

NDE of Novel Repair/Replacement Materials

Update: 2026 NRC-EPRI TIE



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Outline

- Background
- NDE exploration for wet layup Carbon Fibre Reinforced Polymer (CFRP) continuing prior EPRI work [1,2]
 - Mockup procurement and inserted flaws [3]
 - Selected NDE results using low-frequency conventional UT, DRS, manual and electronic tap testing [3]
- Recent Total Focusing Method (TFM) results from glass fibre and carbon fibre structures
 - Preliminary results on FMC/TFM and PWI/TFM at high frequencies
- Summary and Perspectives

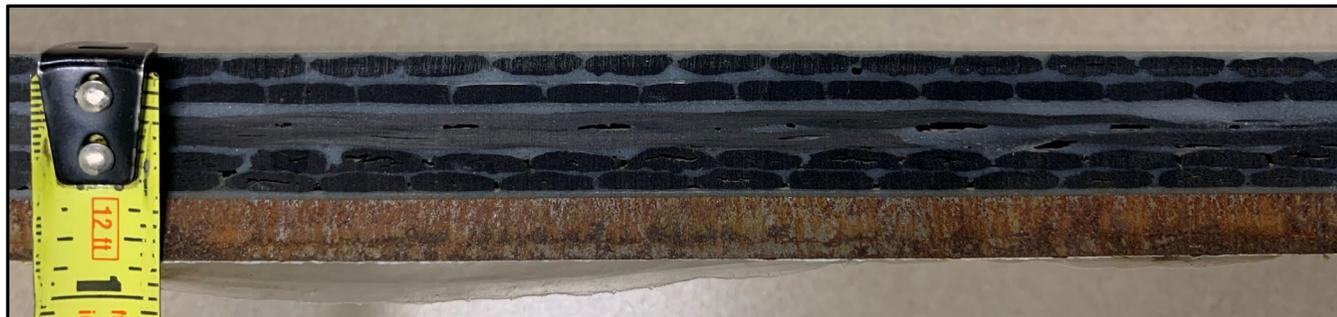
[1] *Non-Contact Nondestructive Evaluation Technology: Dynamic Response Spectroscopy and Pulsed Eddy Current*. EPRI, Palo Alto, CA: **2018**. 3002013174

[2] *Nondestructive Evaluation of Metallic Substrates Through Carbon Fiber Reinforced Polymer (CFRP) Composite Repair Systems*. EPRI, Palo Alto, CA: **2022**. 3002020823

[3] *Nondestructive Evaluation Performance Characteristics for Carbon Fiber Reinforced Polymer Repair Structures*. EPRI, Palo Alto, CA: **2025**. 3002032154.

Background

- CFRP materials are being implemented as repair options in ageing piping
- Advantages [4]:
 - No excavation
 - Environmentally resistant to MIC
 - Standalone design without reliance on pipe under repair
 - Rapid process
 - Minimal diameter reduction and effect on internal flow; result can be sculpted to fit required geometry
- NDE is needed to assess integrity of CFRP repair materials
- Inspection difficulties:
 - Heterogeneous composition of attenuative material
 - Sometimes containing small voids
 - Construction may be done by hand resulting in irregularities in thickness and internal structure
 - Flaw mechanisms caused by service or installation not well understood

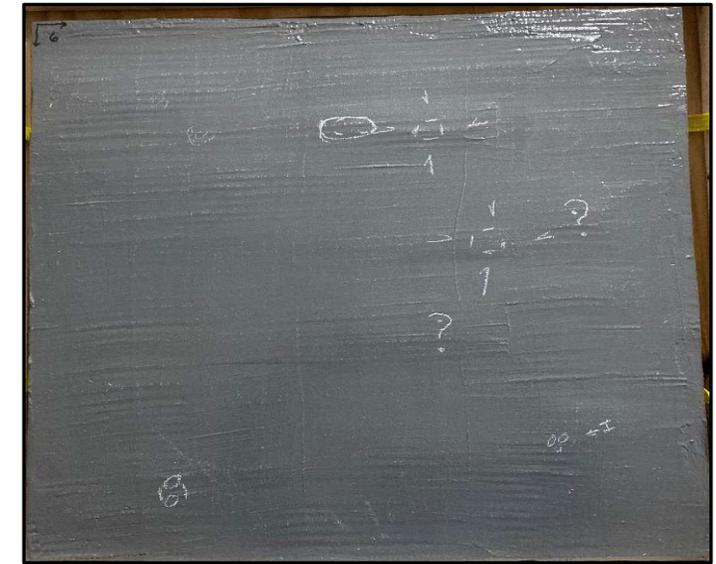


[4] Miller, G., Sealey, J., Henderson, J., Gordon, L. *Surry Power Station Carbon Fiber Reinforced Polymer (CFRP) Alternative Request Pre-submittal Meeting 2016*. ML16355A346

Mockups and Implanted Flaws

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- Mockups:
 - Twenty-four plate mockups (0.61×0.61)m and two pipe mockups (Ø0.91m or Ø36in.)
 - Number of laminar layers varies between mockups
- Implanted flaws:
 - Gas voids of size in range 1-16 sq. in. at varying depths
 - Undersaturated layer regions of size in range 1-10 sq. in.
 - Repaired gas voids (bubble flaws backfilled with epoxy)
- For each mockup:
 - Manual tap testing to inform annotation of upper surface to indicate potential regions of interest
 - Electronic tap testing using EVOTIS Device [5]
 - Dynamic Response Spectroscopy (DRS) [6] developed by Sonomatic for mapping corrosion through coatings
 - Conventional encoded UT using round monocrystal probes ranging from 0.5MHz to 2.25MHz
 - Includes focused probes



Example plate mockup from the first set



Example pipe mockup from the second set

[5] Poole, A., Hartley, N. *Force and Sound Data Fusion for Enhanced Tap Testing* in: IEEE Access **2023**(11) 53485-53496, doi: 10.1109/ACCESS.2023.3279712

[6] Anon *Sonomatic Data Sheet: DRS Inspection Through Coatings* **2025** url: <https://sonomatic.com/wp-content/uploads/sites/7/DRS-Inspection-through-Coatings.pdf>

Results from single layer mockup: Tap testing and DRS

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■ Structure:

