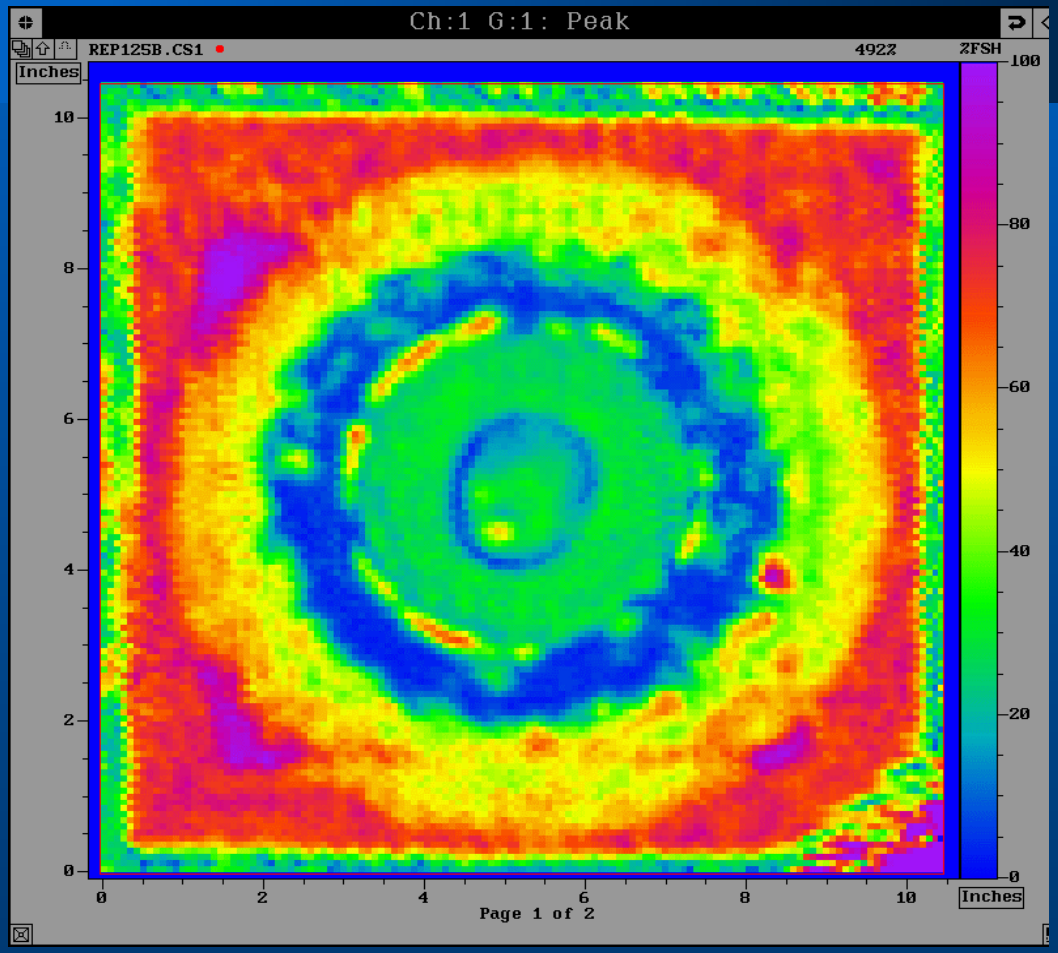
Inspection of Composites with Air-Coupled Ultrasonics

Air-Coupled System from QMI, Inc.
UT scanner from SONIX, Inc.



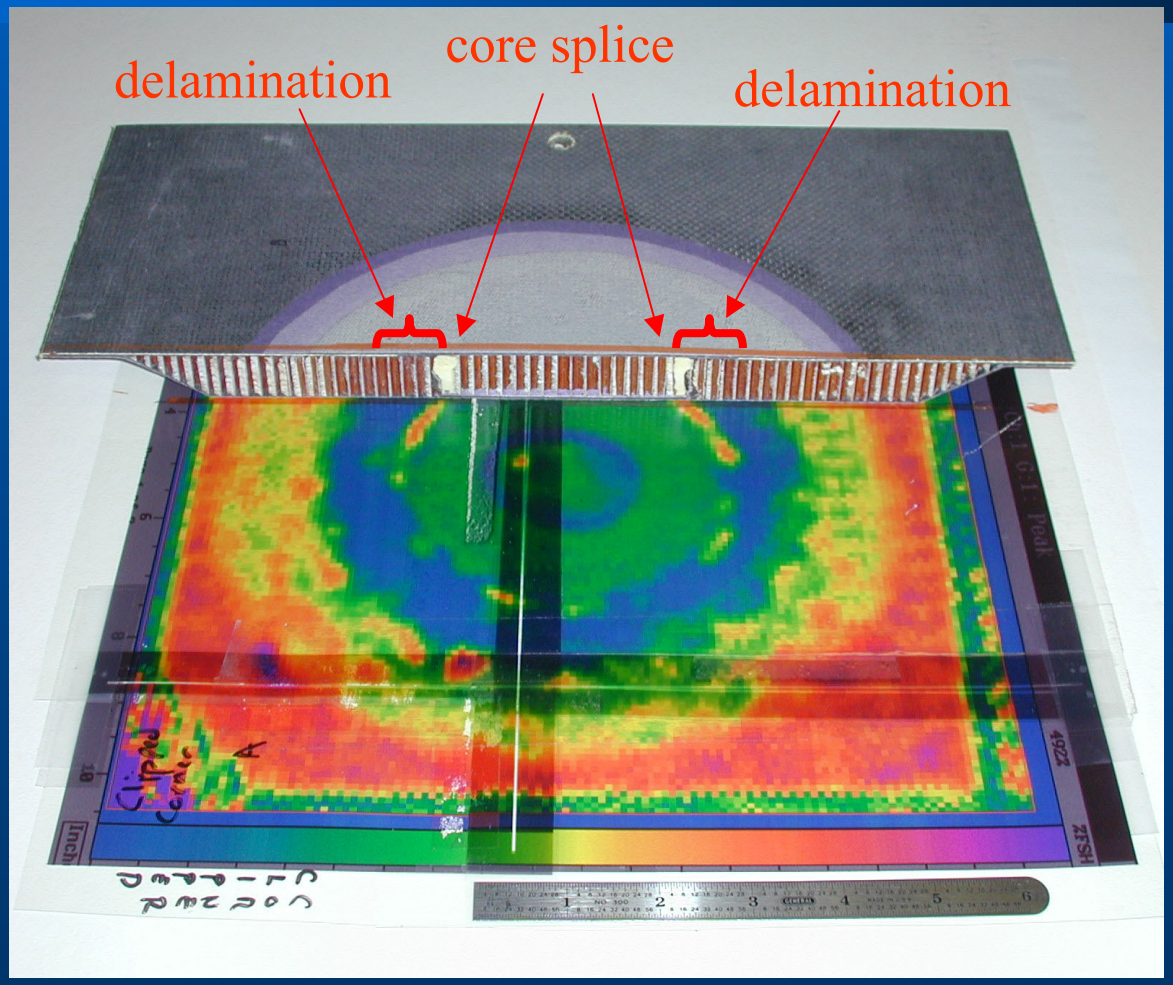
Scanning a Nordam repair panel

Air-coupled Ultrasonic Scan Images of Composite Repairs



Through transmission C-scan using 120 kHz transducers
Scan area 10.5” x 10.5”

Correlation between internal conditions of composite repair and the Air-Coupled Ultrasonic Transmission C-Scan Image

