



Multi-Layer Bonded Composite Inspection Using UltraSpec[®]

A4A NDT Forum, September 22, 2026

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Motivation/Inspection Challenge

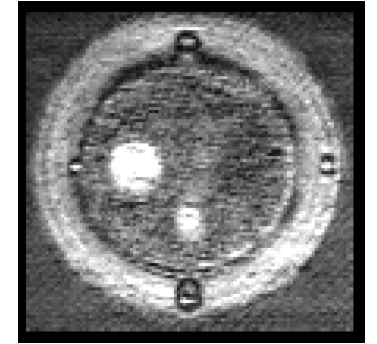
Problem: Advanced composite bonded structures are challenging to inspect due to their complex multi-layered structures.

Future military aircraft will use advanced composite bonded structures that will require recurring inspection and maintenance throughout the system lifecycle.

NDE techniques must be performed **from a single side through an outer fairing material** and **must be able to discern** material defects related to the **health of the composite layers and adhesive bond layer**.

Approach: UltraSpec® – swept frequency ultrasonic spectroscopy

- Proven to be effective at evaluating a wide range of composite materials
- Unique ability to provide frequency, resonance and time reflection data for enhanced material understanding
- Automated Inspection and Advanced Analysis



ULTRASPEC®

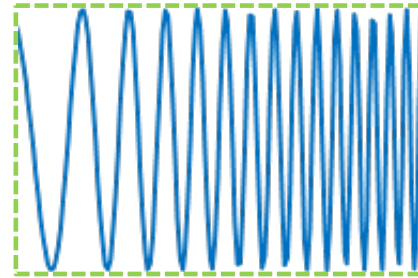
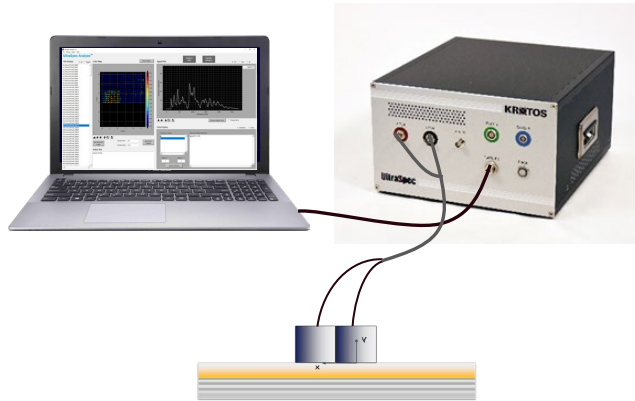


How UltraSpec® is Different from Traditional UT

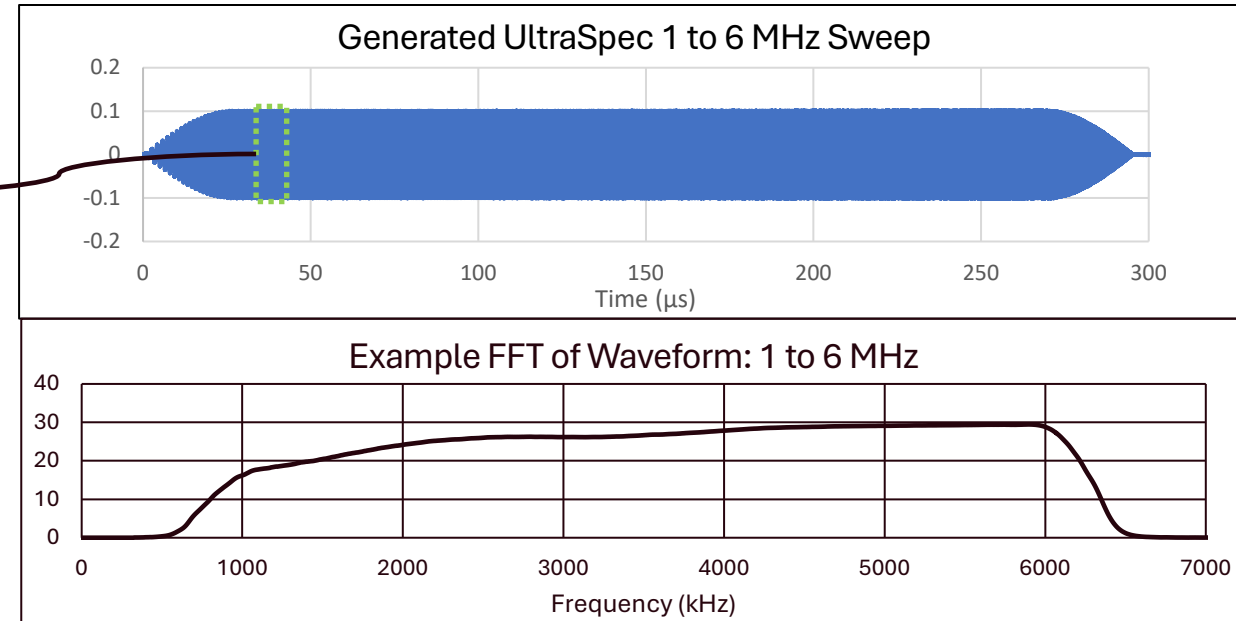
US Patent# 10605789

Long Duration Pulse

- User-defined frequency range
- Based on material
- Improved signal-to-noise
- **MORE ENERGY** into and out of the material structure



ULTRASPEC®



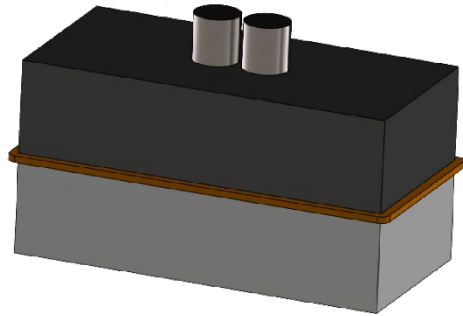
Traditional UT: Single Frequency
Time-of-Flight
Amplitude



UltraSpec® – Swept-frequency ultrasonic spectroscopy

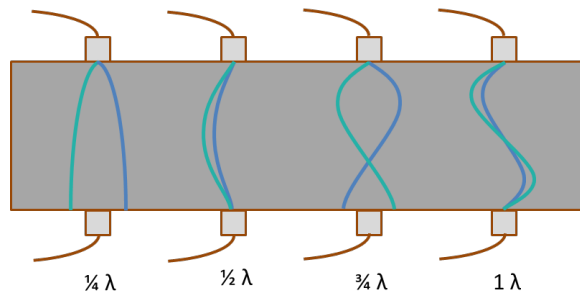
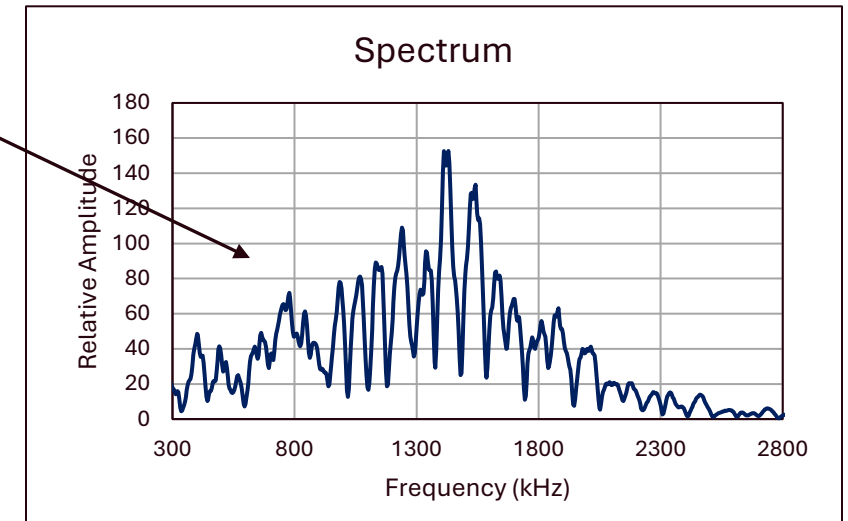
- Proven to be effective at evaluating a wide range of composite materials and highly attenuative materials
- Unique ability to provide frequency, resonance and time reflections for *enhanced material understanding*
- Advanced analytical tools for delamination detection, crack detection, porosity evaluation and bond evaluation

UltraSpec[®]: Three Classes of Data (Example)

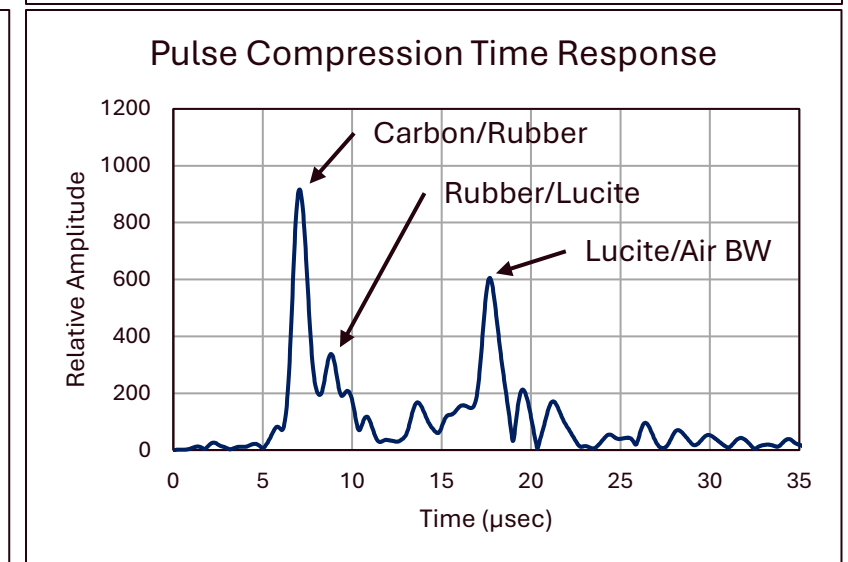
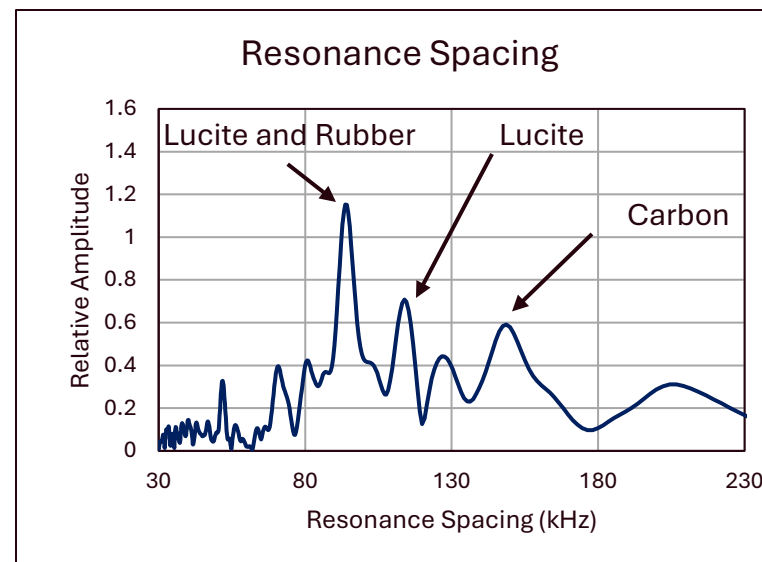


Spectral Response (Signature)

- Very Repeatable
- Contains Resonances of Each Layer Individually
- Contains Resonances of Full Thickness or Combinations of Layers