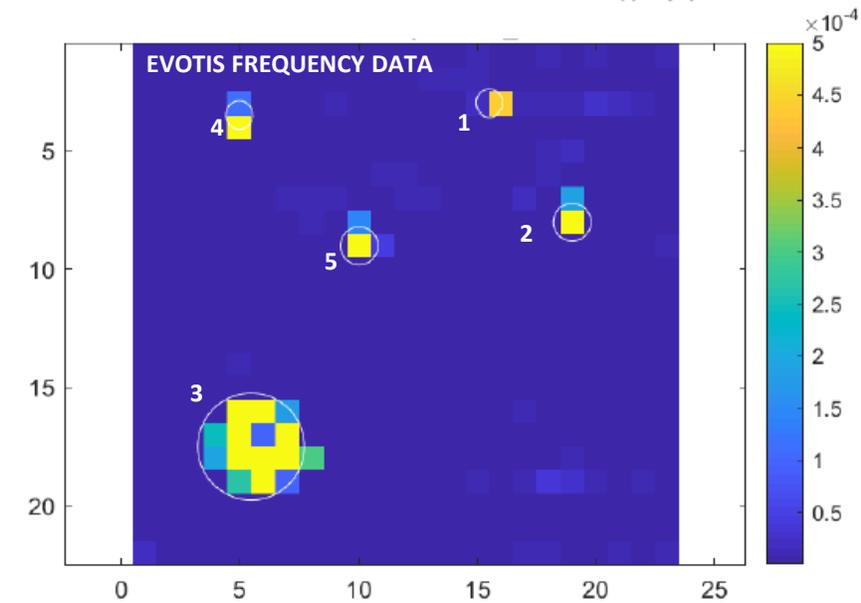
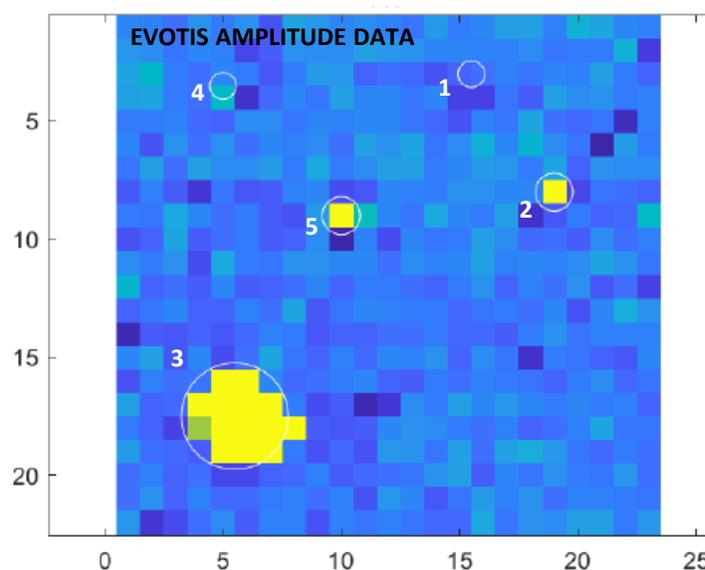
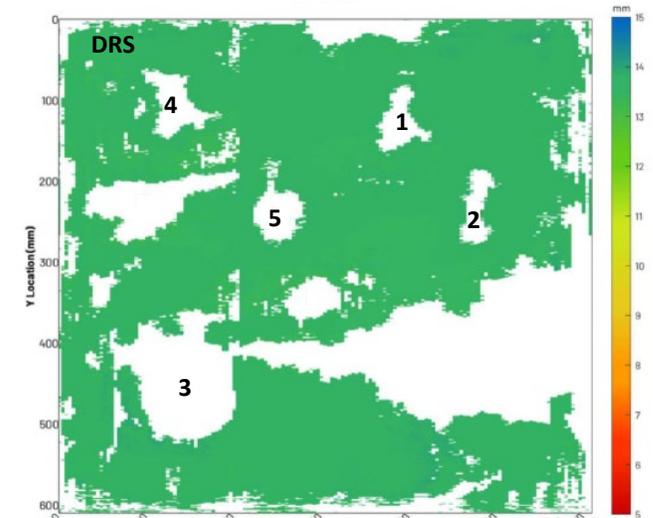
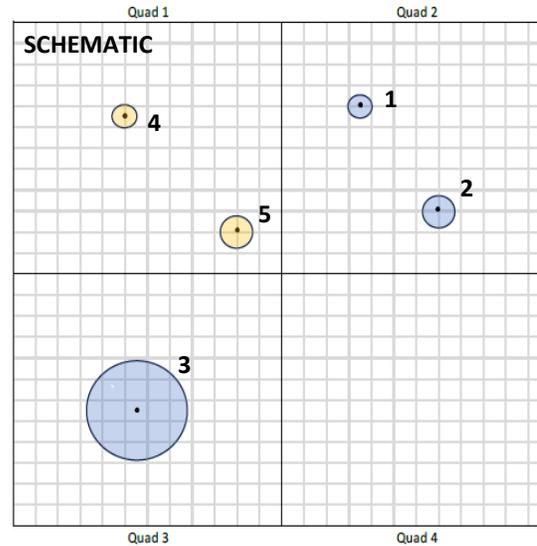
- One layer of CF 2339
- One layer of FG 1210
- Thick epoxy topcoat approx. 0.125 in.

■ DRS identified additional four flaws

■ Successful detection by all applied NDE methods including conventional UT (next slide)

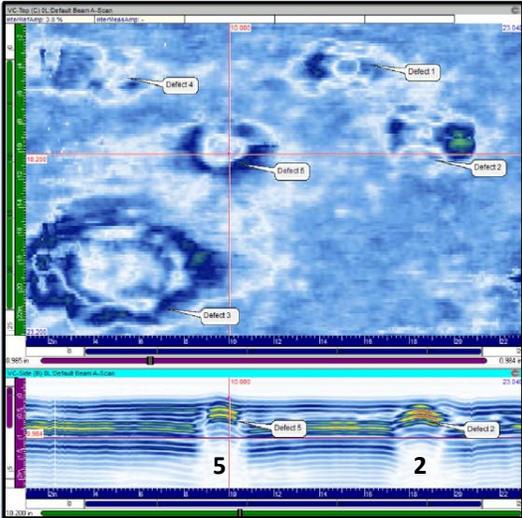
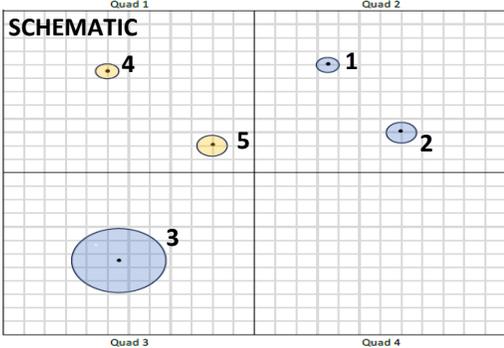
- Immersion probes with spherical (point) or cylindrical (line) focusing provided improved sensitivity and resolution