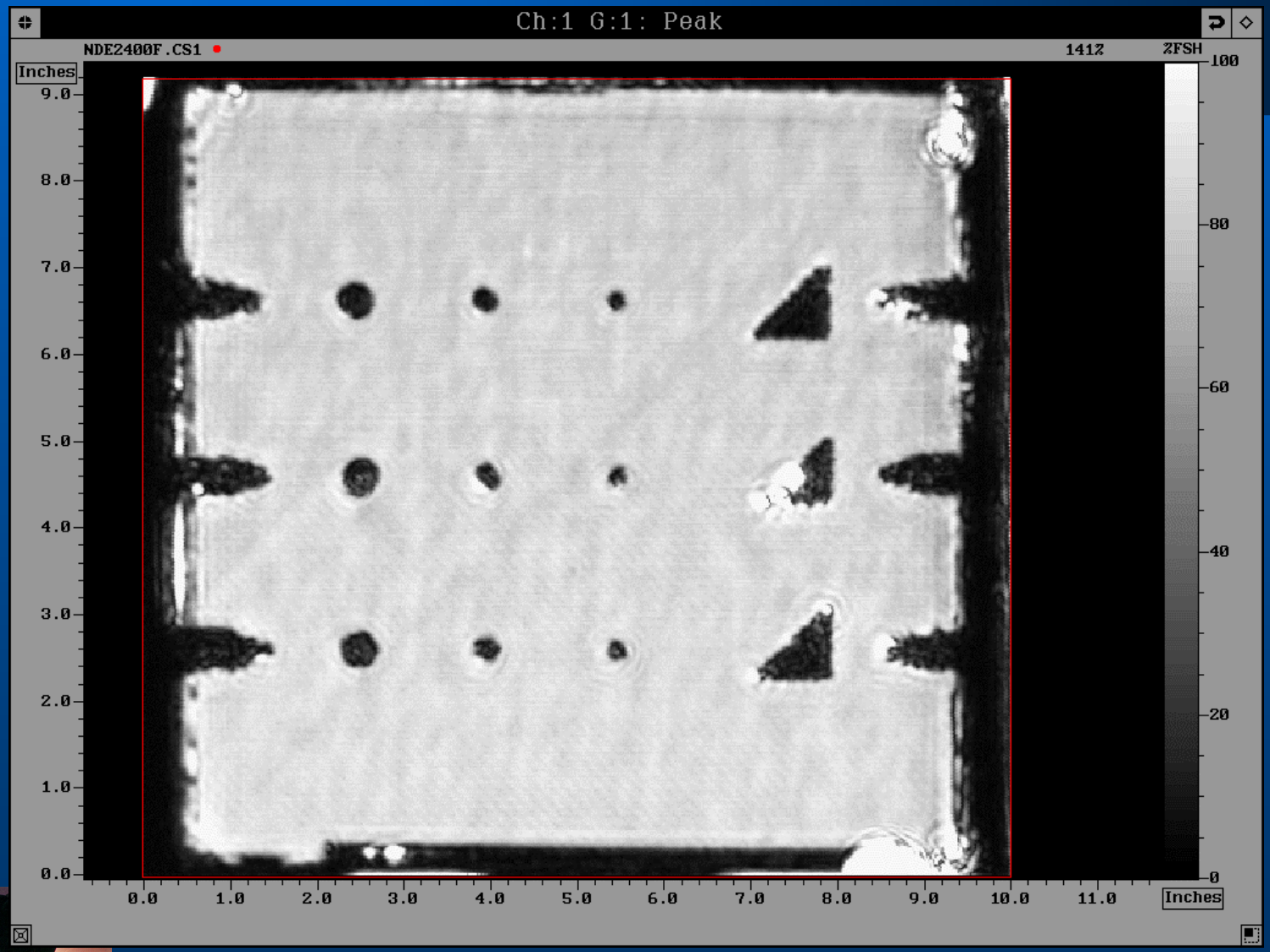


COLORS:

Red & orange-- high transmission

Blue & green—low transmission

Air-Coupled UT Image of CFRP Facesheet with Flaws



Flaws:

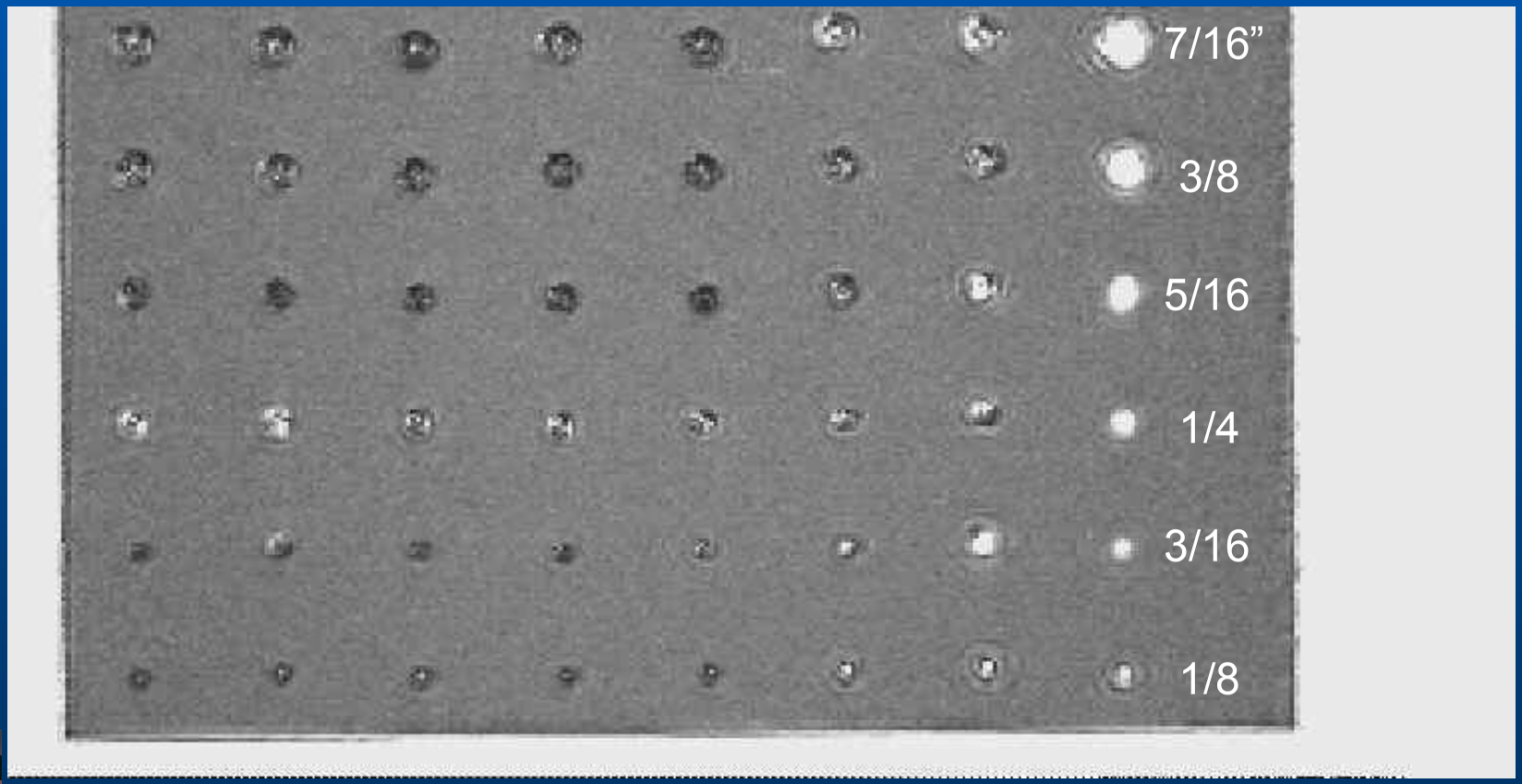
Circles 3/8”, ¼”, 1/5”

Triangle 1”

Pull tabs

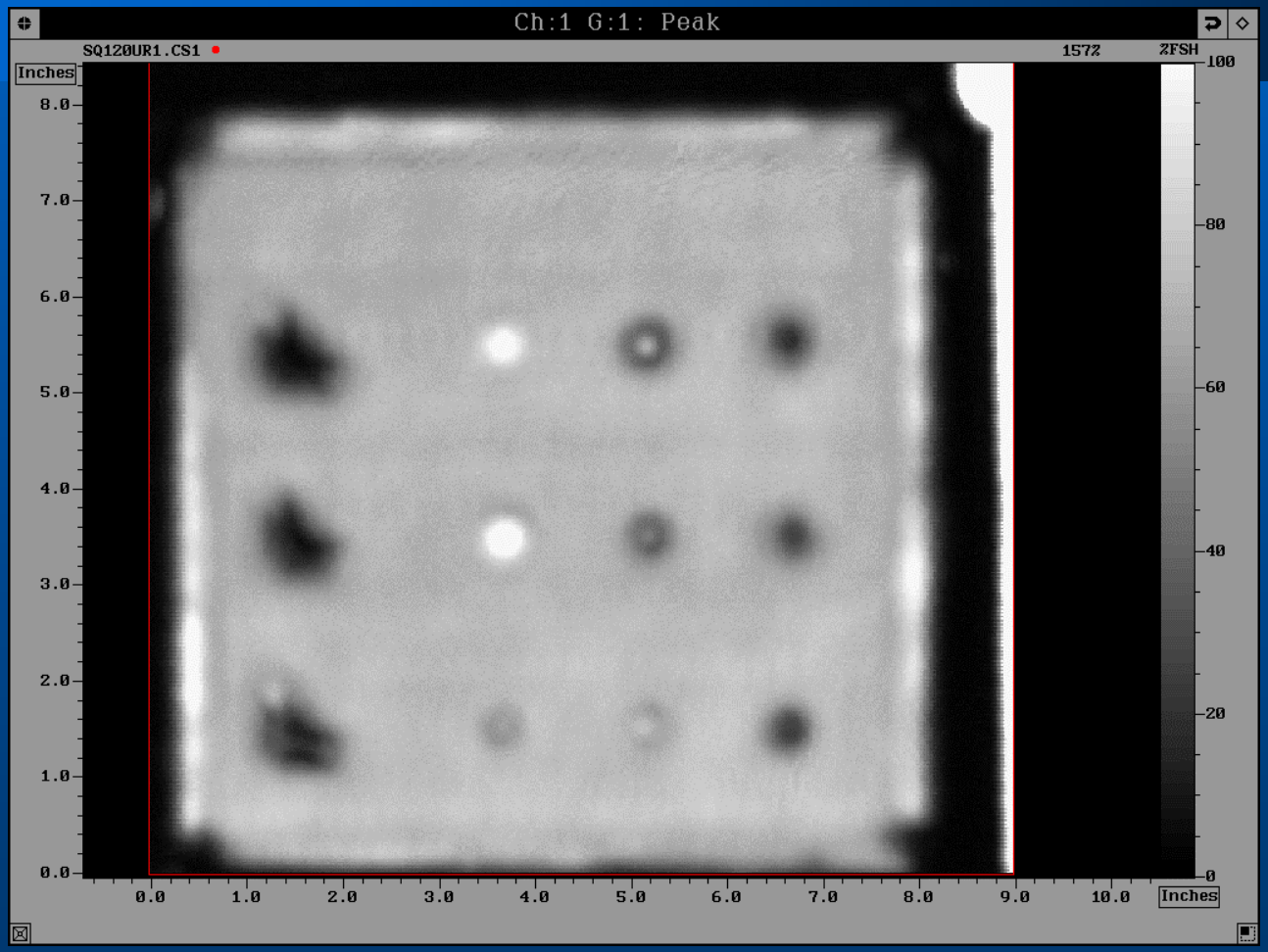
Transmitter & Receiver 400 kHz - (Receiver ~1” focus)