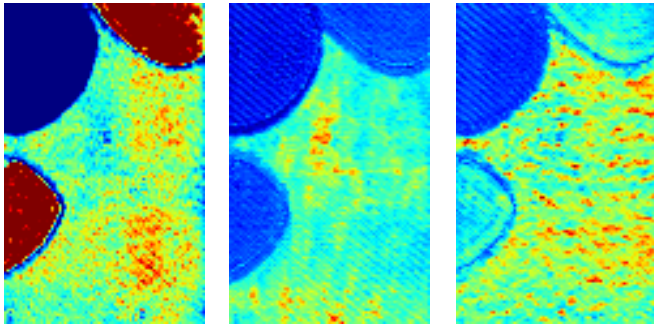


$$\text{Resonant Frequency} = \frac{\text{velocity}}{2 * \text{thickness}}$$

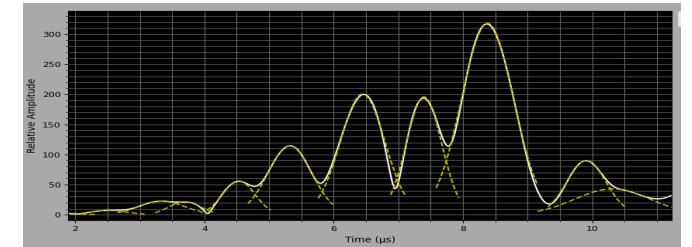


UltraSpec® Advanced Interpretation Module

Data Cube “Slices”
Structure/Feature Identification

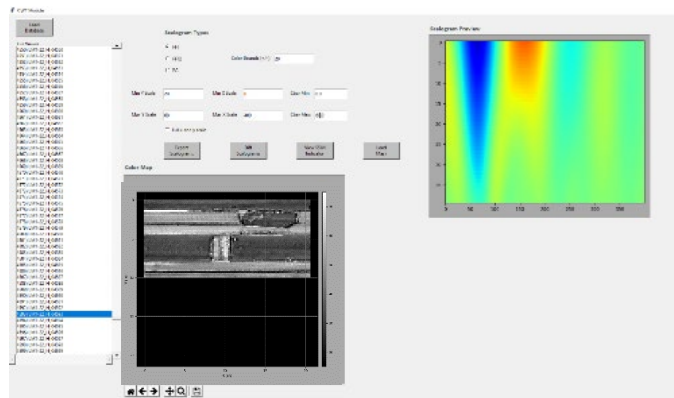


Peak/Valley Fits with Physics Calculator



	FREQ (kHz)	TIME (μs)
1 Layer	900	3.8
2 Layers	450	4.9
3 Layers	300	6.0
4 Layers	225	7.1
5 Layers	180	8.2
6 Layers	150	9.3

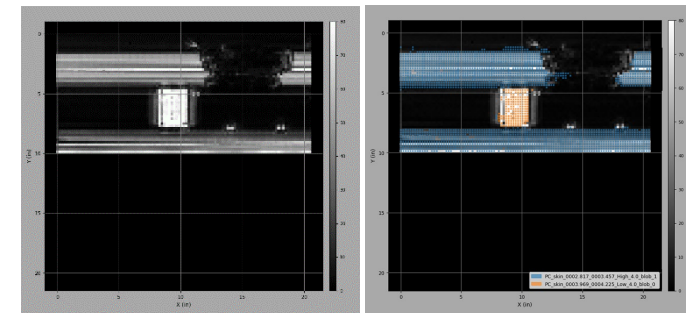
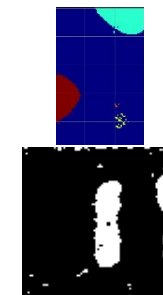
Self-Referencing Algorithm
Identifies Areas of Change



Advanced
Interpretation
Module (AIM)

2D/3D Modeling
Computational
Tools
pogo.
www.pogo.software

Spatial Comparisons
Blob Detection, Grouping



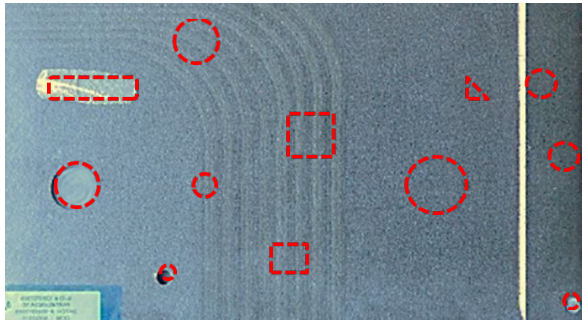
Case#: AFRL-2026-3036

Example WITHOUT Fairing Material: Illustration of AIM Data Cube Movies

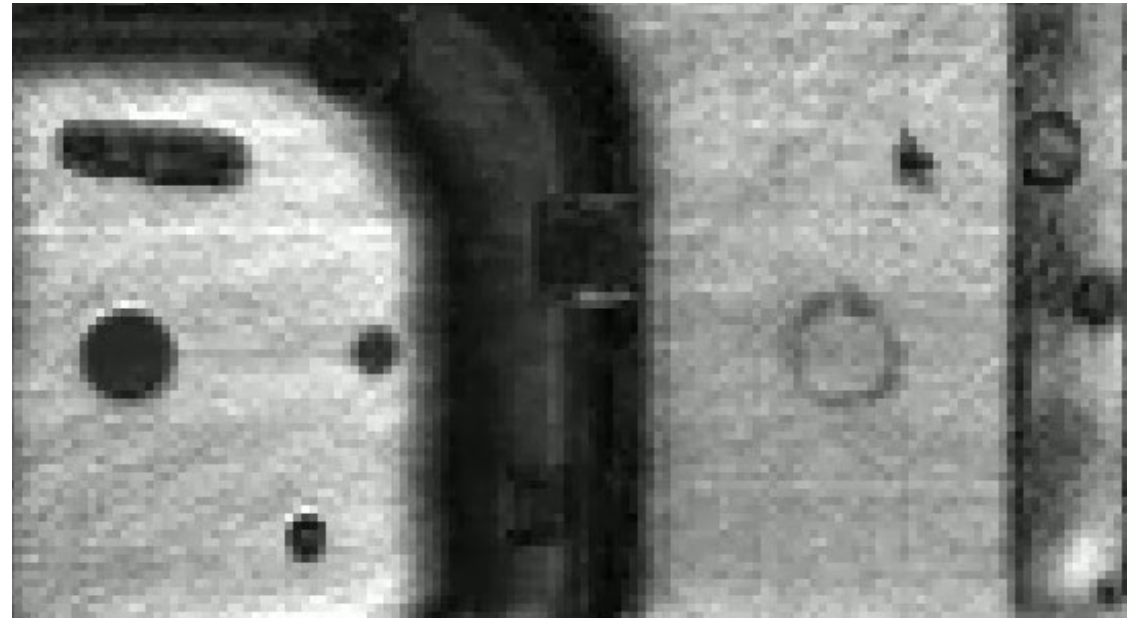
Time-based Data Cube:

Watch for “white” defects → early reflections at differing depths as movie progresses from top surface to backwall.

Inverted Image to Match Front

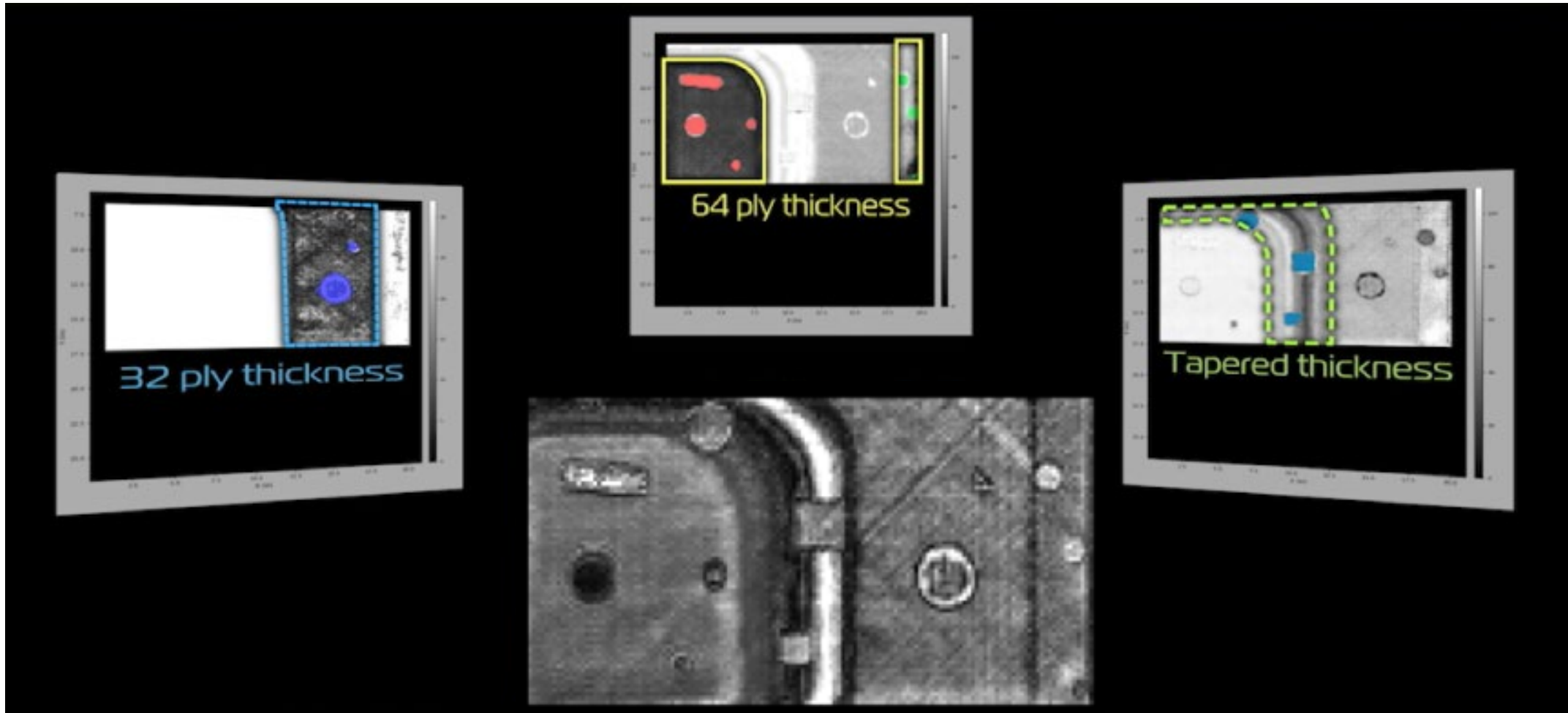


Ability to Extract/Size Features
with Depth Information



FAA-AANC NDI Test Specimen Library Sample

Example WITHOUT Fairing Material: Illustration of AIM Results

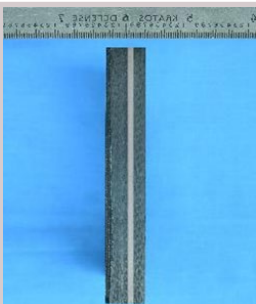
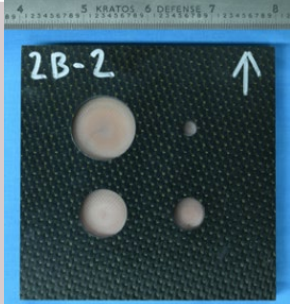
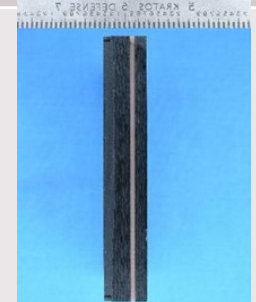
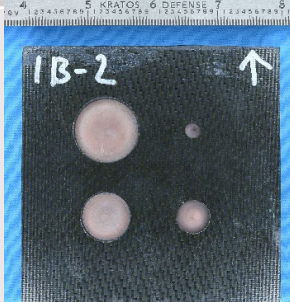
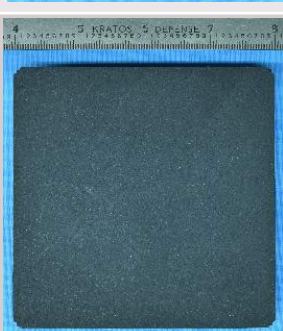
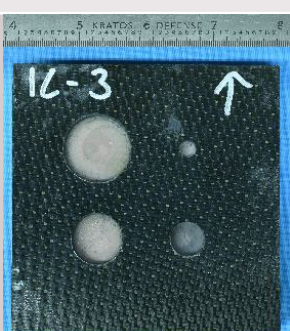