Schematic legend: First interface (yellow); base (blue)

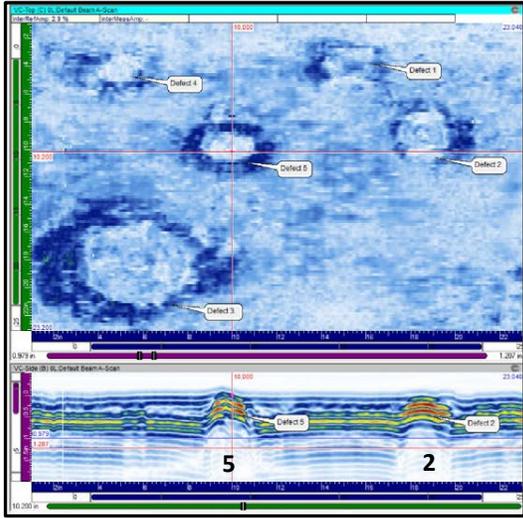


Results from single layer mockup: UT

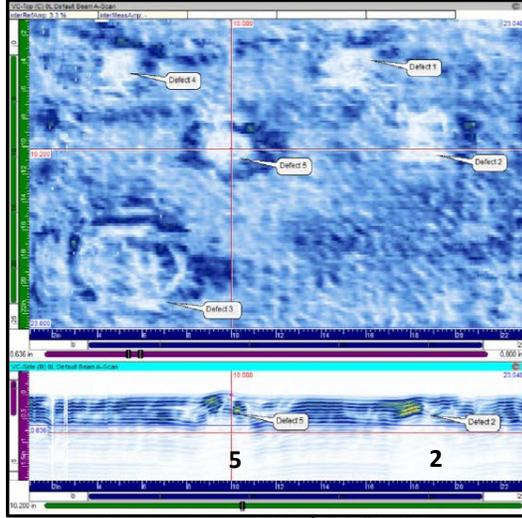
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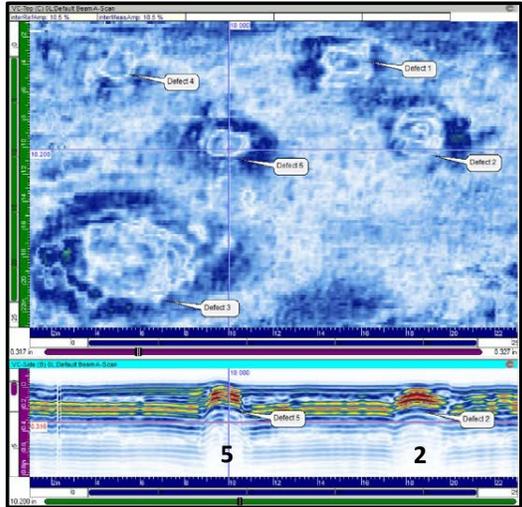
Immersion, 0.5 MHz/1''C, NF