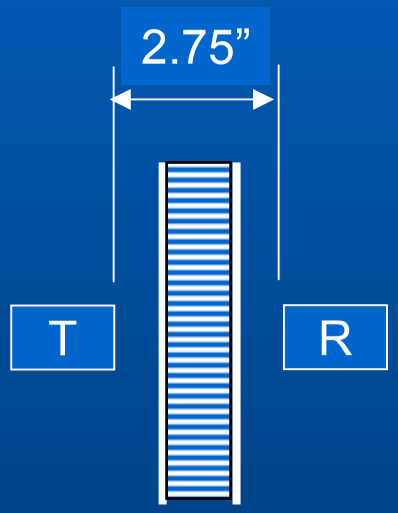
Transmission Air Scan of Flaws in 16-Ply Laminate (at 400 kHz with focused receiver)



Flaws at different depth do not look alike in this TTU image.

“Poisson’s Bright Spot” in Air Scanned Flaw Images”



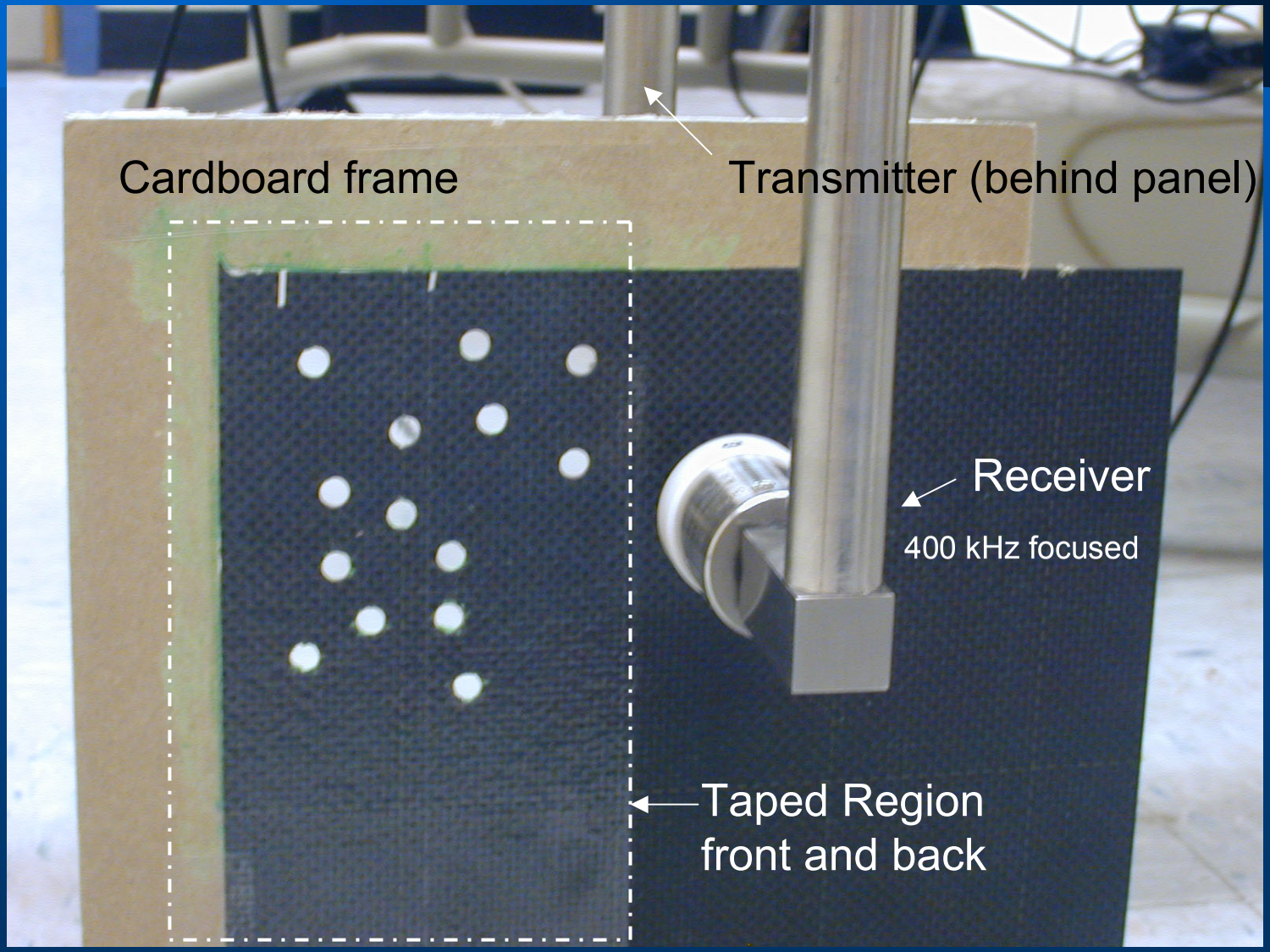


Flaws in skin are:
3/8”, ¼”, 1/5” circles
and 1” x 1” triangles

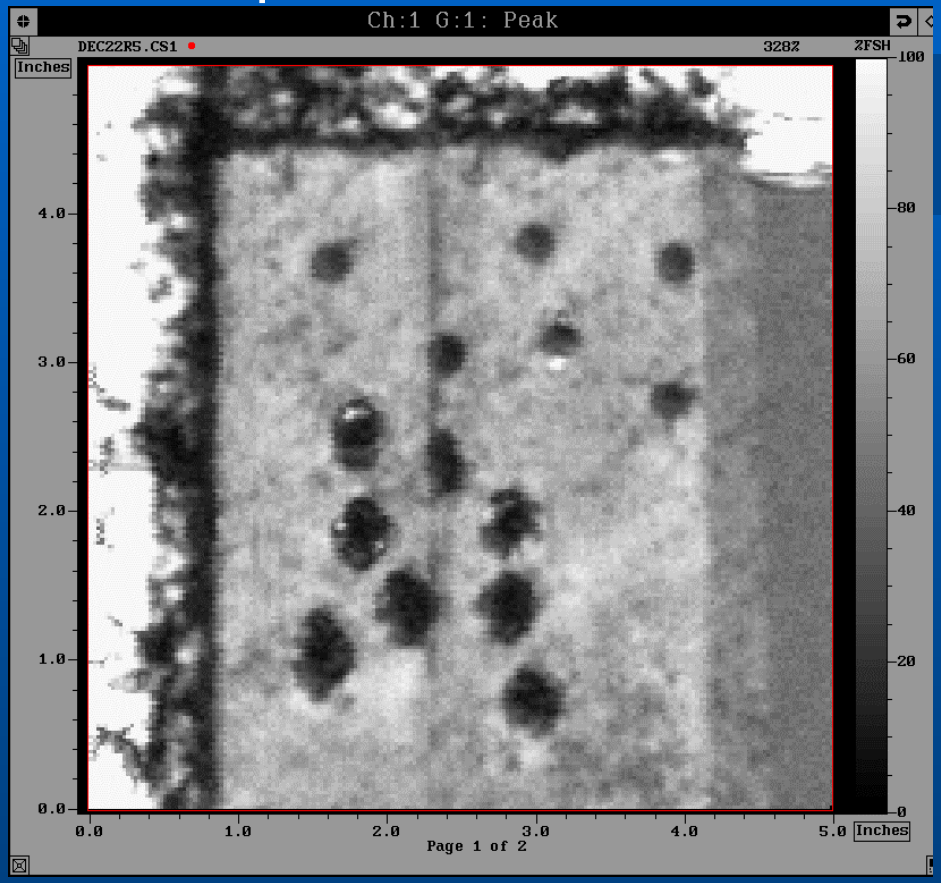
Aluminum H/C core
1/8” cell, ¾” thick

Transmitter & Receiver 120 kHz (no focus)