FAA-AANC NDI Test Specimen Library Sample

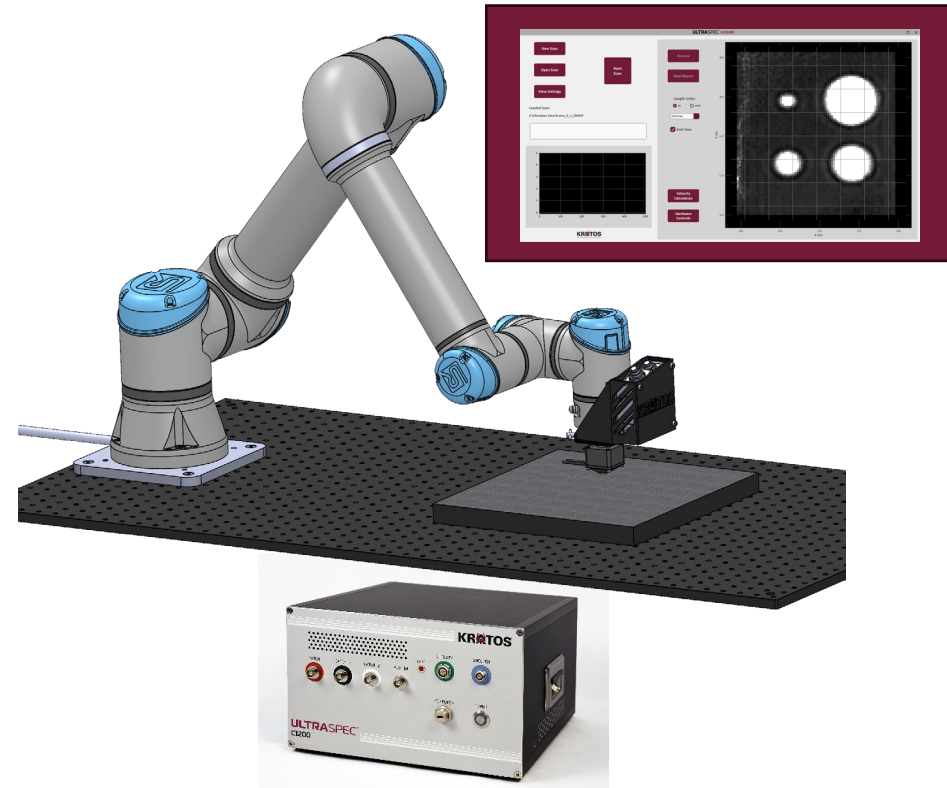
Case#: AFRL-2026-3036

Sample Descriptions

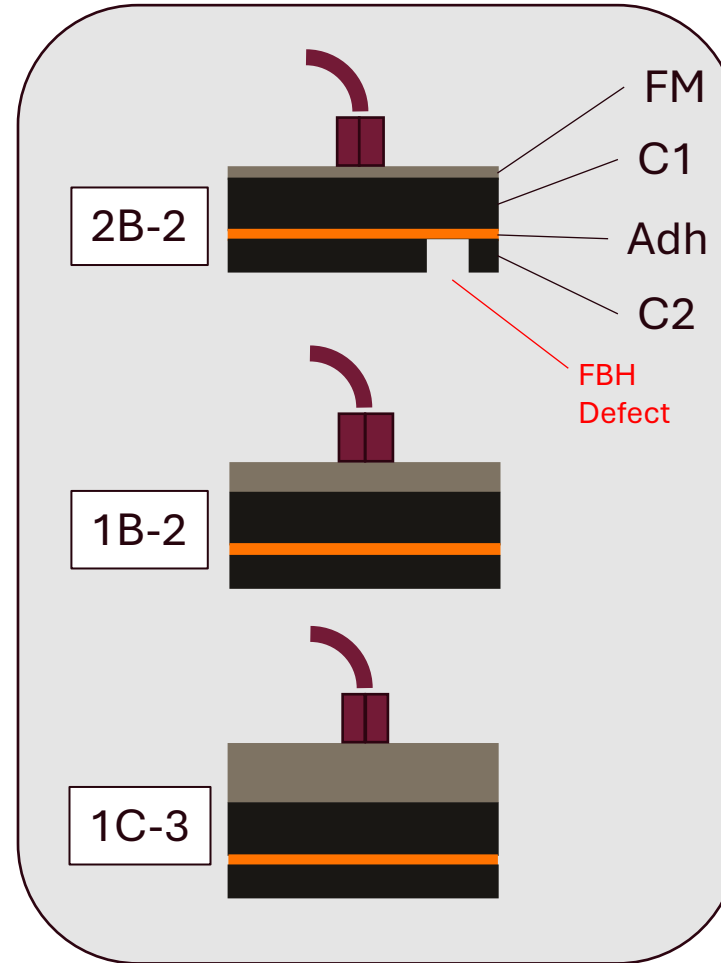
Flat Bottom Hole (FBH) defect sizes: 1.25", 1.0", 0.5", and 0.25" diameter

Sample Name	Layer Material & Thickness		Front	Side	Back (FBH Defects)
2B-2	Fairing Material	~0.05"			
	Composite #1	~0.28"			
	Adhesive	~0.085"			
	Composite #2	~0.18"			
1B-2	Fairing Material	~0.1"			
	Composite #1	~0.28"			
	Adhesive	~0.08"			
	Composite #2	~0.18"			
1C-3	Fairing Material	~0.2"			
	Composite #1	~0.28"			
	Adhesive	~0.03"			
	Composite #2	~0.18"			

Scan Setup



UltraSpec® CobotScan System



UltraSpec® Inspection
100kHz to 2 MHz

2 Ultran WC25-2-SSL
(0.25" Diameter 2.25 MHz)

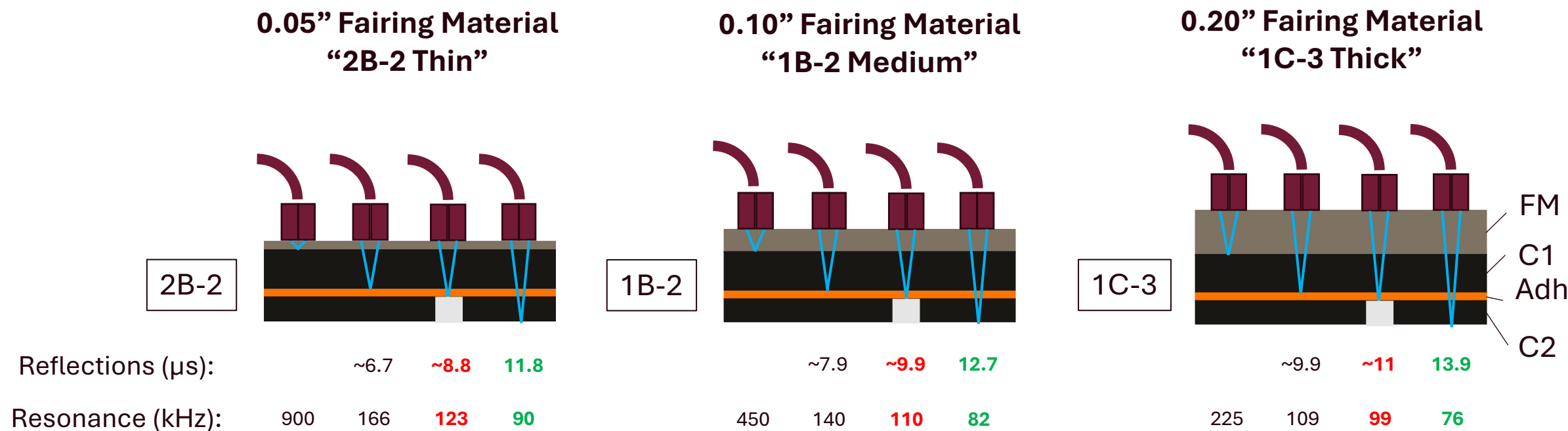
Pitch-Catch Mode
Inspect from Fairing Material Side
Transducers - X-Direction



1 mm (0.04") Step Size

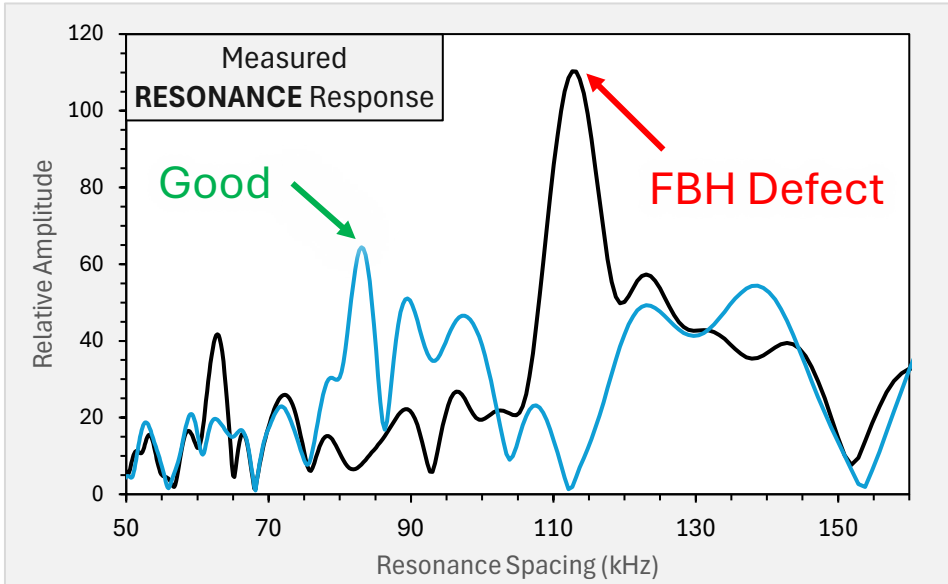
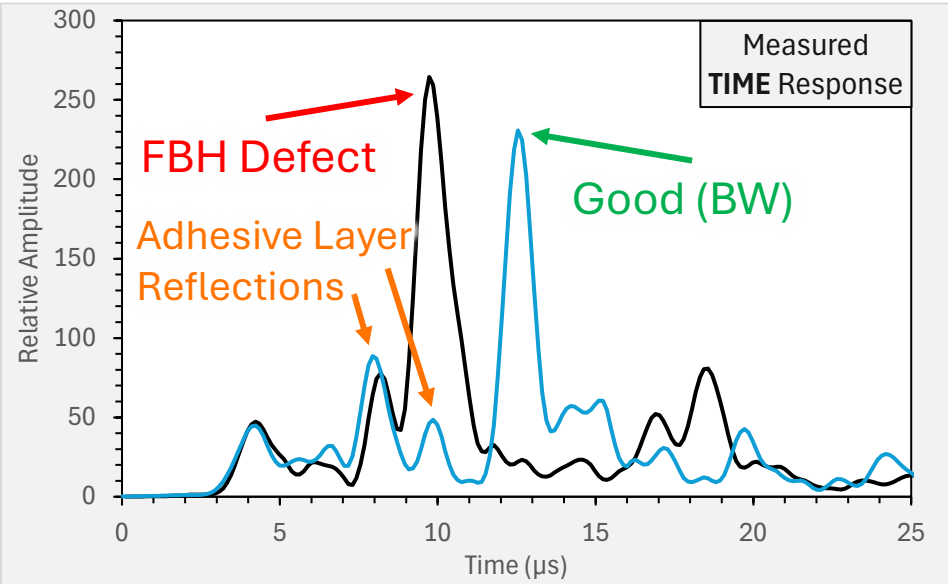
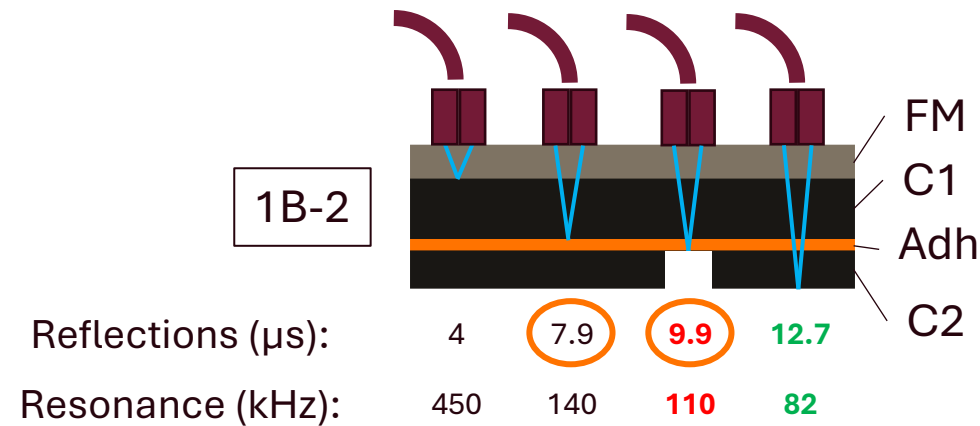
Couplant Options:
1. No couplant
2. Water couplant
Similar RESULTS