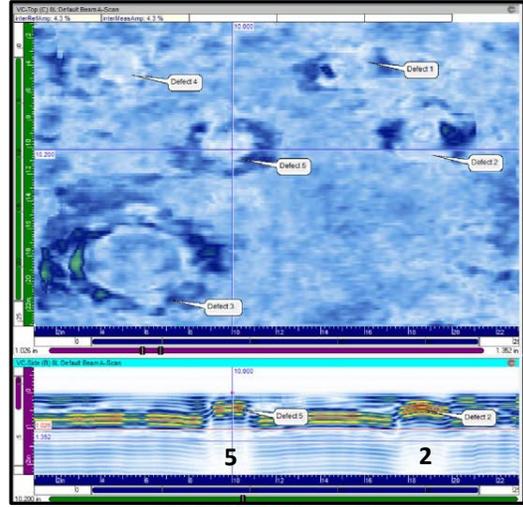
Immersion, 0.5 MHz/1''C, 1.5S



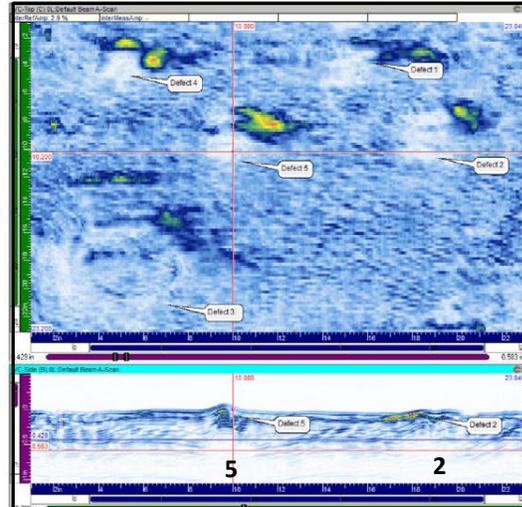
Immersion, 1 MHz/0.75''C, NF



Immersion, 0.5 MHz/1''C, 1.5C



Contact, 0.5 MHz/1''C, NF



Immersion, 2.25 MHz/0.75''C, NF

Results from multi-layer mockup: Tap testing and DRS

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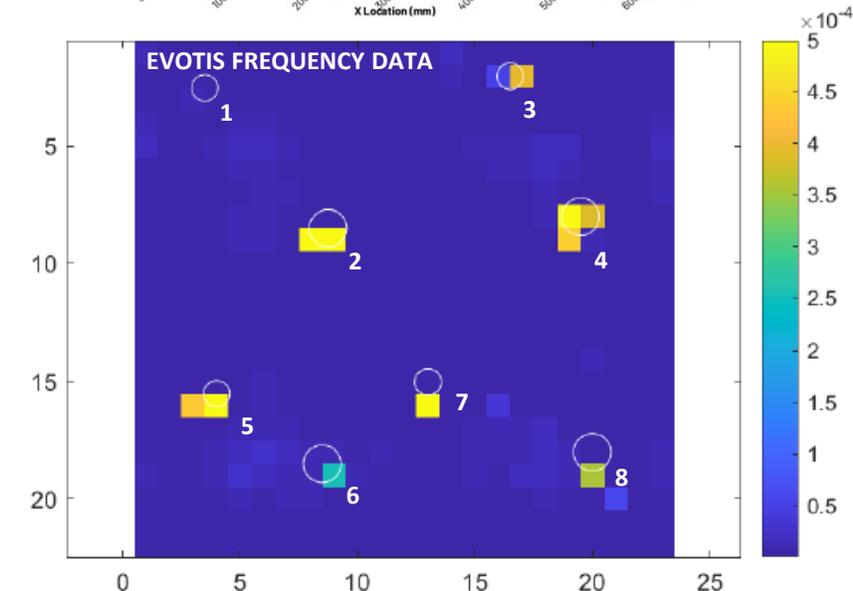
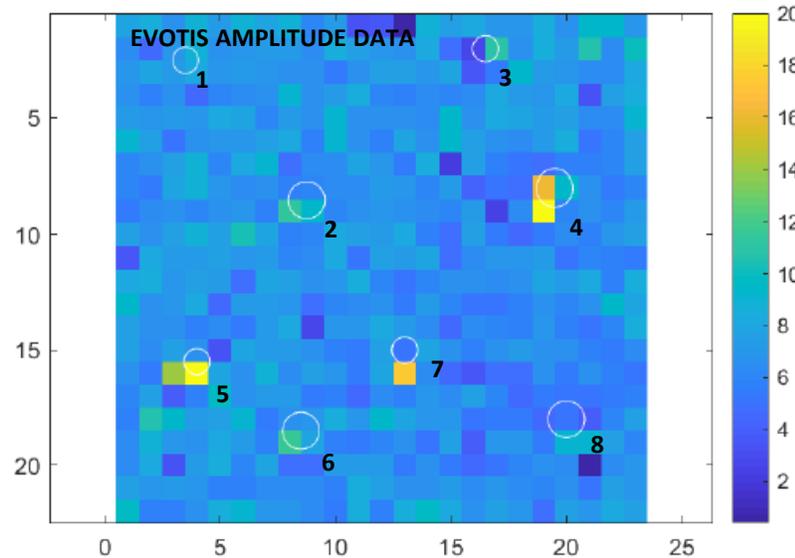
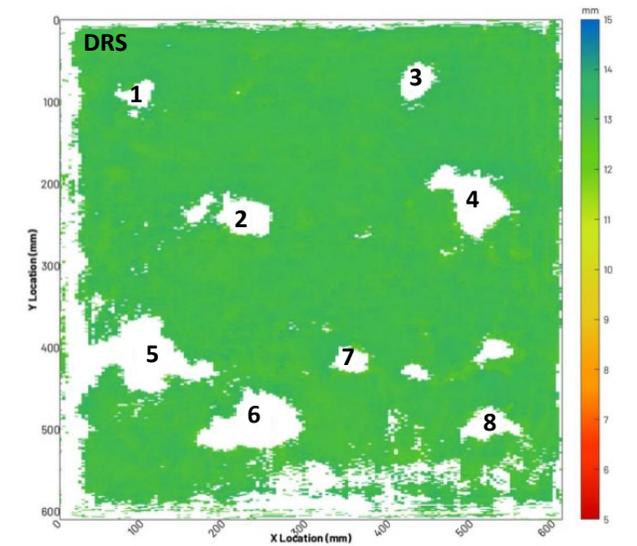
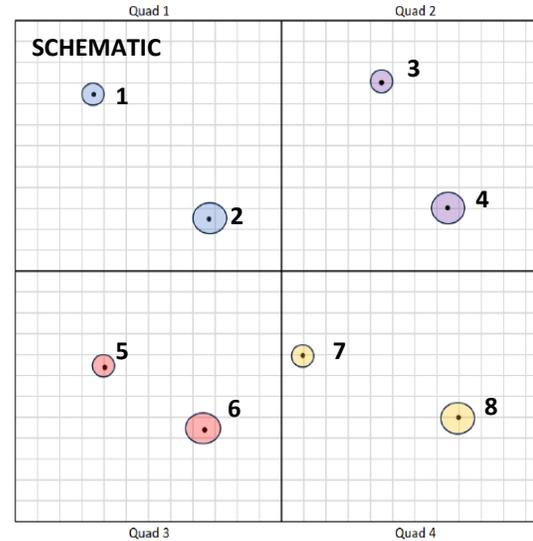
■ Structure:

- Five CF 2339 layers
- No FG 1210
- Thin epoxy topcoat approx. 0.050 in.

■ DRS shows successful detection of all flaws albeit with two additional flaws

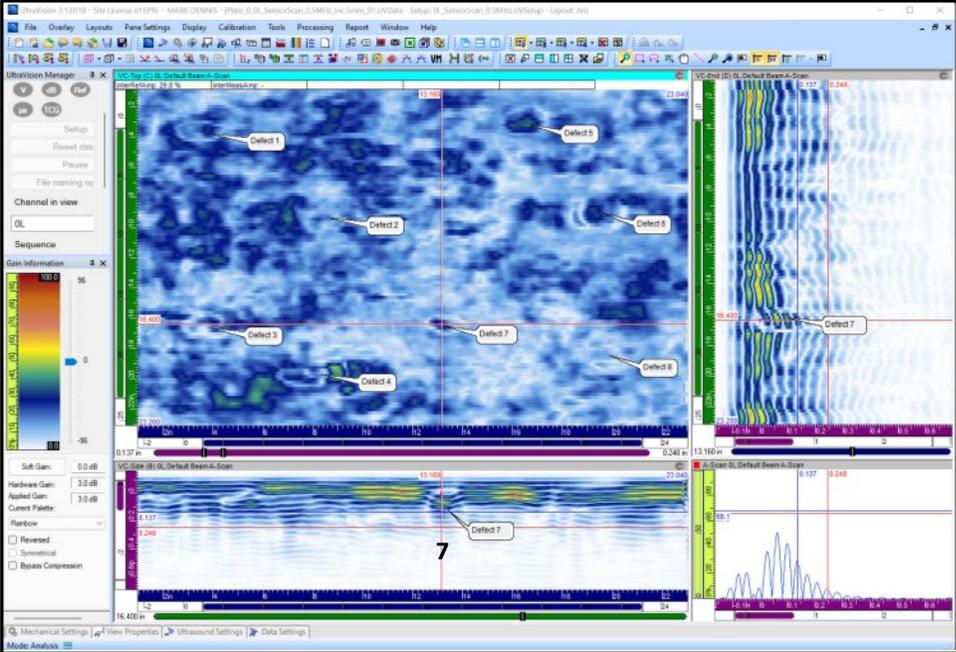
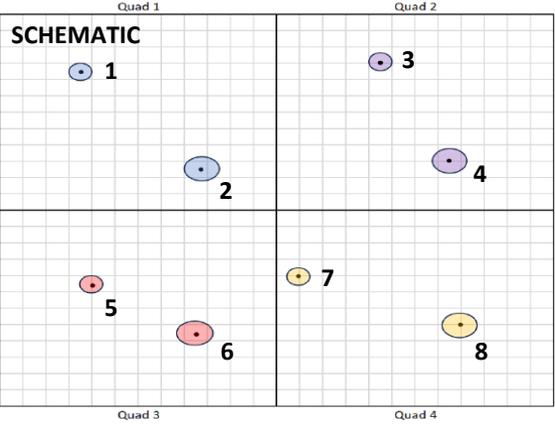
- Electronic tap testing detects all flaws except the first
- Regardless of probe type, UT detection found to be more challenging (next slide)