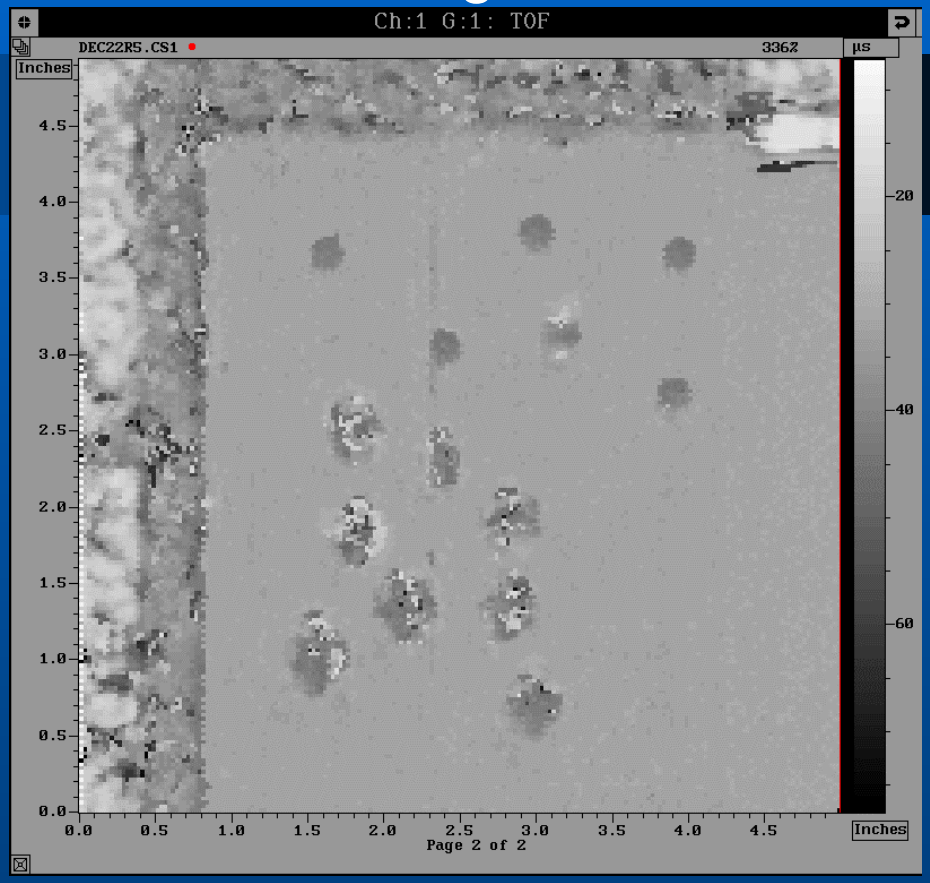
Testing Airscan's Ability to Image Thru-Holes and Corner Flaws



Air-coupled C-scan of Panel With Holes and Edge Features



Amplitude image of transmitted signal



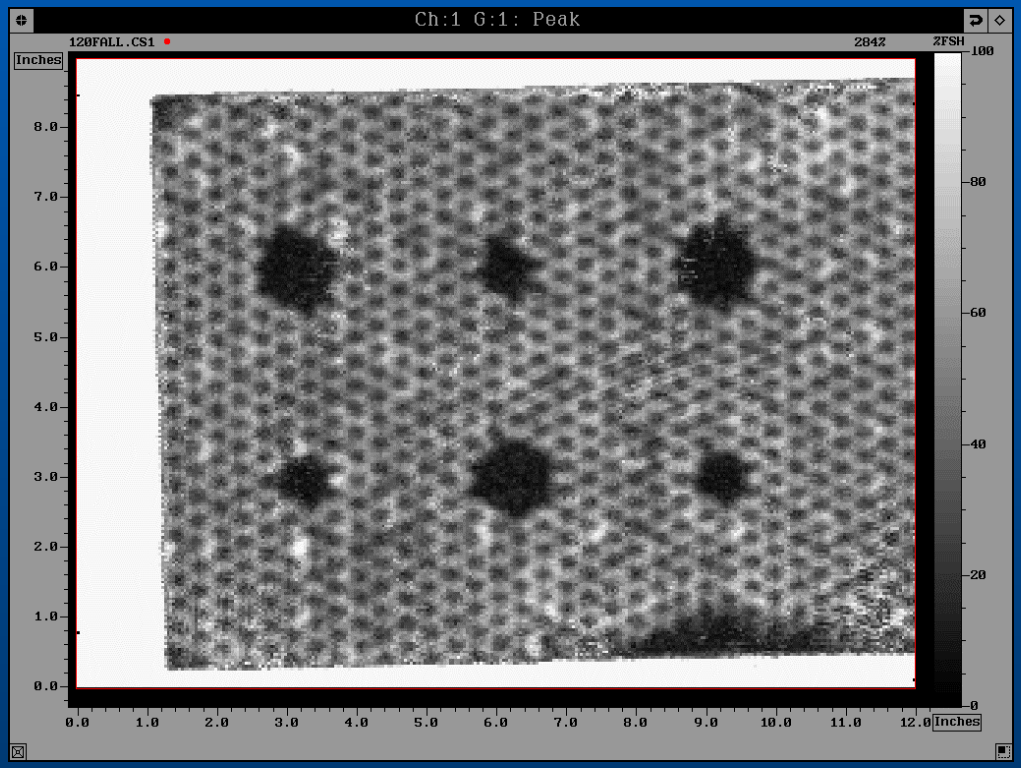
Time-of-flight image of transmitted signal

Region with holes is covered with packing tape to prevent signal saturation in the vicinity of holes. The upper 6 holes had no drilling damage, while the bottom 8 holes had fiber pull-out and delamination.

Transducers are Air-coupled 400 kHz probes.
Transmitter is unfocused, Receiver has a focal length of ~1”

TTU airscan of flaws in aluminum honeycomb with perforated skin

Using 120 kHz, ¾” diameter focused probes



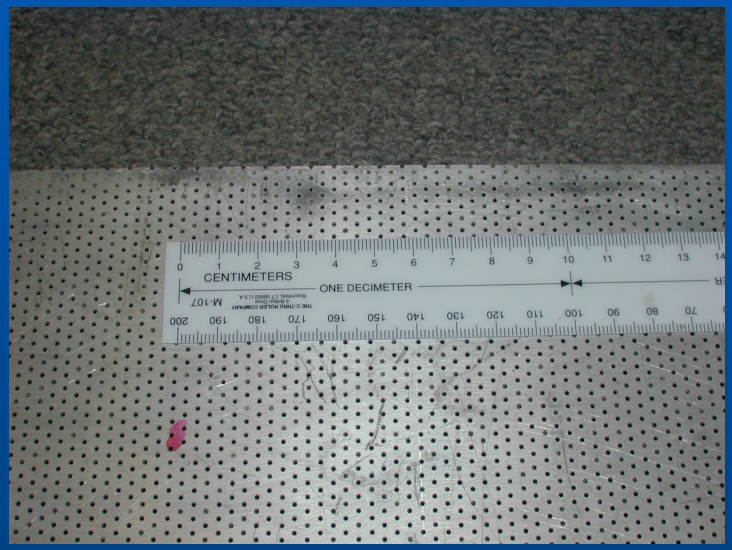
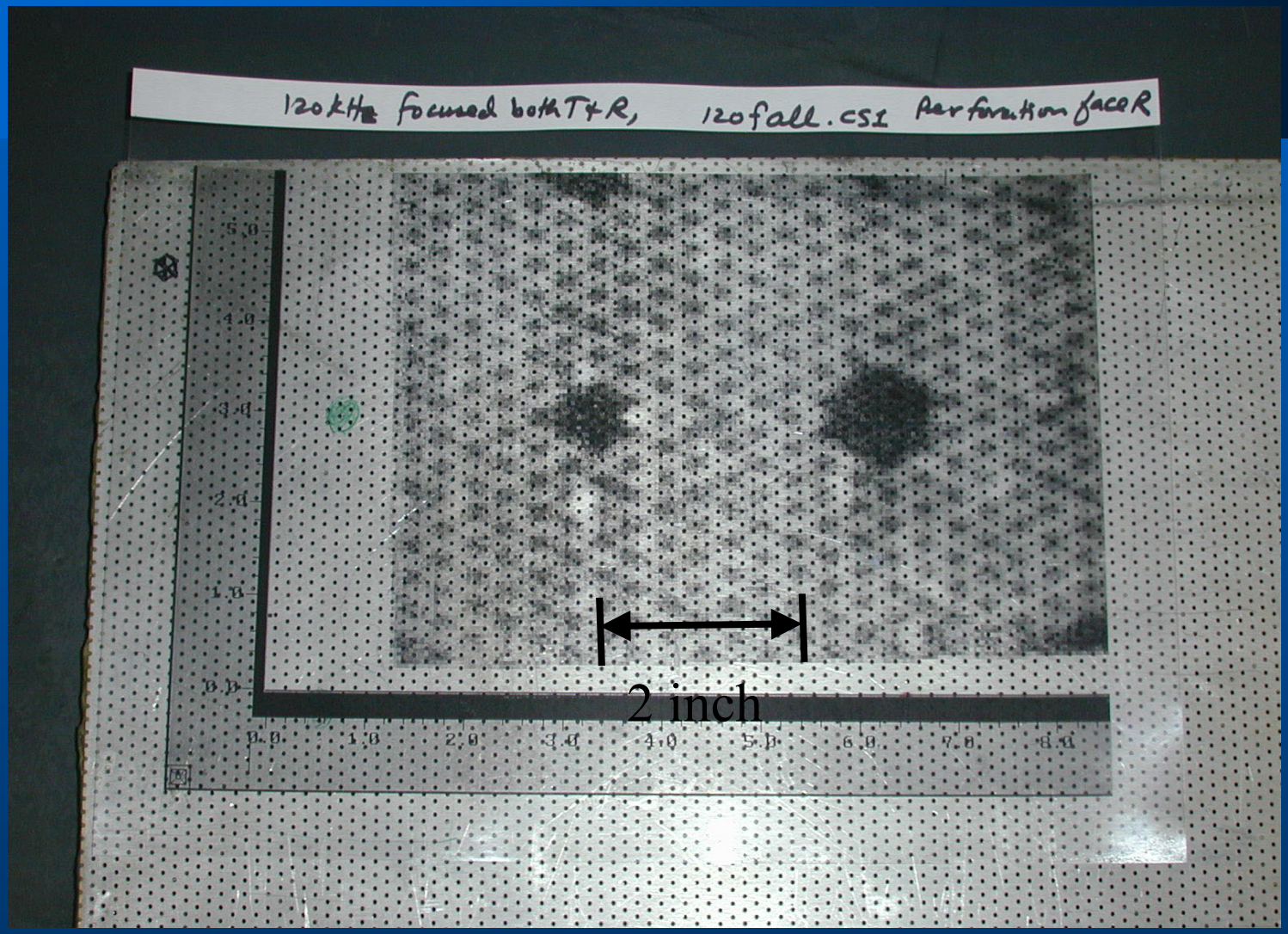