Calculated Resonance and Interface Reflections

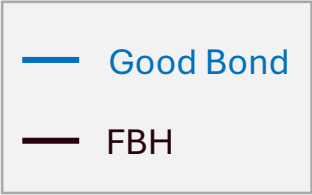
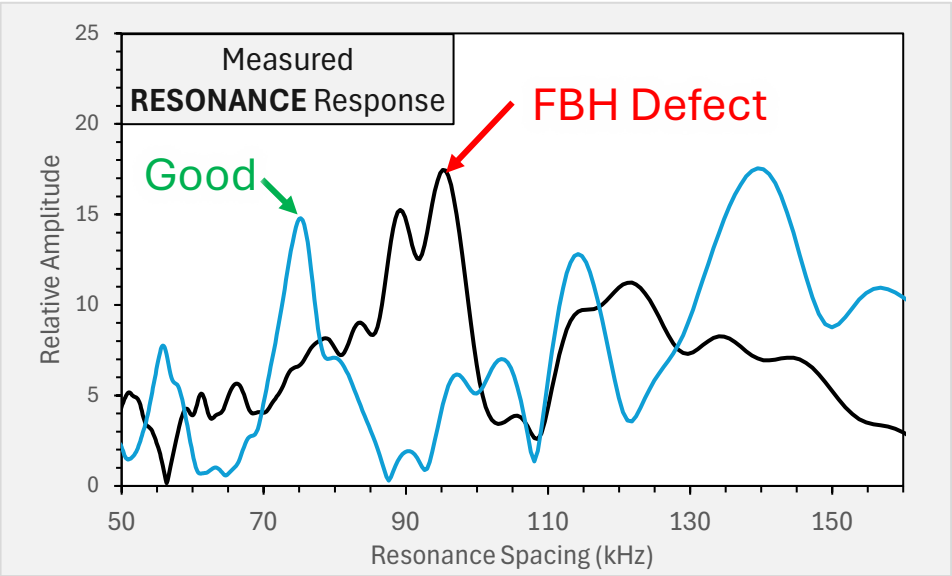
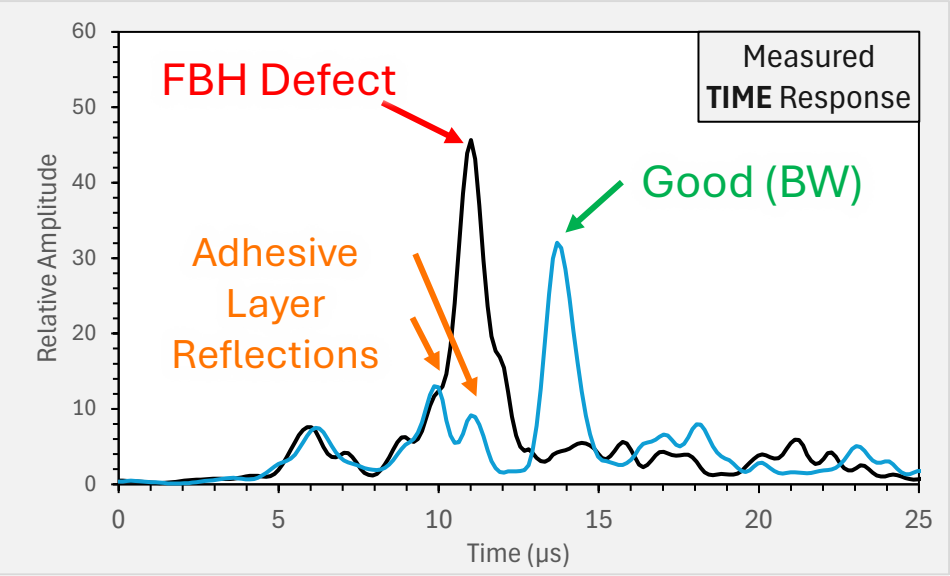
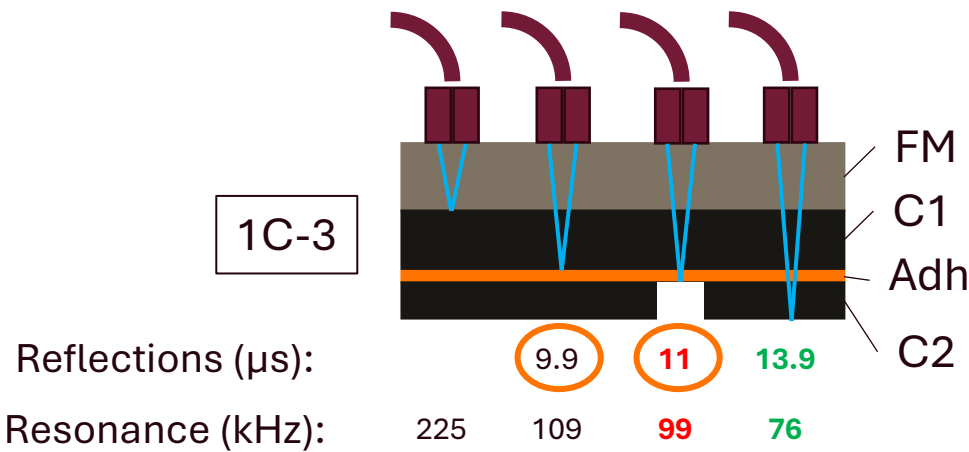


Flat Bottom Hole (FBH) Defects are drilled from the far side near the 2nd adhesive interface (Adh to C2).

1B-2 Medium Results (0.10" Thick Fairing Material)



1C-3 Thick Results (0.2" Thick Fairing Material)

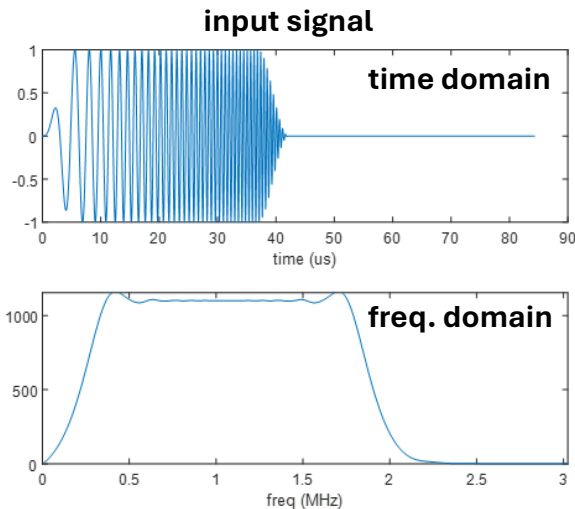


Model of UltraSpec[®] Inspection: Composite Bond with Fairing Material

Pogo – An Explicit FEM Solver for UT of Complex Geometry

[Huthwaite, Imperial College; <http://www.pogo.software>]:

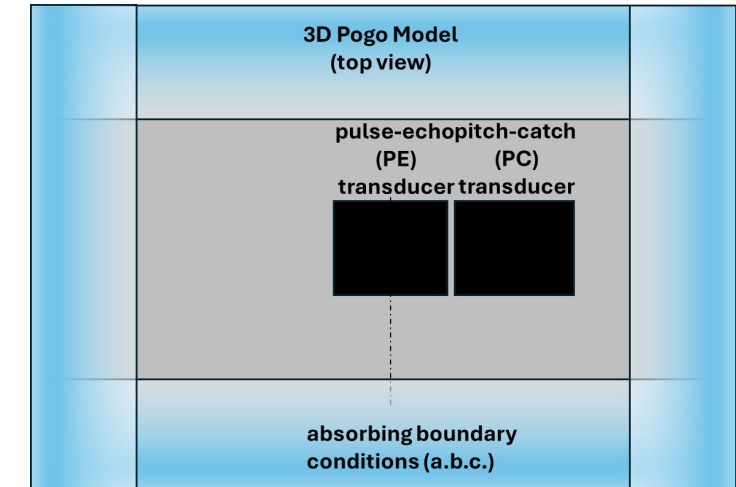
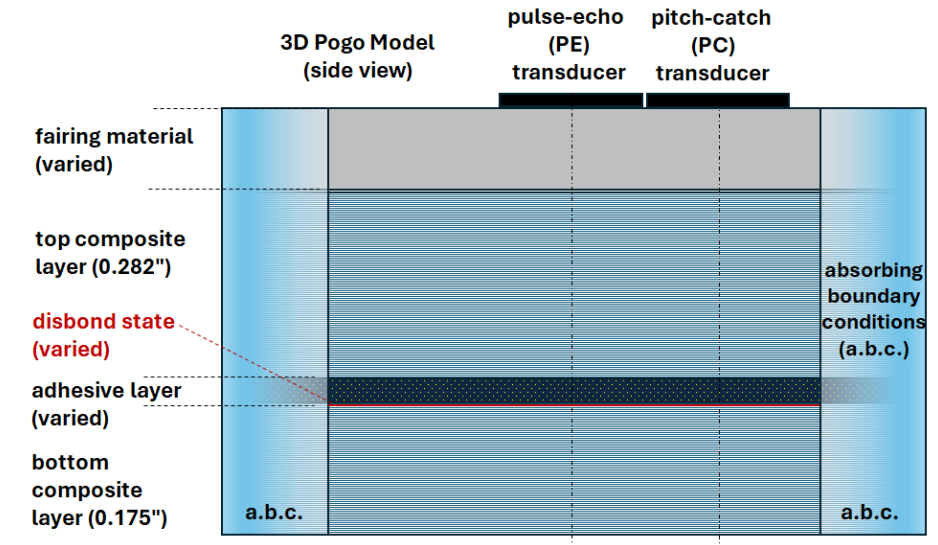
- Originally open source 2D UT solver
 - 2D / 3D solver now available via commercial license by IC Consulting
- Uses explicit FEM numerical model
- Implementation on NVIDIA GPU (CUDA) enables fast computations
- **Model for Pitch-Catch UltraSpec[®] Inspection of Composite Bond**
- *Using 4 card / 80 GB GPU cluster to run 3D Simulations*



FEM mesh / specs. for simulation:

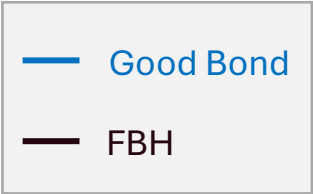
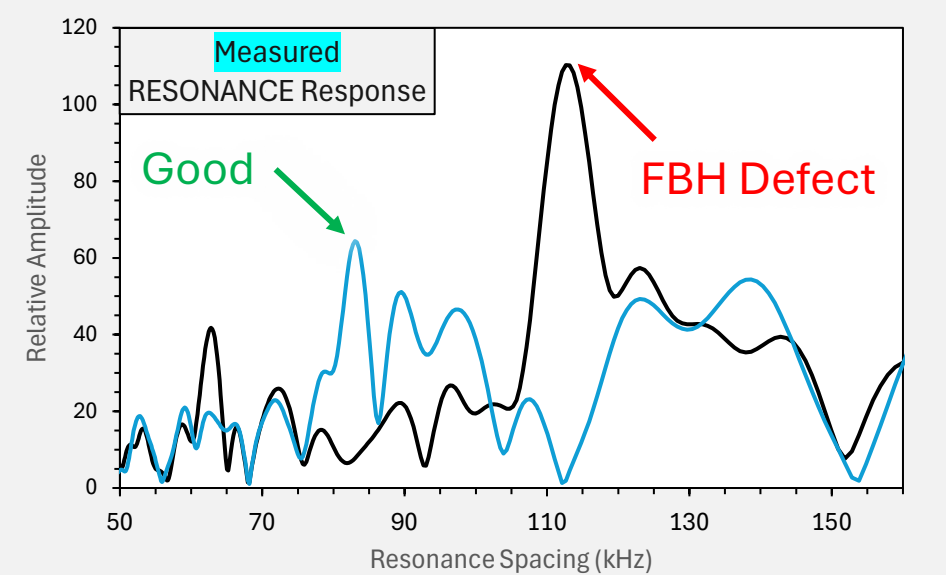
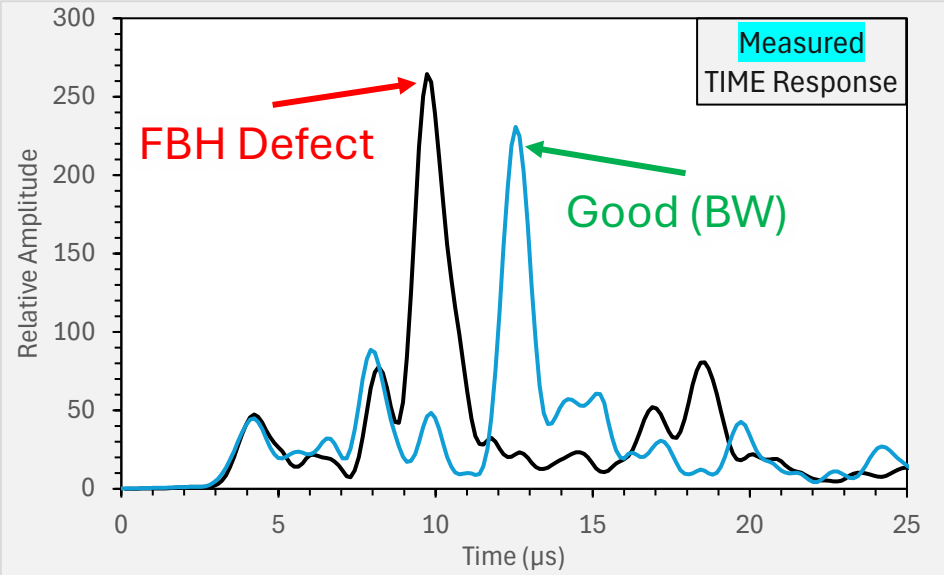
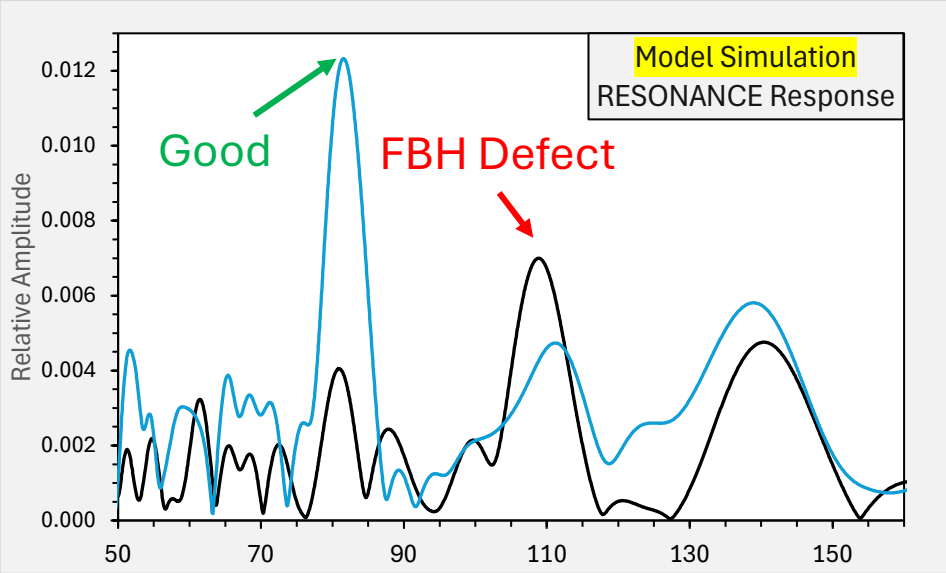
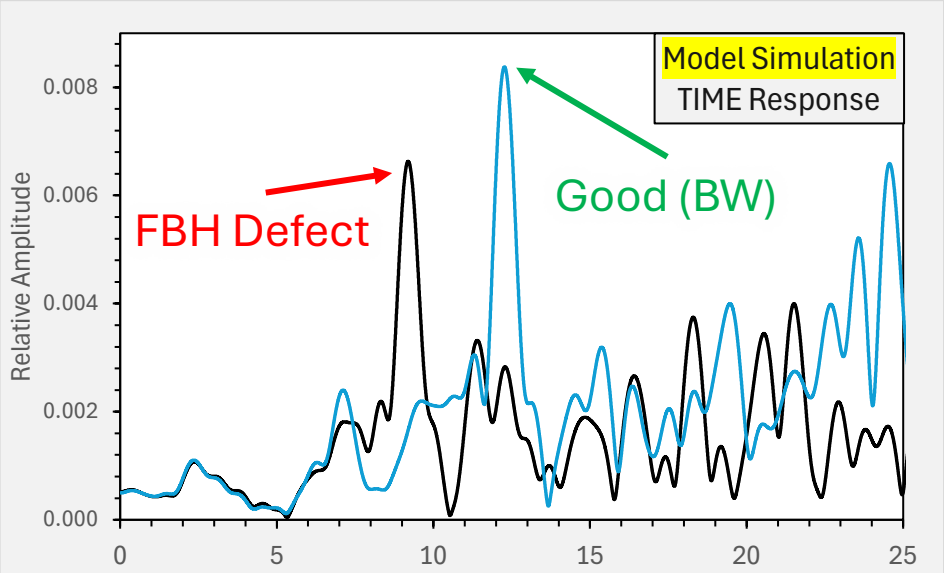
Fixed element size:
50 um x 50 um x 25 um (x by y by z)
[2 mils x 2 mils x 1 mil voxels]
Simulation time:
Single A-scan was ~ 65 minutes

Case#: AFRL-2026-3036



Model versus Measured Responses:
0.10" Fairing Material, 0.08" Adhesive Layer Thickness

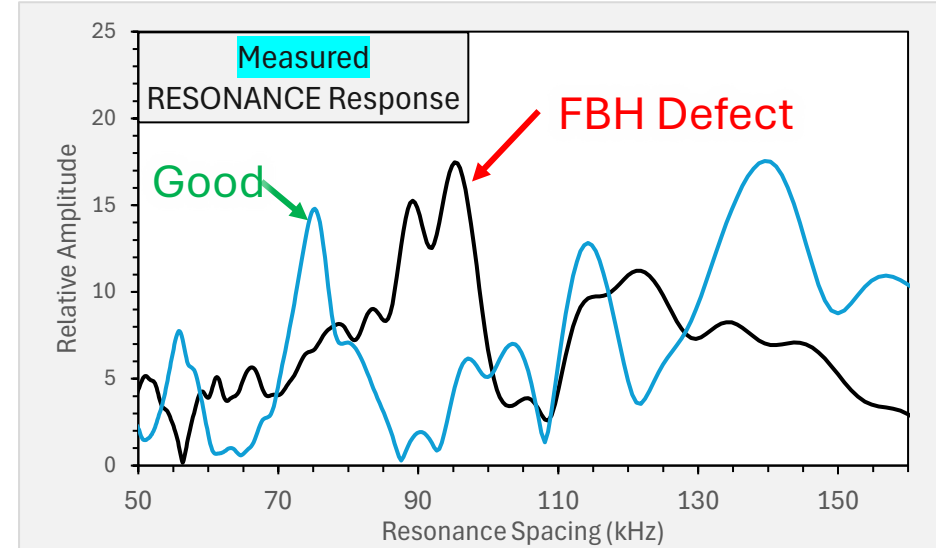
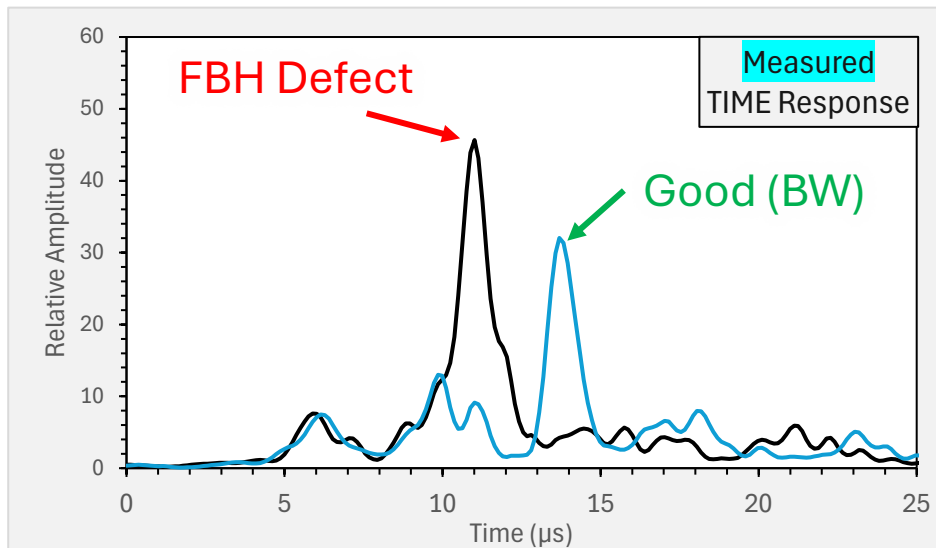
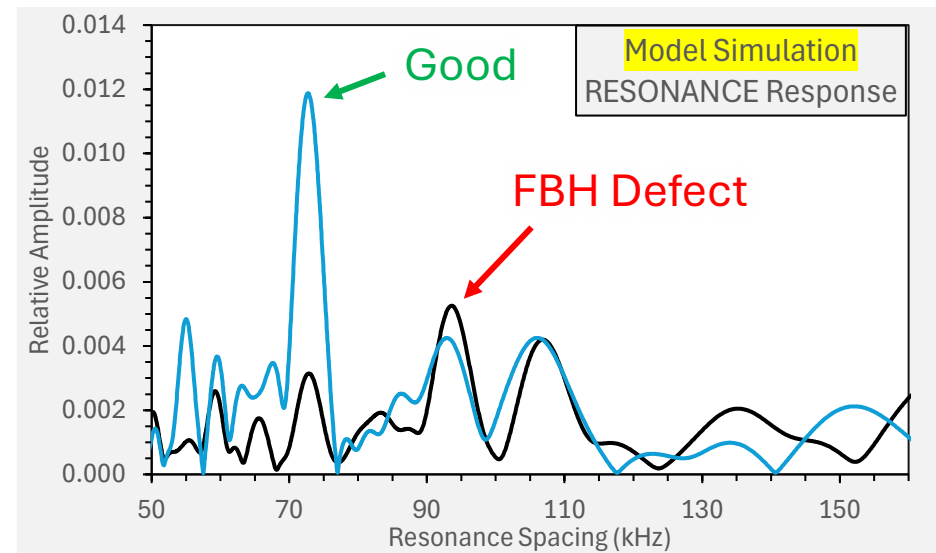
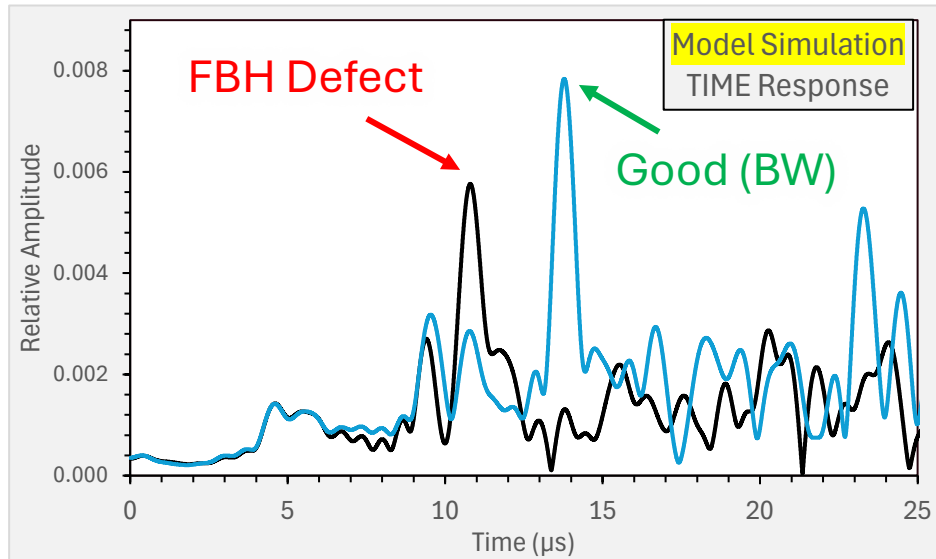
Very Strong Agreement