Schematic legend: First interface (yellow); second interface (purple); third interface (pink); base (blue)

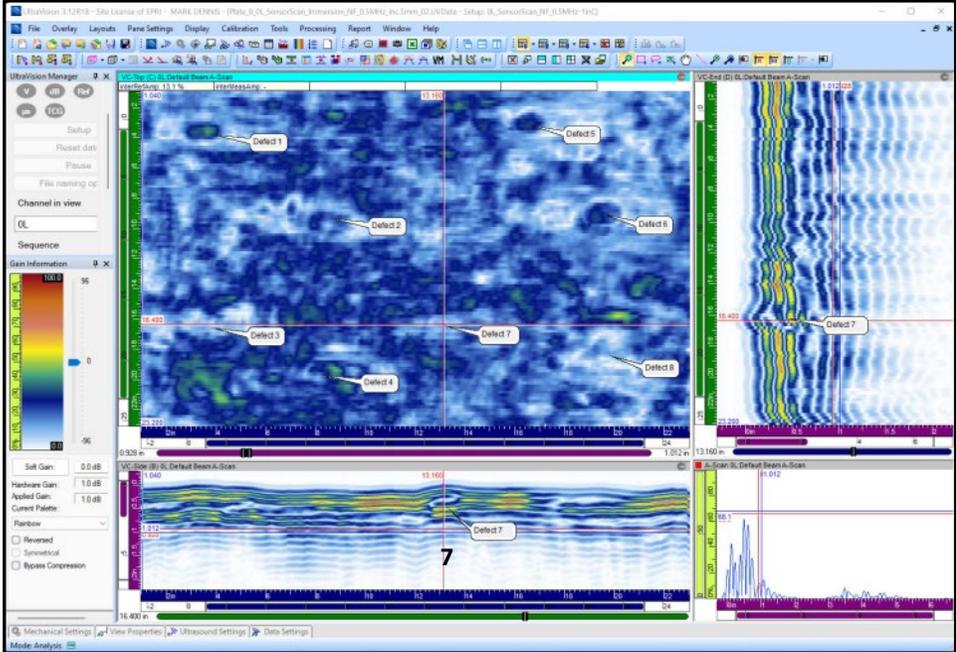


Results from multi-layer mockup: Conventional UT

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Contact, 0.5 MHz/1" C, NF



Immersion, 0.5 MHz/1" C, NF

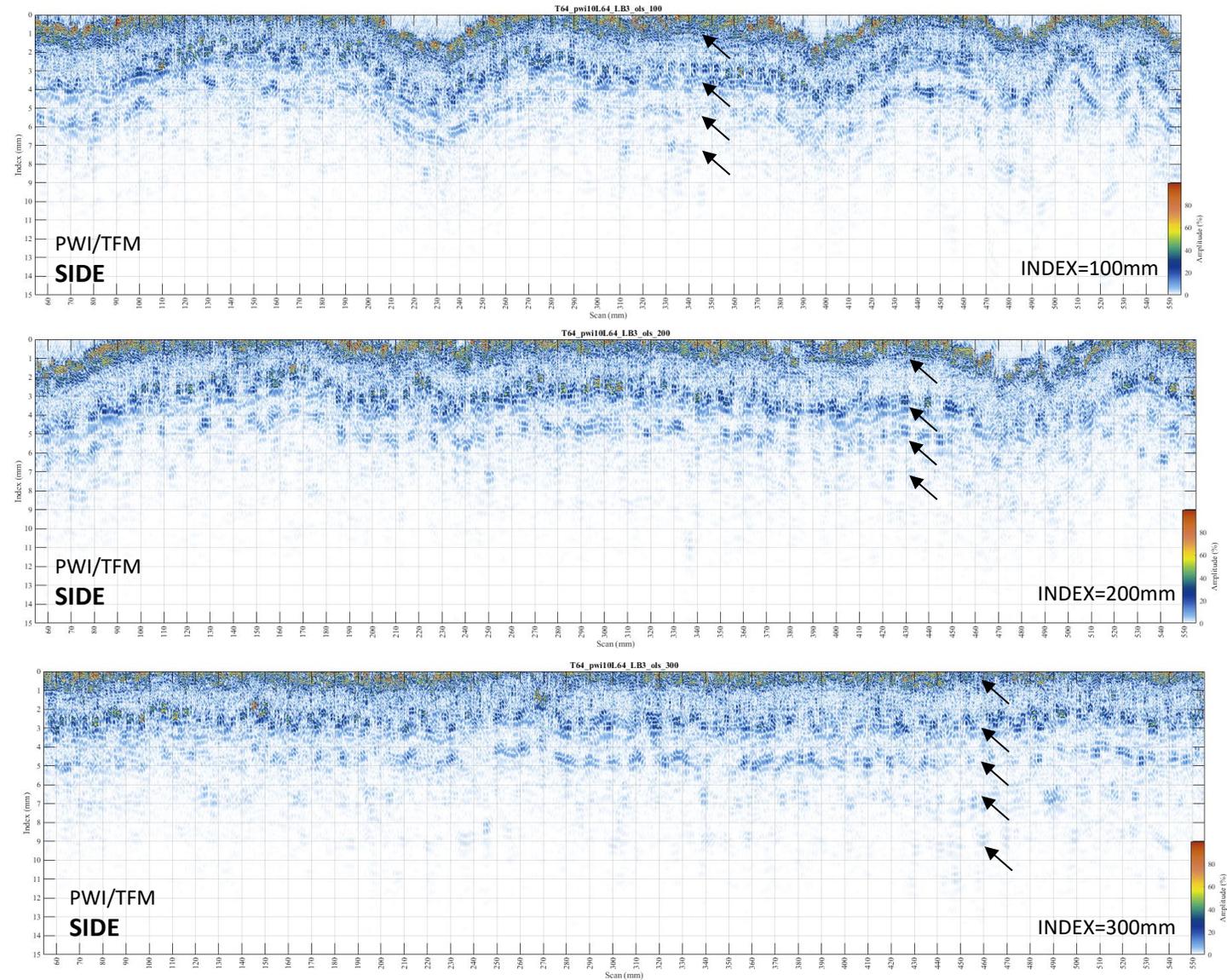
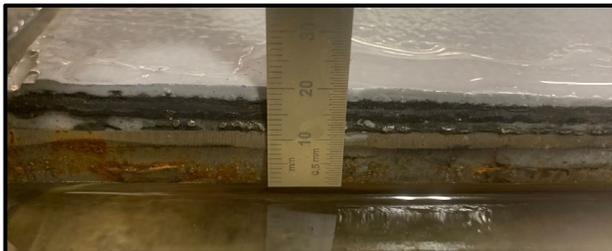
The image features a blue-tinted background with a starry space pattern. In the center, a pair of hands is shown holding a globe. The text "Preliminary TFM Results" is overlaid on the globe in a white, bold, sans-serif font.