Photo of perforated skin on aluminum honeycomb panel

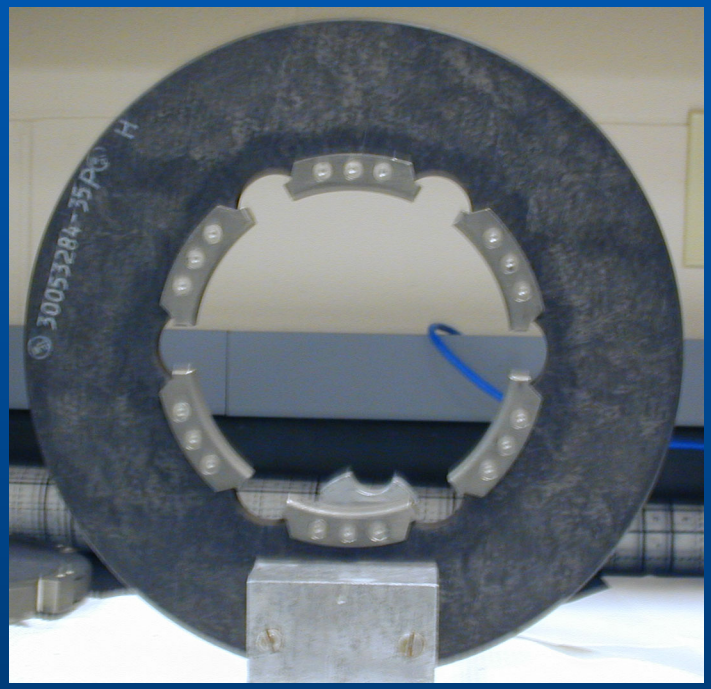
Skin thickness = 0.032”, honeycomb thickness = 0.5”, cell size ~ 3/8”
Upper two flaws on perforated side, lower two flaws on un-perforated side

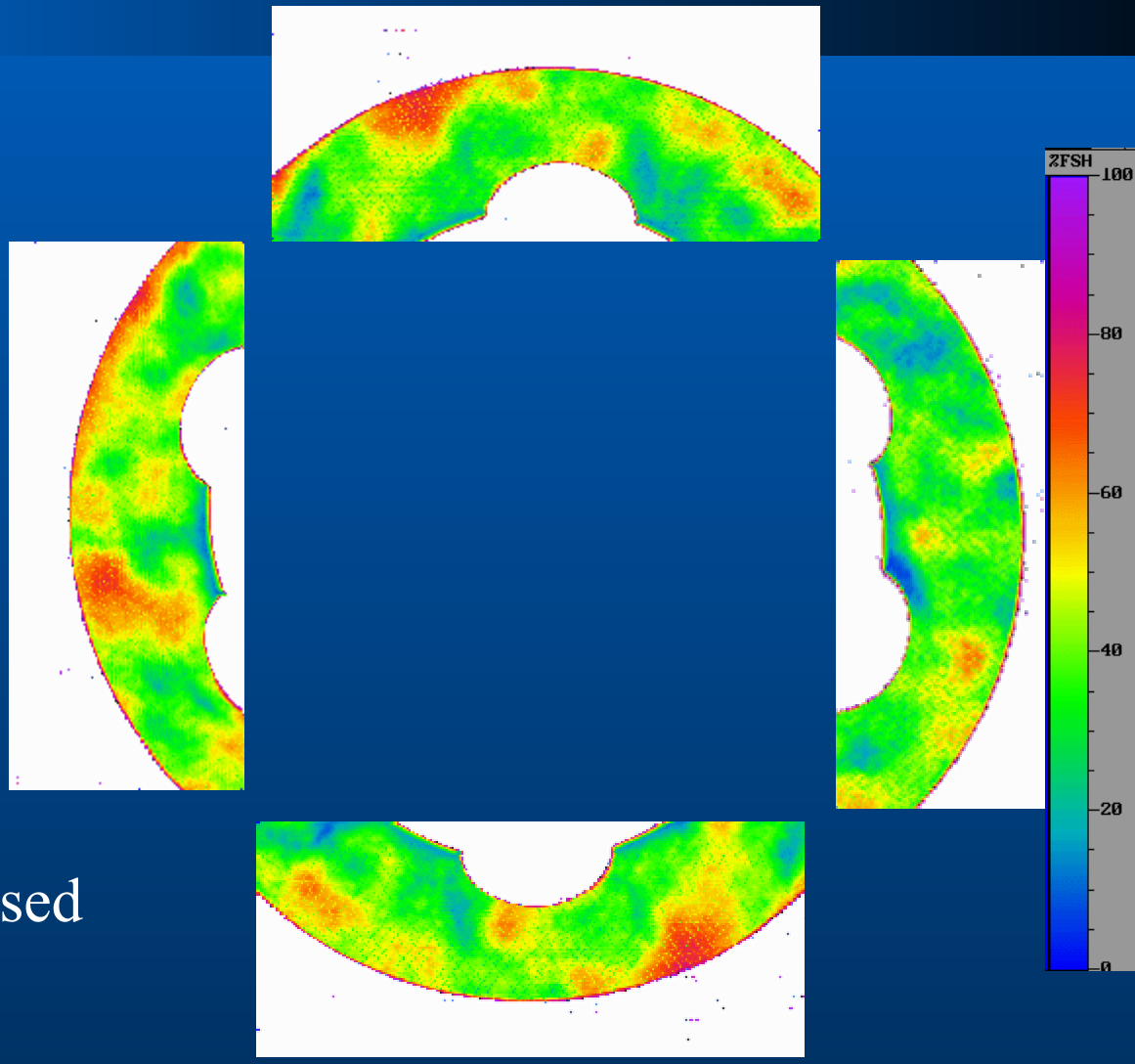
Perforation did not affect imaging of flaws and honeycomb cells