Model versus Measured Responses:

0.20" Fairing Material, 0.05" Adhesive Layer Thickness

Very Strong Agreement



— Good Bond

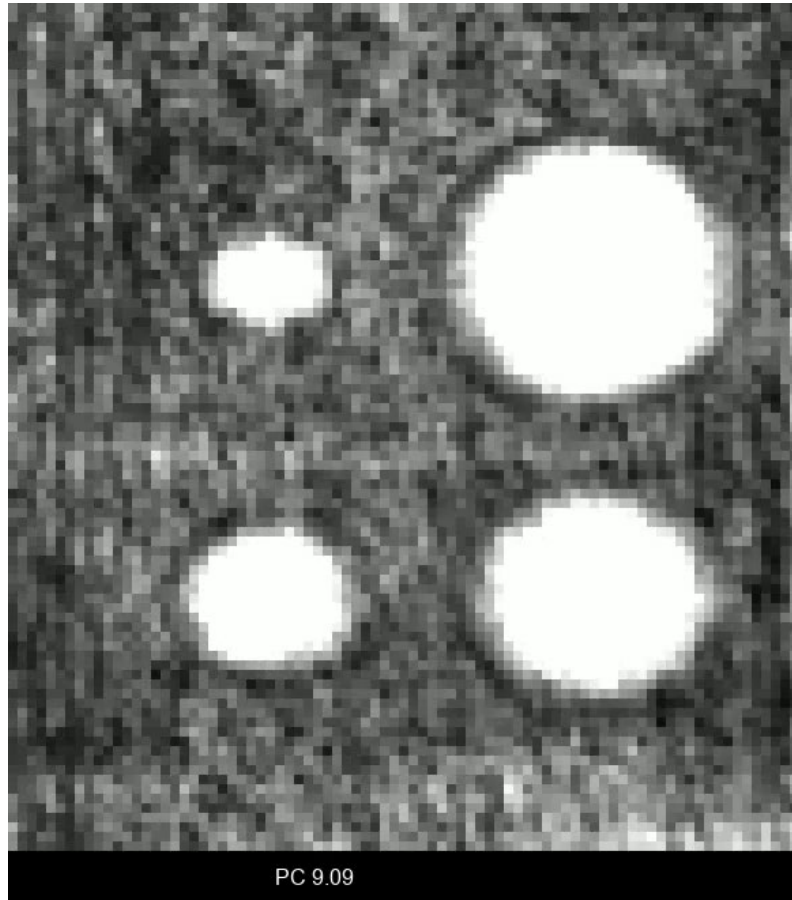
— FBH

Time Amplitude Data Cube Movies

Watch for White Early Reflections, Dark Near Full BW

1B-2 Medium

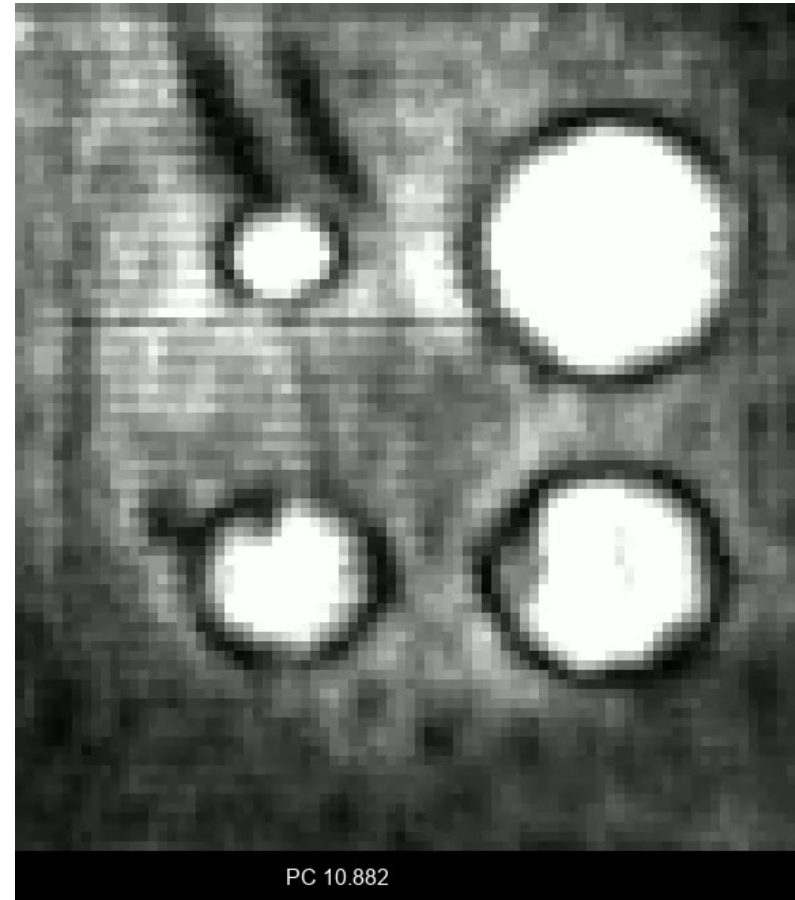
In the Full Composite Layer...



1C-3 Thick

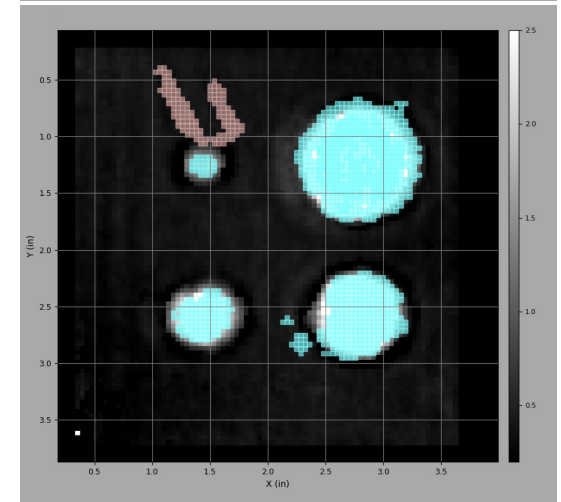
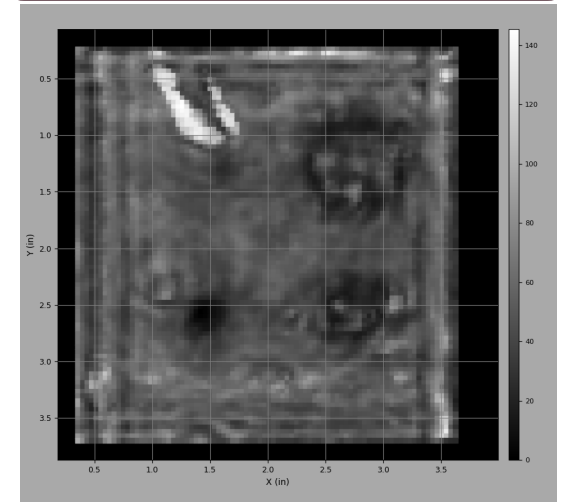
Indications within Coating Layer

In the Full Composite Layer...



Case#: AFRL-2026-3036

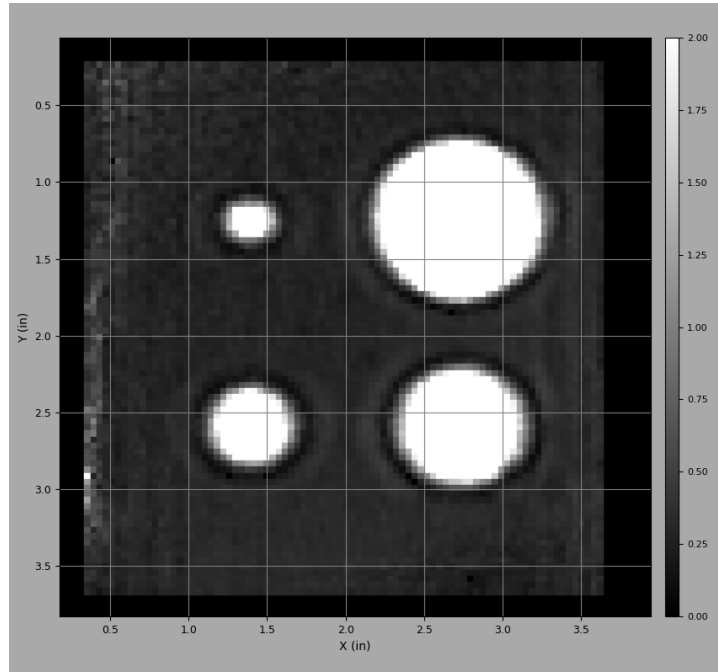
AIM Results: Coating
Anomalies Distinguishable
from FBH Defects