Preliminary TFM Results

One-Line PWI/TFM at 10MHz

CFRP Plate Mockup

- Structure:
 - Epoxy layer (2mm)
 - Four laminar layers ($\approx 1.5\text{mm}$ each)
 - Steel substrate ($\approx 12\text{mm}$)
- One-line scans conducted at 100mm intervals
 - Local immersion
 - PWI/TFM (insonification angles from -20° to $+20^\circ$) at 10MHz
 - Probe oriented with aperture *in* RoI plane
- Observations:
 - Reflections from internal layers visible
 - Sensitivity to slight surface undulations, which formed rings around implanted flaws

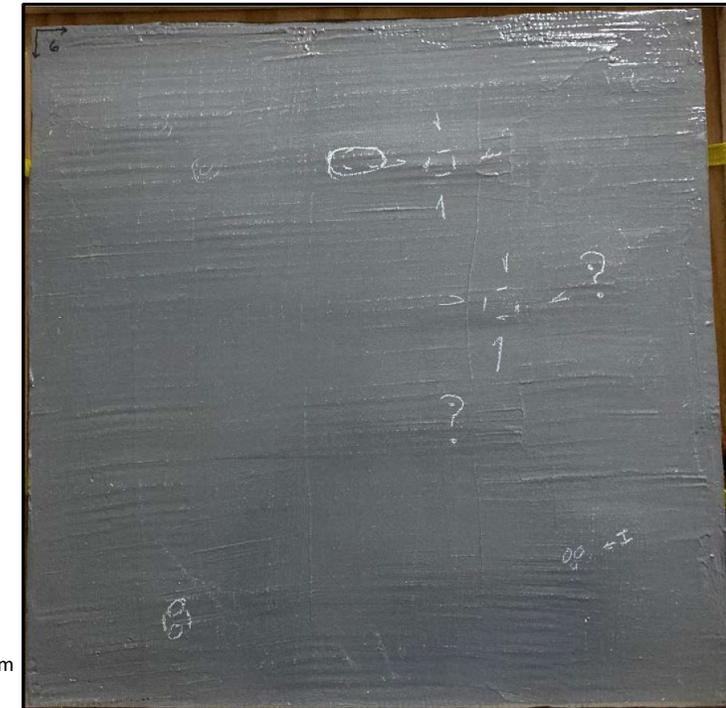
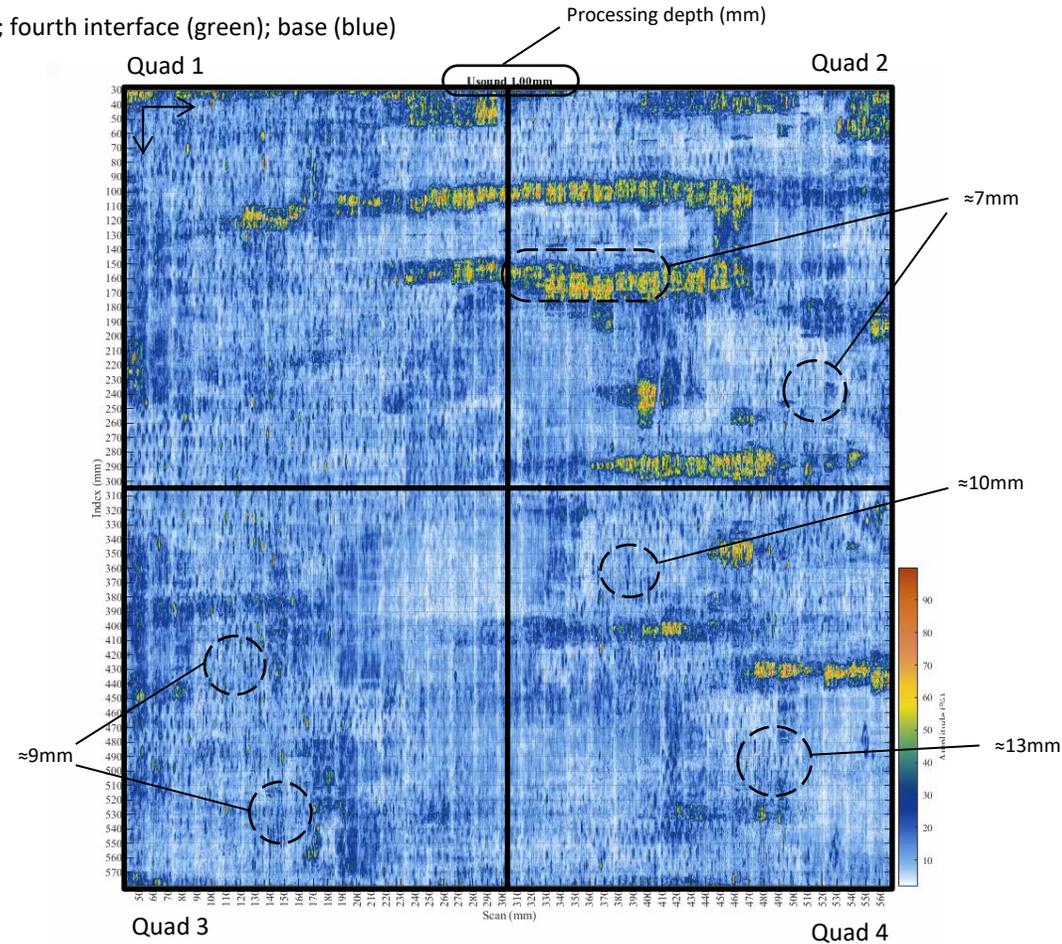
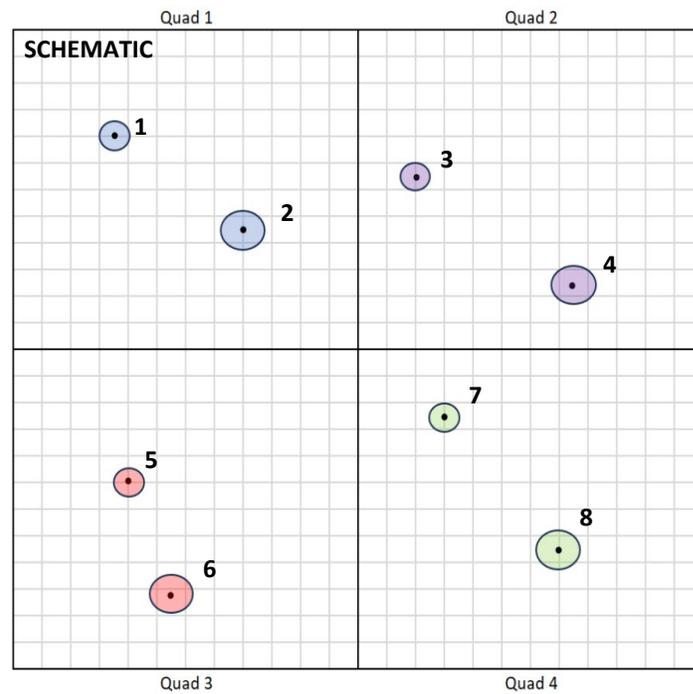