TTU airscan image (on transparency) laid over perforated skin

Transmission airscan of a C/C brake disk

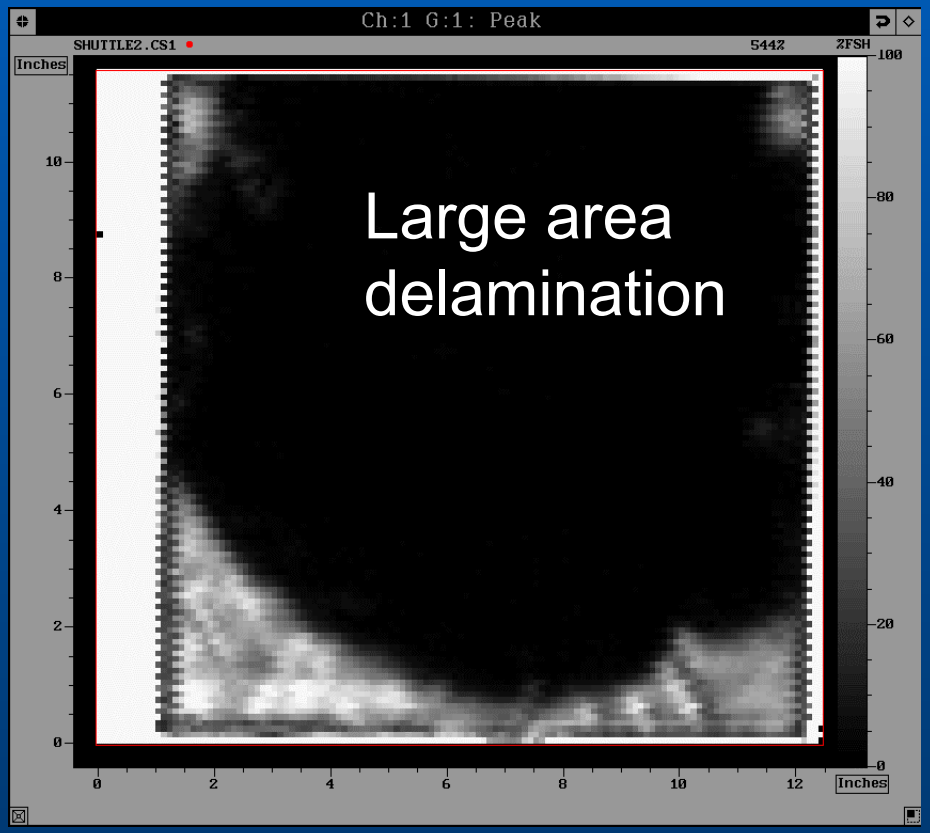


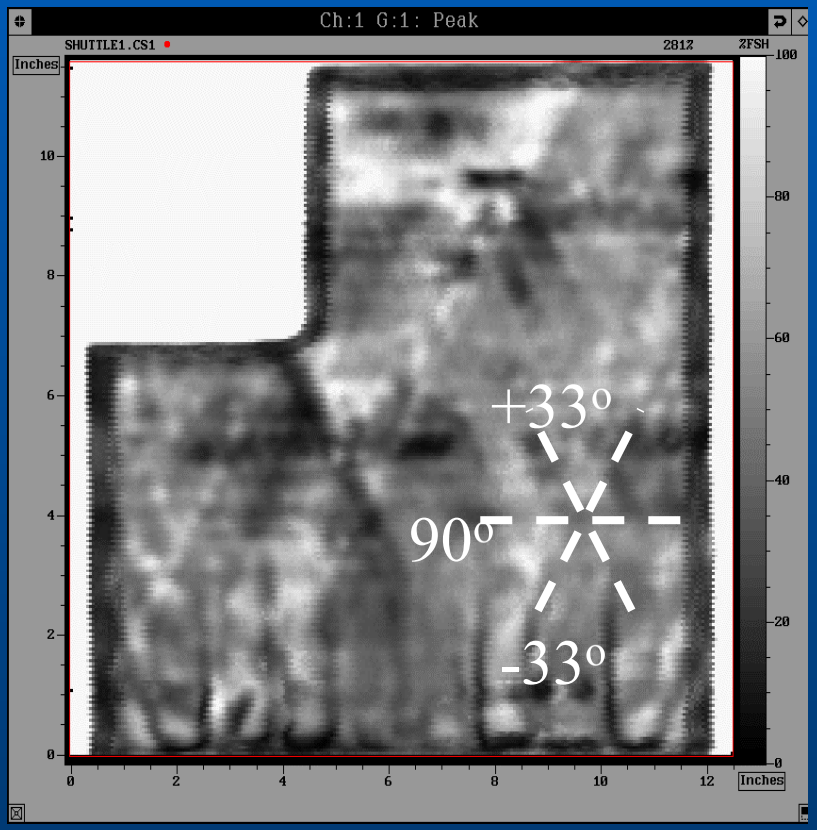


120 kHz unfocused

THICK COMPOSITE ROCKET CASE

Air-Coupled Transmission UT Scan, 120 kHz



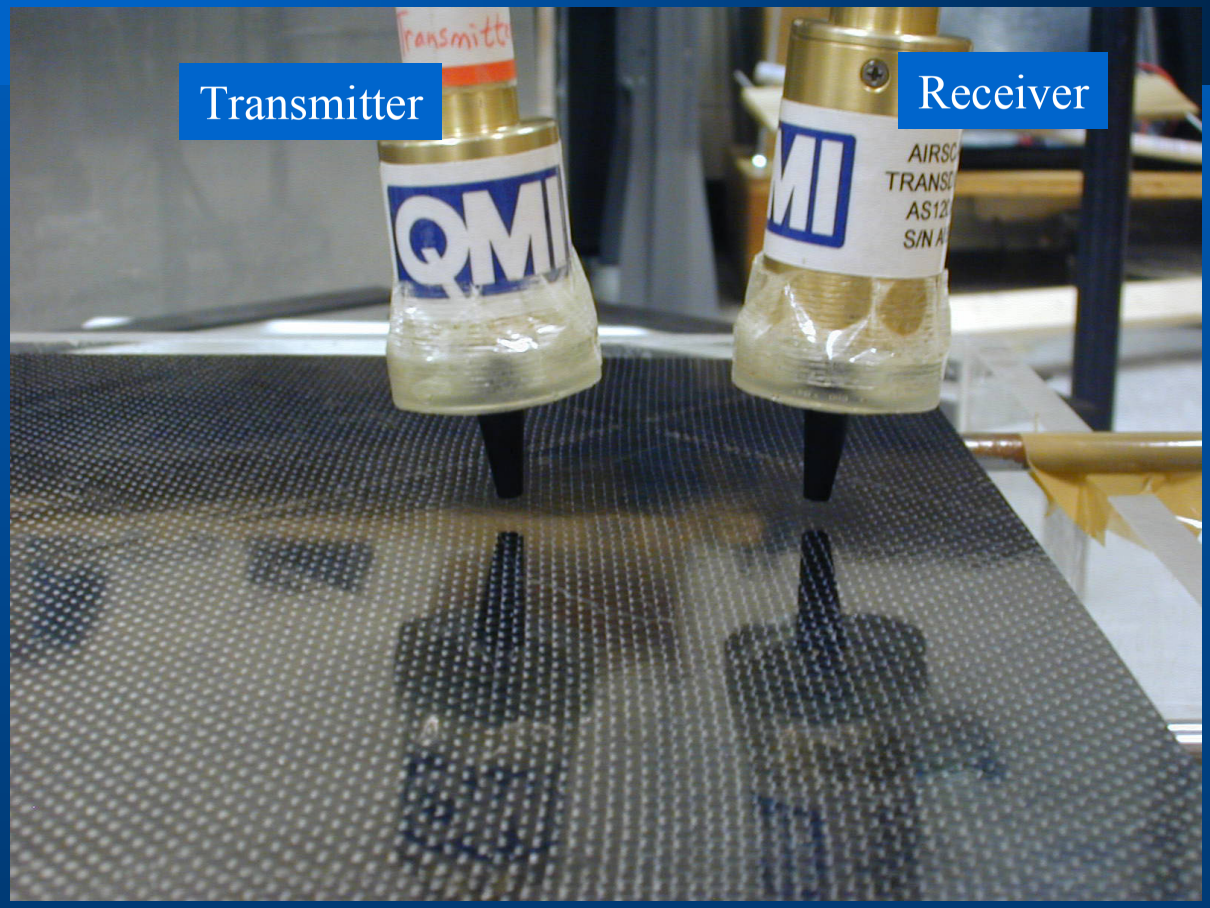


12” x 12” x 1.25”

12” x 12” x 1.5”