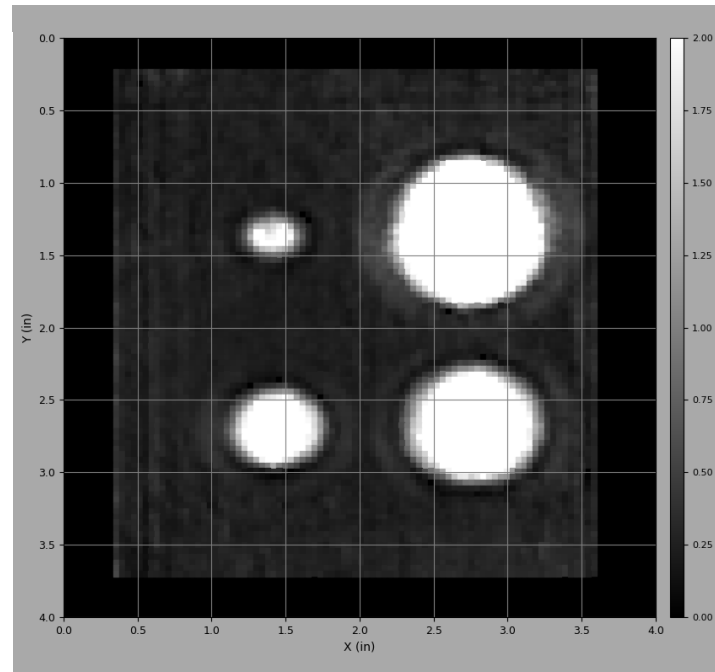
UltraSpec[®] Results

FBH BW Peak Amp / Full BW Peak Amp

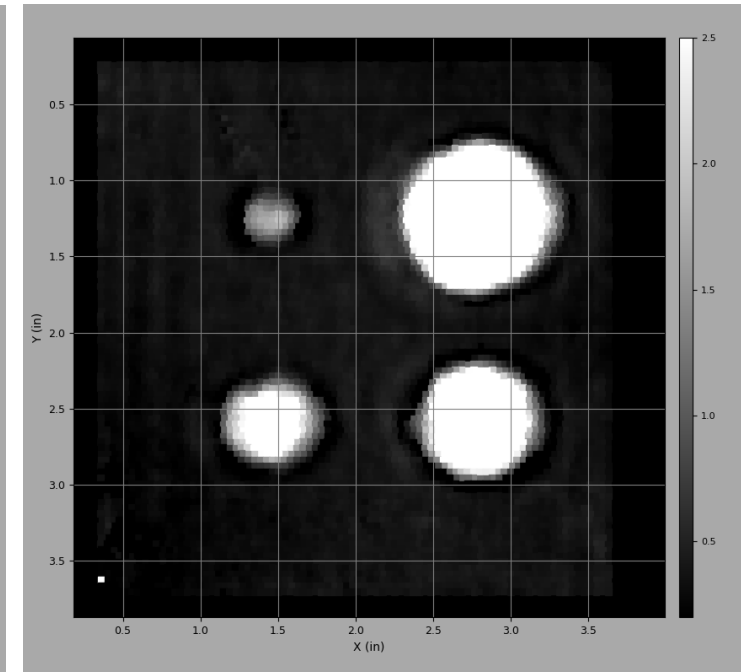
2B-2 Thin



1B-2 Medium



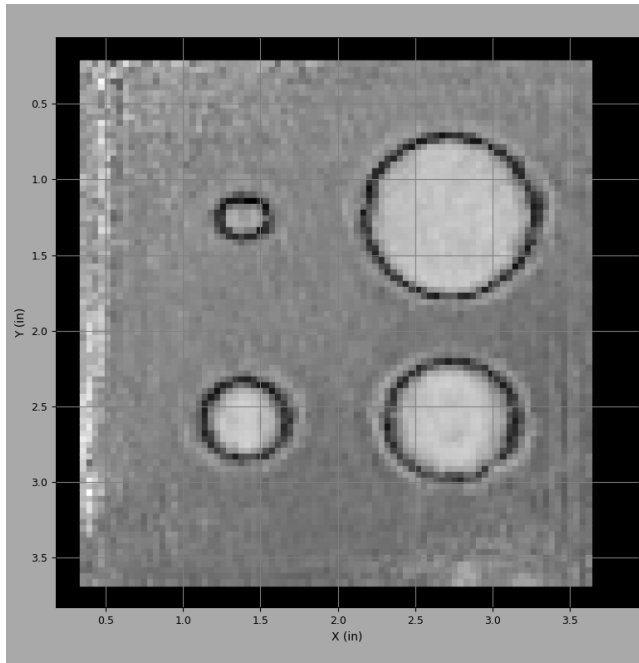
1C-3 Thick



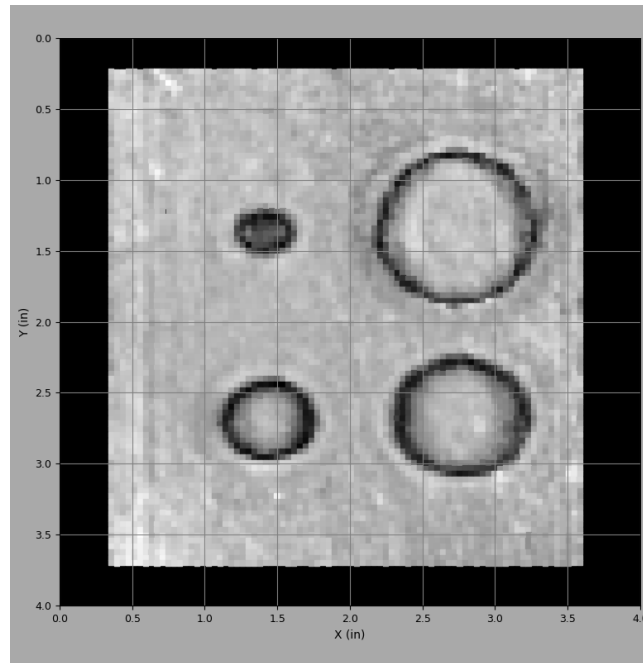
UltraSpec® Results

Change Maps: FBH Edges

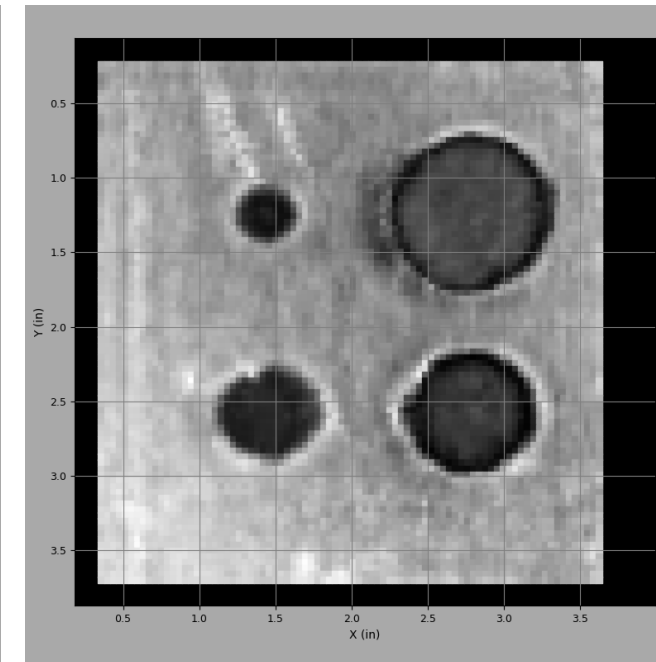
2B-2 Thin



1B-2 Medium

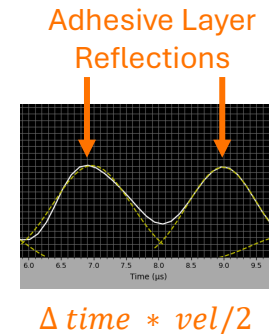


1C-3 Thick

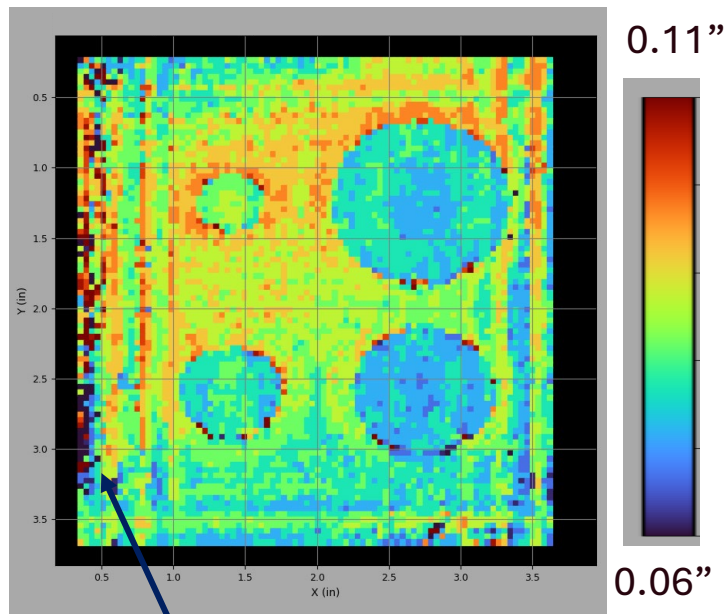


UltraSpec[®] Results

Estimated Adhesive Layer Thickness Maps

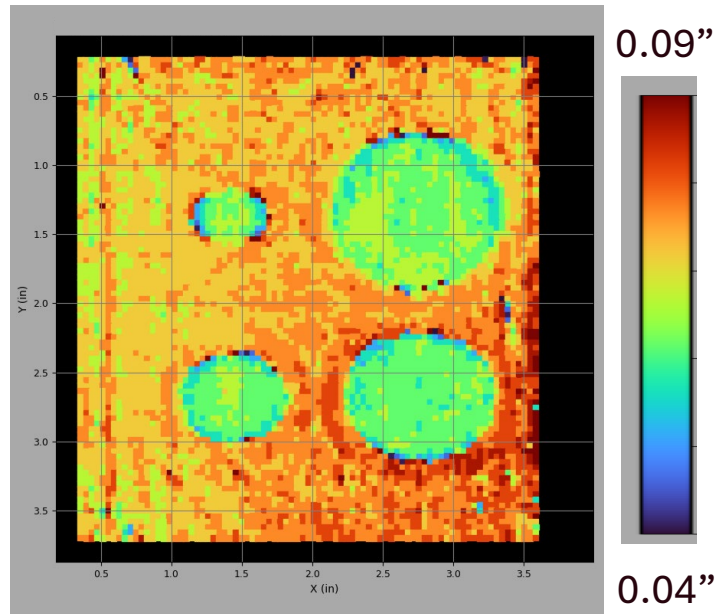


2B-2 Thin

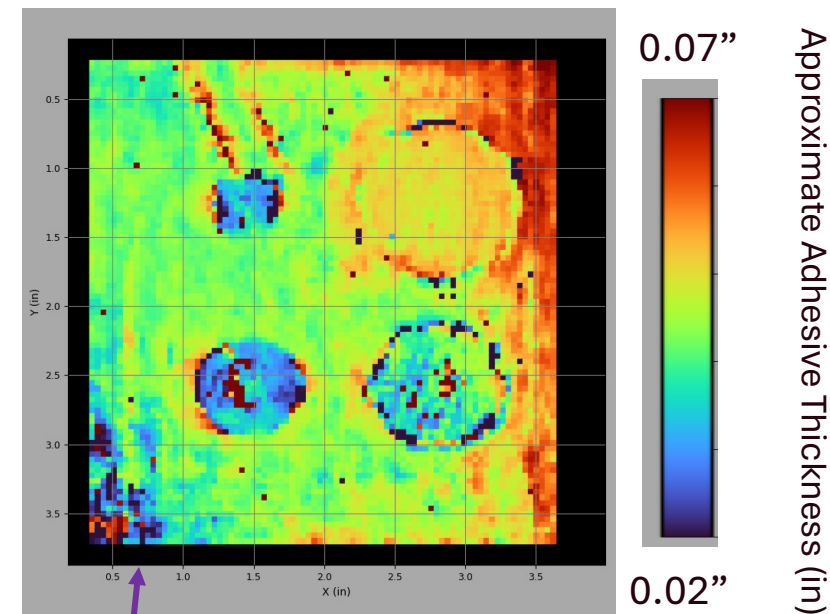


Areas with Dark Blue or Dark Red: Did not have a peak within the gates. Potentially porous adhesive layer?