Volumetric PWI/TFM at 10MHz

CFRP Plate Mockup

- Animation shows maximum projection from specified depth to bottom of scan
- Some correspondence to schematic with knowledge of intended flaw locations

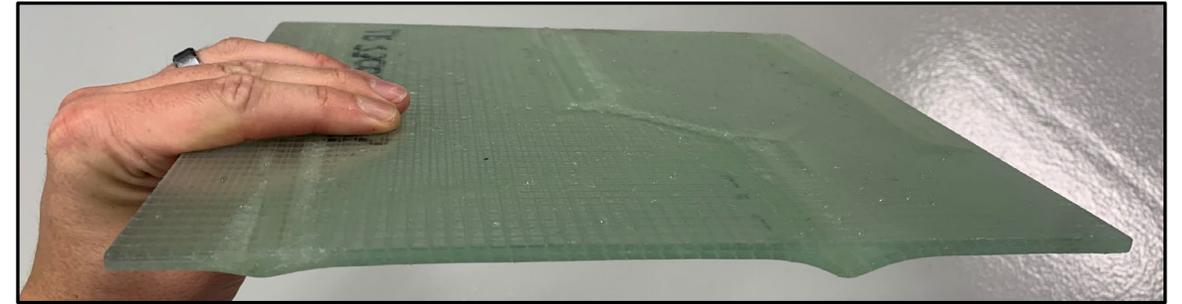
Schematic legend: second interface (purple); third interface (pink); fourth interface (green); base (blue)



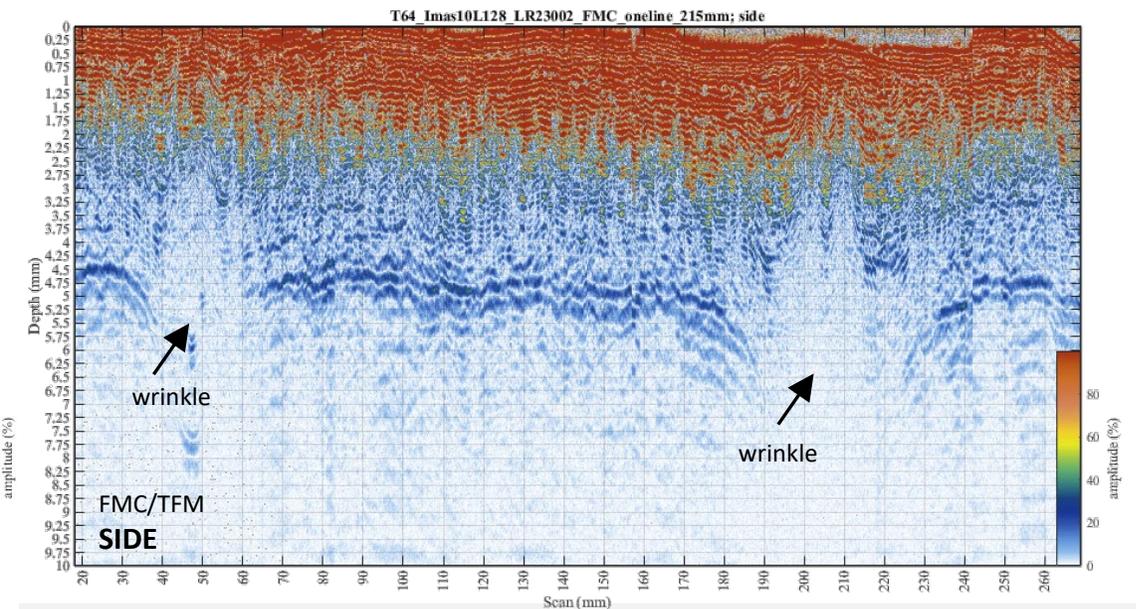
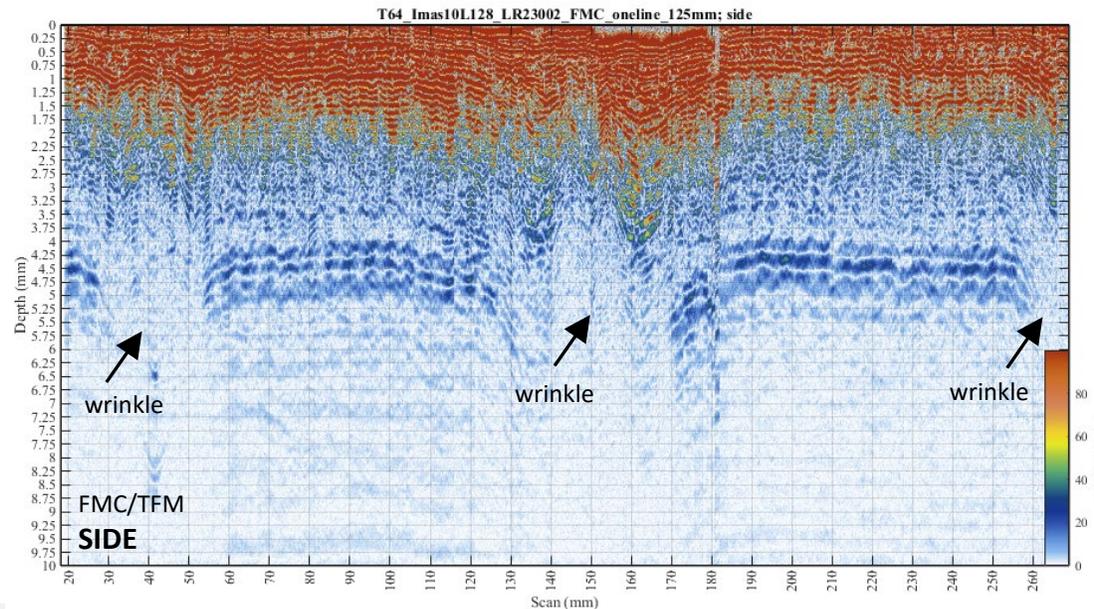
One-Line FMC/TFM at 10MHz