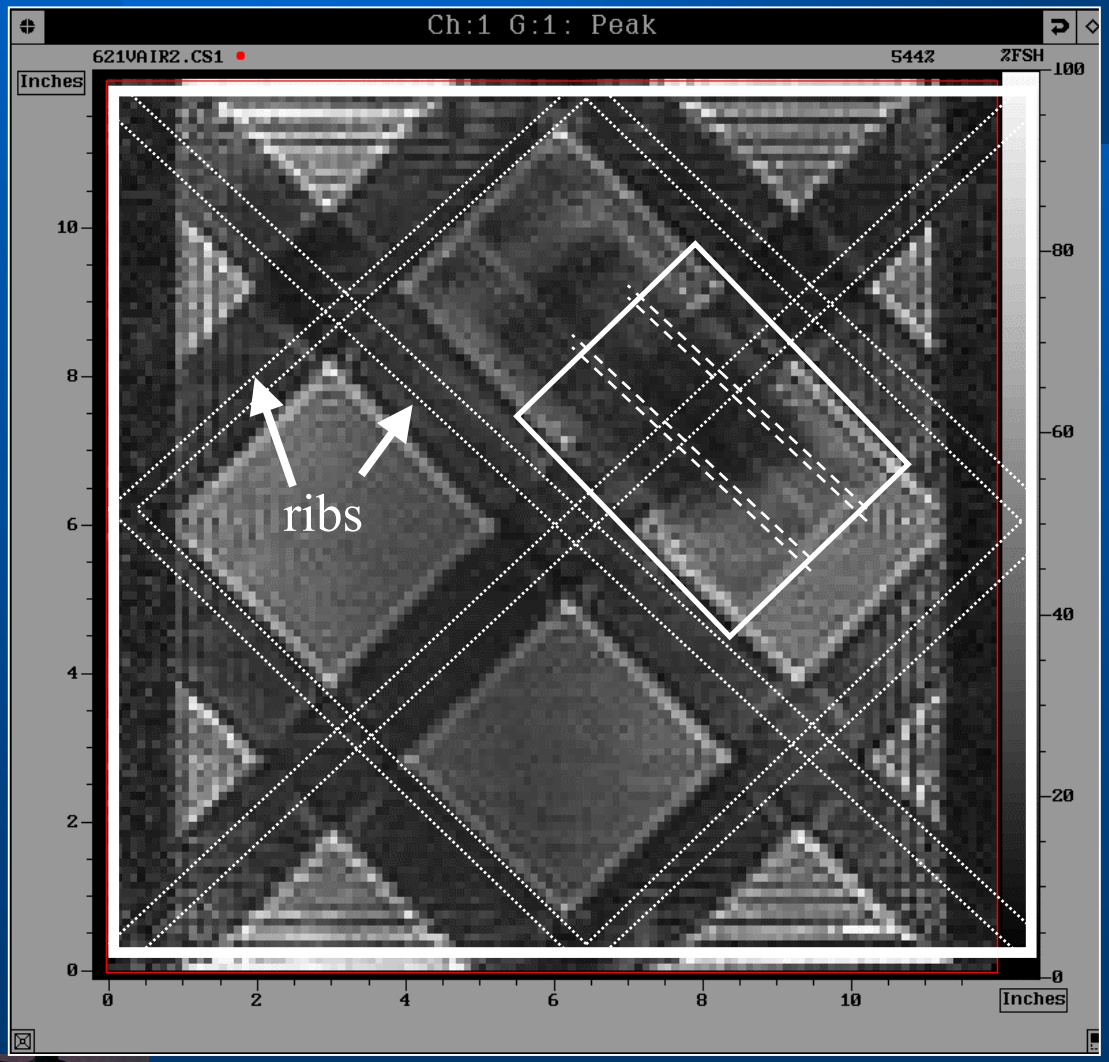
Fiber directions (90º, +/- 33º) of filament wound case are visible

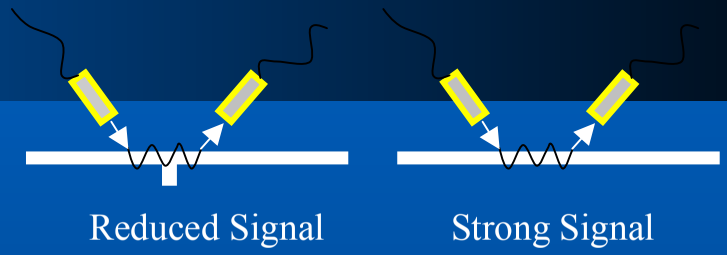
Transducer Modification for Lamb Wave Scanning



Otoscope cones on transmitting and receiving transducer eliminated the need for a sound barrier and made scanning easier.

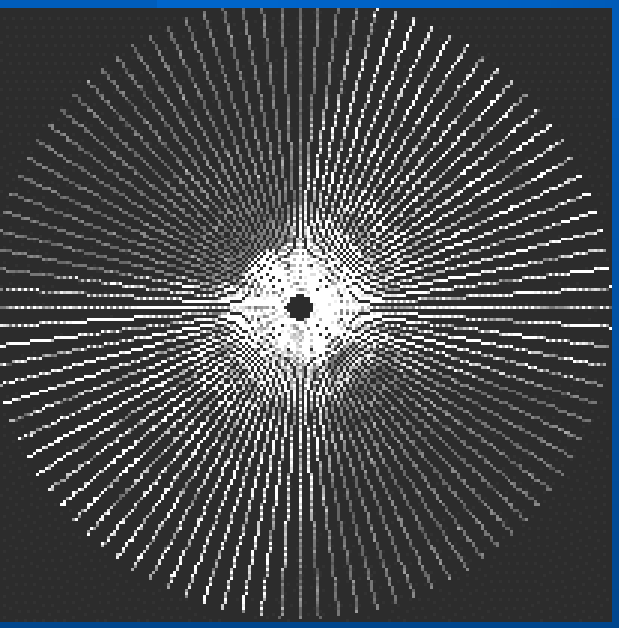
Air Coupled Lamb Wave Scan of Reinforced Composite Plate



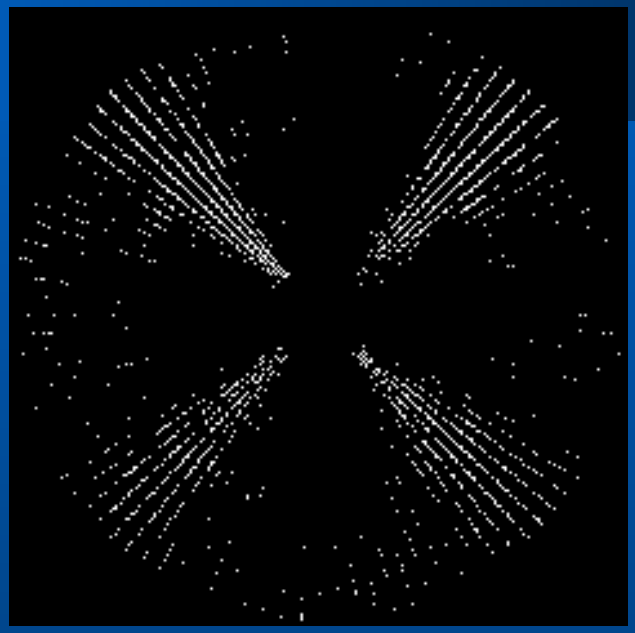


Underlying structure affects amplitude of received Lamb wave

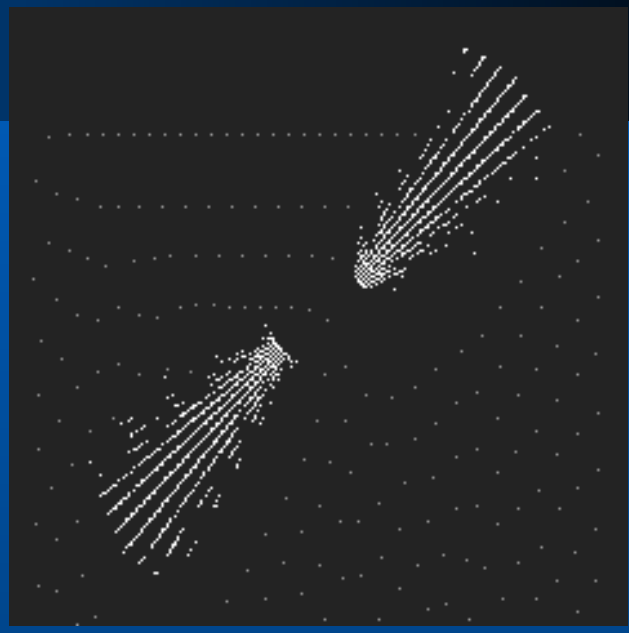
Effect of Ply Orientation on Lamb Wave Amplitude