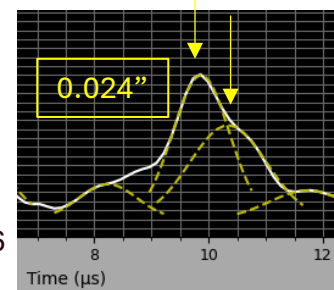
1B-2 Medium



1C-3 Thick

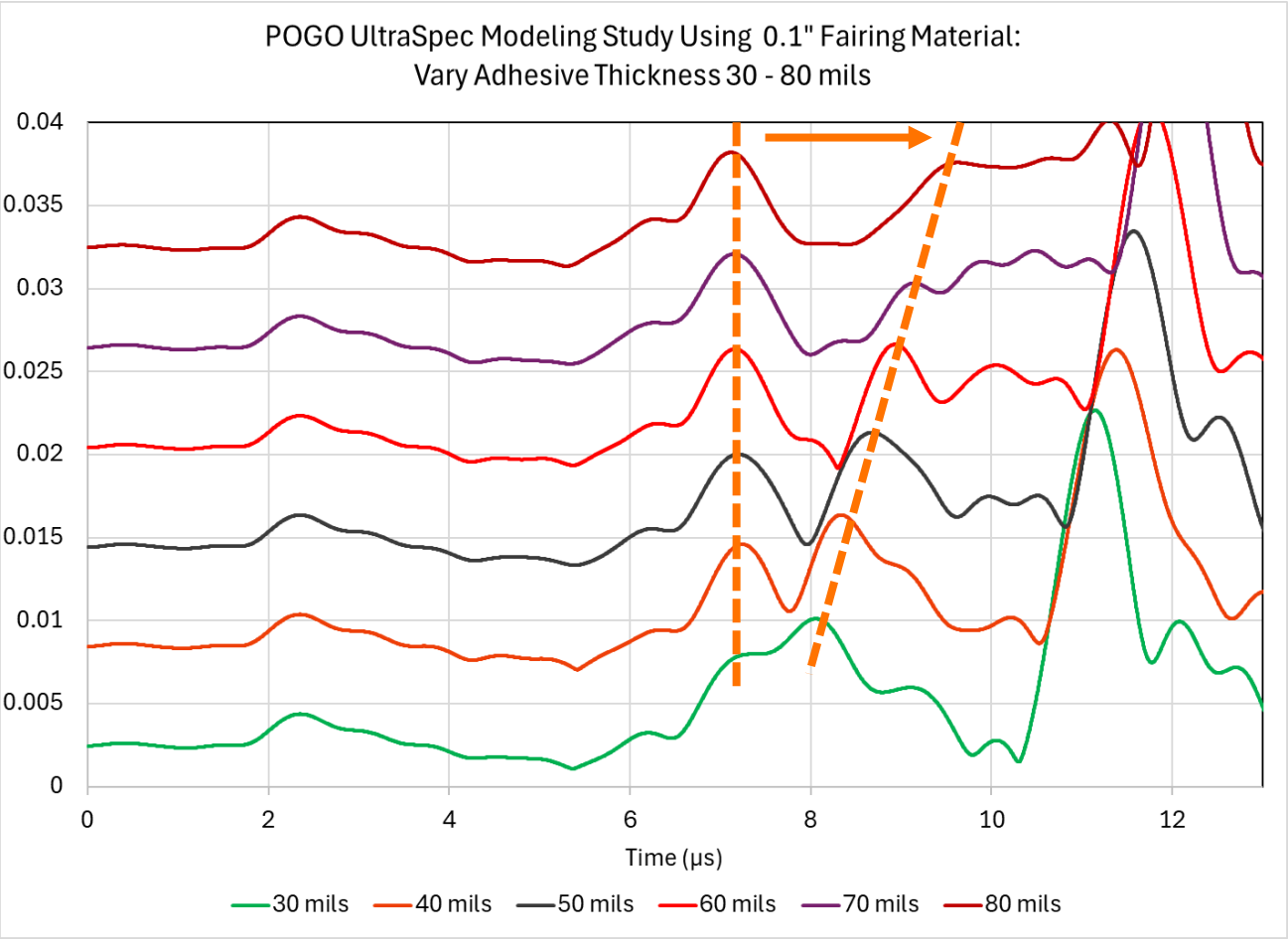


Adhesive Layer is thin: peaks are combined (doublet peak) we use Gaussian fits to extract.

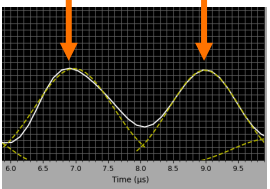


Case#: AFRL-2026-3036

Modeling Responses: Varying Adhesive Layer Thickness



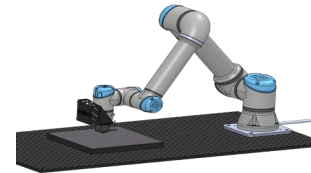
Adhesive Layer
Reflections



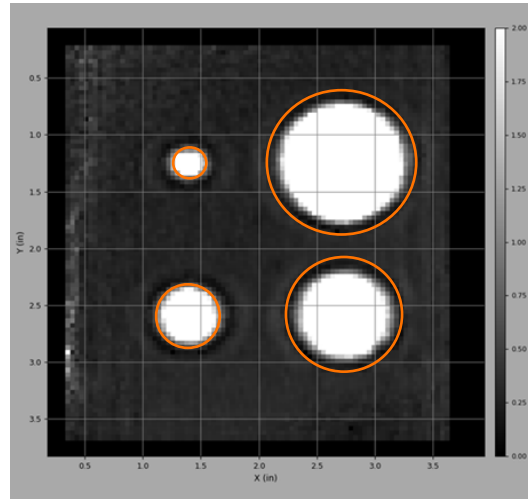
$\Delta \text{time} * \text{vel}/2$

FUTURE WORK:
Ability to add PORES within the
adhesive layer as well as disbonds.

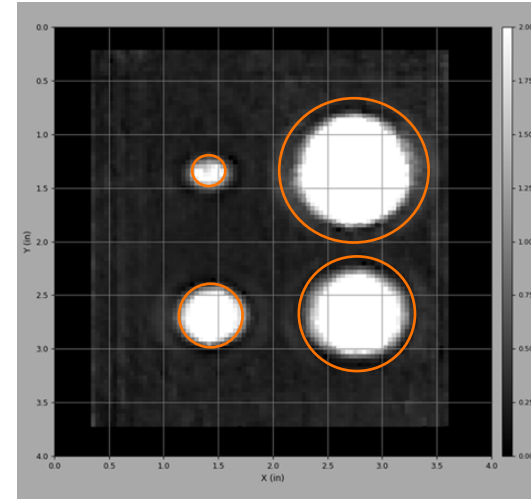
Fine Resolution (Lab) vs. Coarse Resolution (Field)



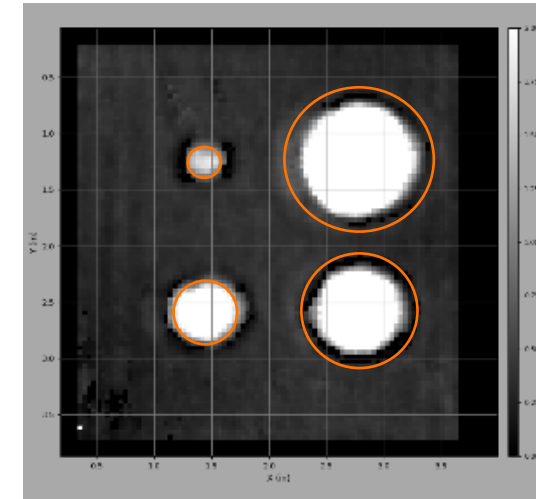
2B-2 Thin



1B-2 Medium

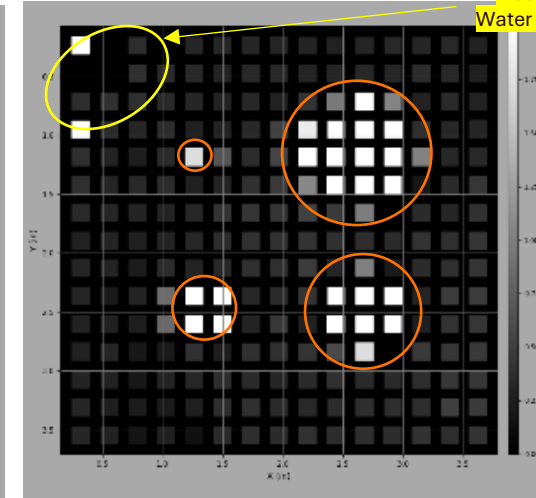
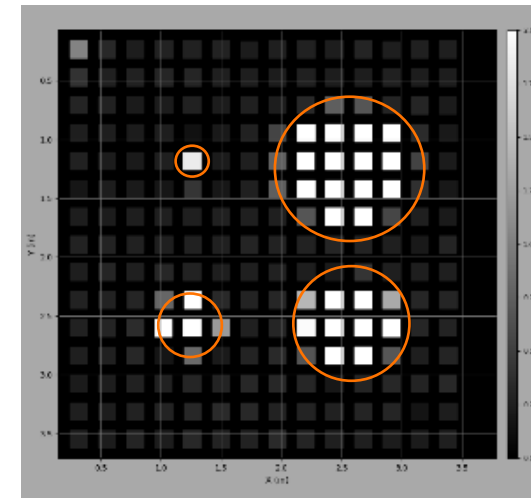
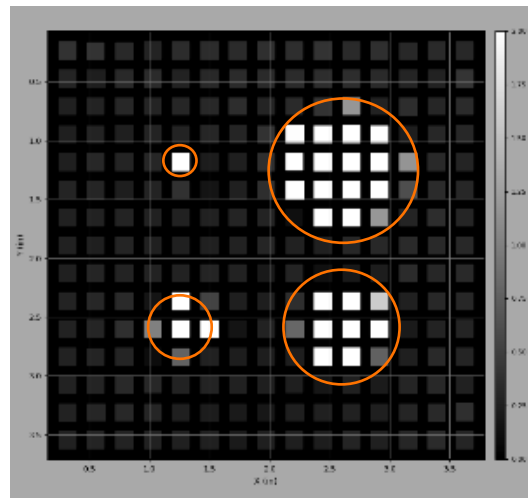


1C-3 Thick



Water Couplant
or Dry Couplant
1mm (0.040") Step Size

Water Couplant
6mm (0.24") Step Size

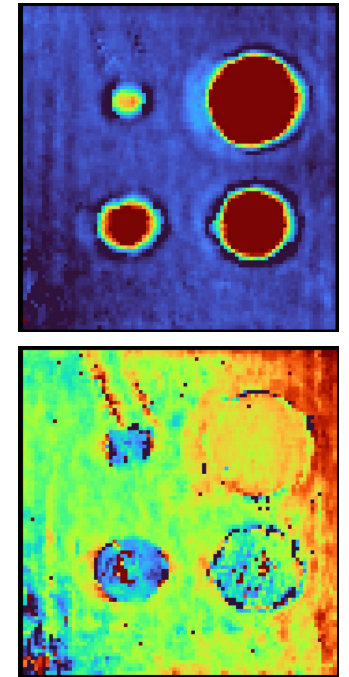
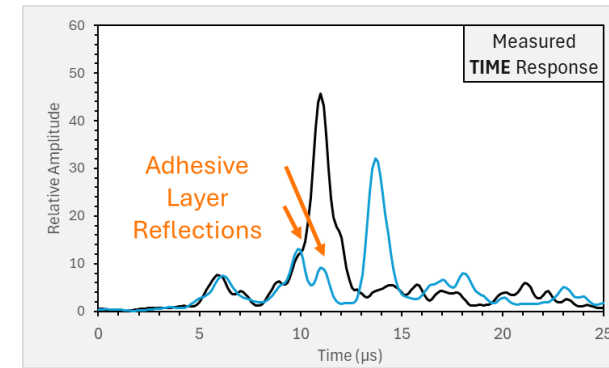


Inadequate
Water Couplant

Conclusions

The UltraSpec® technology provided distinct benefits relating to **clear interpretations of each layer in the structure**, for each sample ranging from 0.05” to 0.20” fairing material thicknesses.

- High resolution results even while inspecting through thick fairing material with multiple dissimilar material layers
- 100% detection rate
- Multi-parameter output: flaw size, depth, and adhesive layer thickness
- Modeling using the 3D POGO solver with an UltraSpec® excitation had exceptional agreement and can be used to run studies with porosity or complex structures



Contact Info:



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Acknowledgements

USAF/AFRL SBIR AF251-0007-0341



Jacob Rindler
John Brausch
Chris Allen
Matthew Peterangelo



Mike Whetzel
Thomas Eischeid