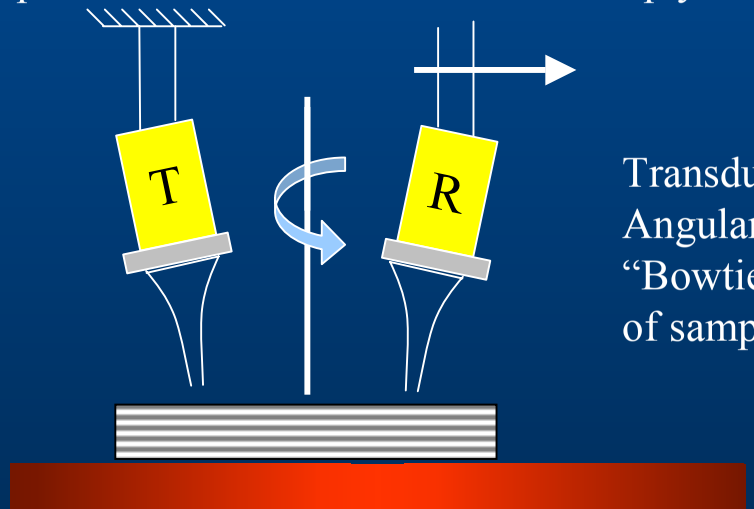
Quasi-Isotropic
Lay-up



0º-90º
Cross-ply

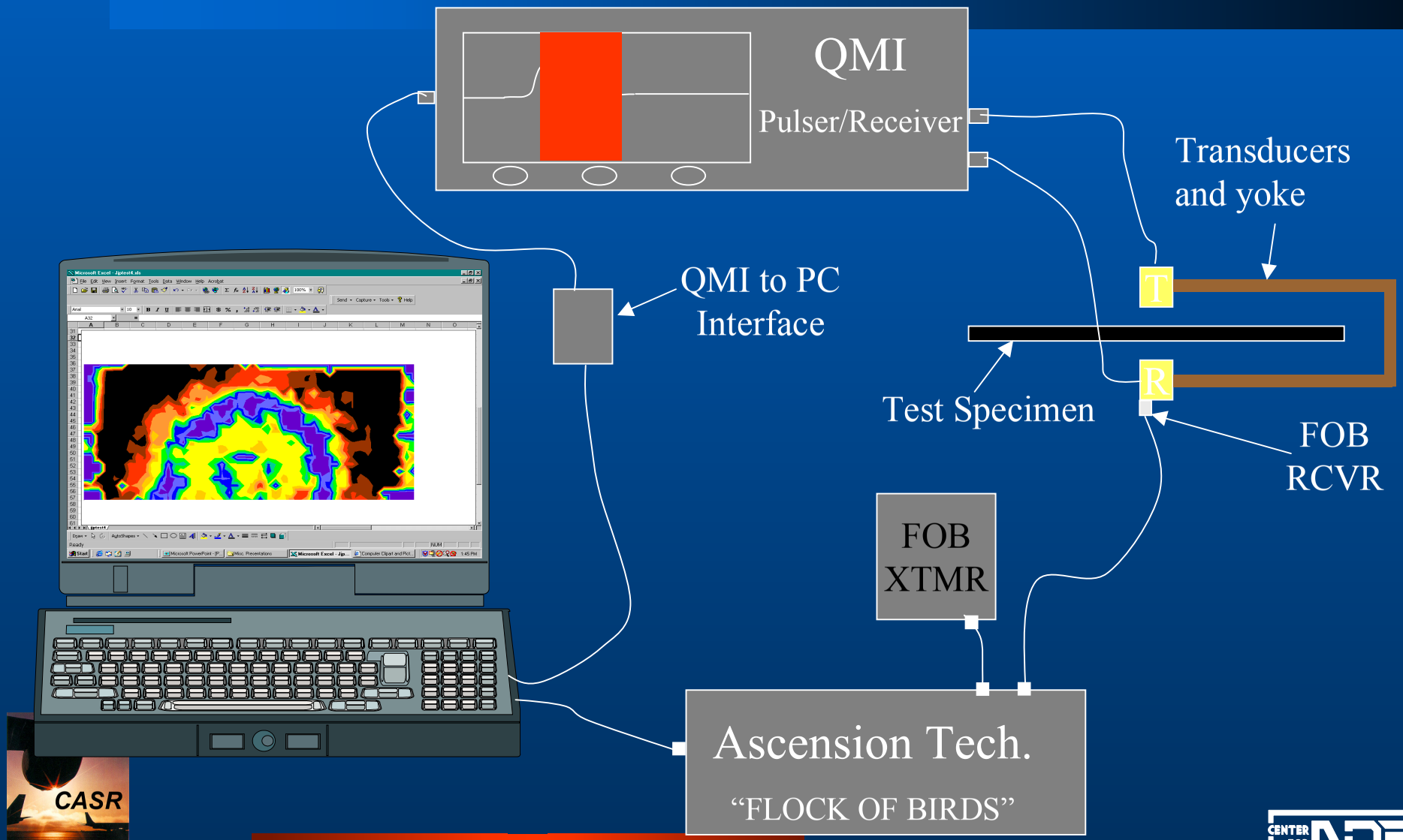


Uni-directional
Lay-up

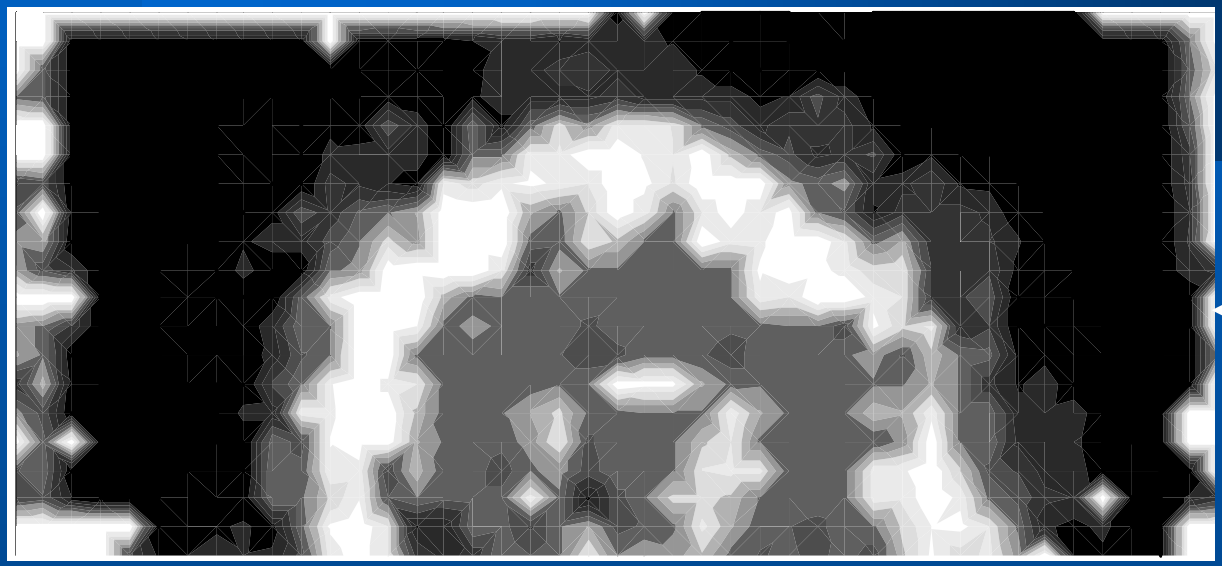


Transducers are 120 kHz, apodized with cones.
Angular scan step = 3.6 degrees.
"Bowtie" on quasi-isotropic caused by edge effect of sample.

Fieldable Air-Coupled UT Scan System

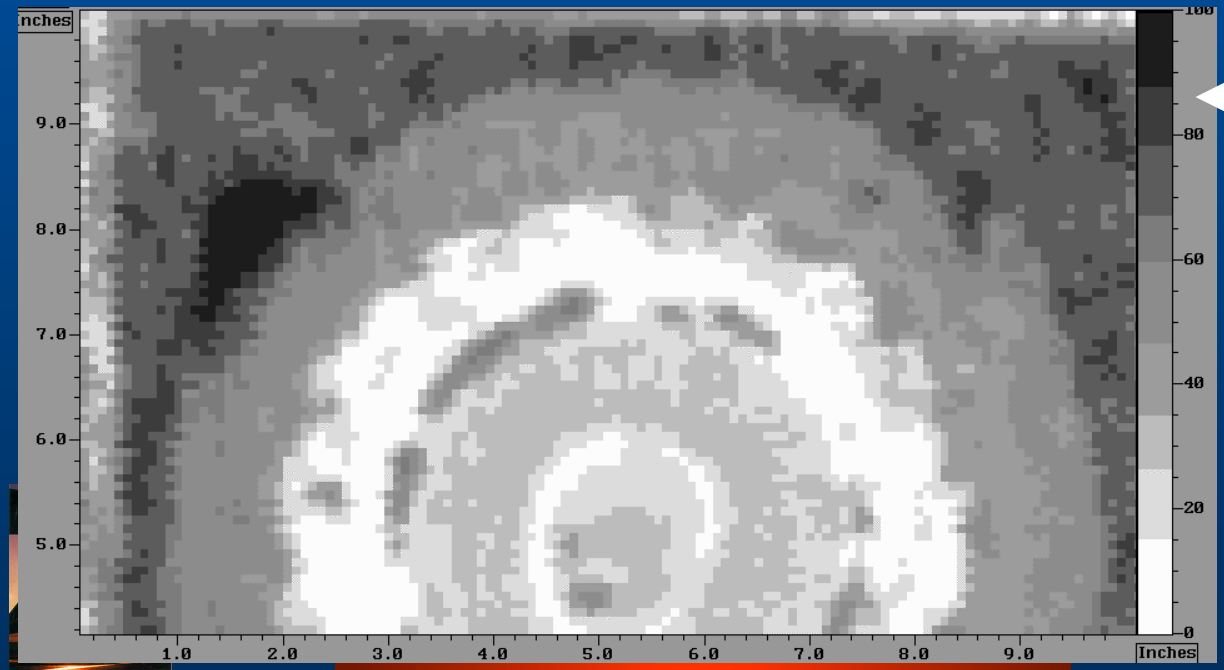


Comparison of “Hand Scan” & Mechanical Scan Results



Transmission scan using
120 kHz unfocused probes

Hand Scan Image
0.25” step size



Mechanical Scan Image
0.04” step size

White semicircle is delamination

SUMMARY REMARKS

1. Air-coupled UT can be used for inspecting a variety of materials and structures.

2. Primary mode of inspection is transmission scan, although one-sided Lamb wave scan is possible.

3. Diffraction and interference effects are more easily observed than in water-coupled UT.

4. Portable, manual air-coupled UT scan system is currently under development.