Glass Fibre Plate with Wrinkles

- One-line scans with probe oriented with aperture *in* RoI plane
 - Imasonic 10MHz phased array probe
 - 128-el (but only 64 active elements); 0.3mm pitch
 - Scan resolution: 1mm
- Backwall clearly visible at 5mm
- Wrinkles identifiable as gaps in backwall with quantifiable extent in scan direction
- Heavy top surface noise ($\approx 2\text{mm}$ thickness)



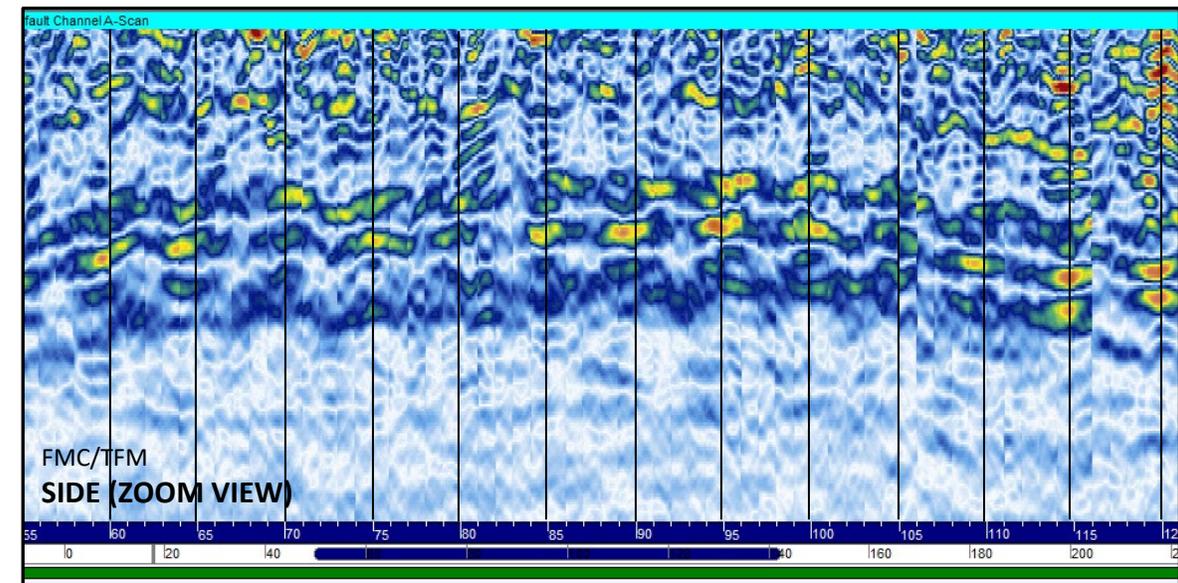
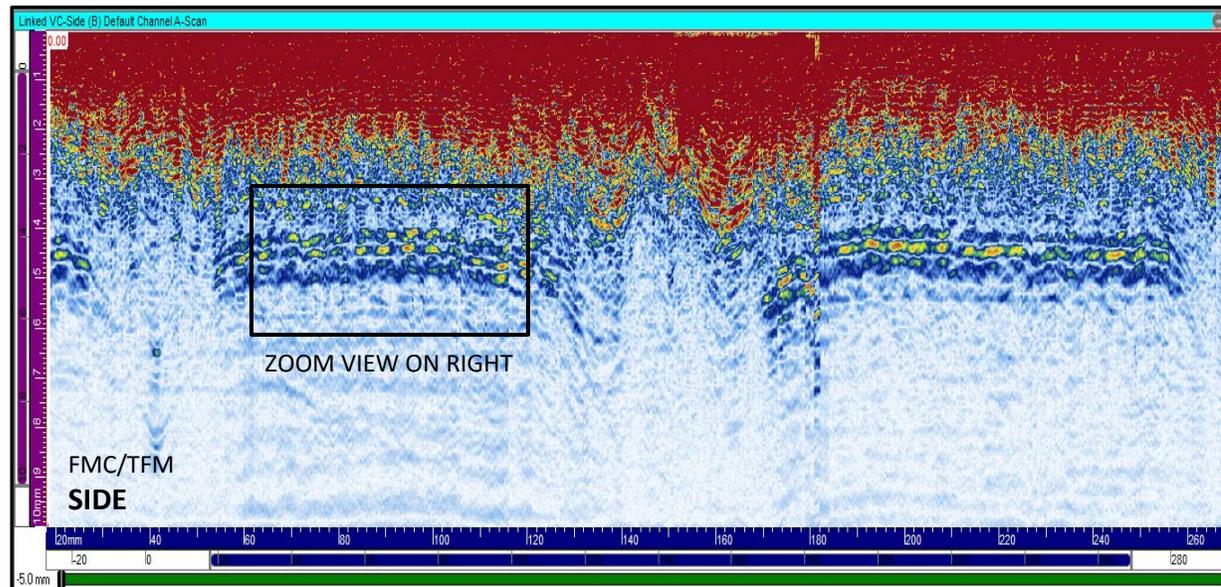
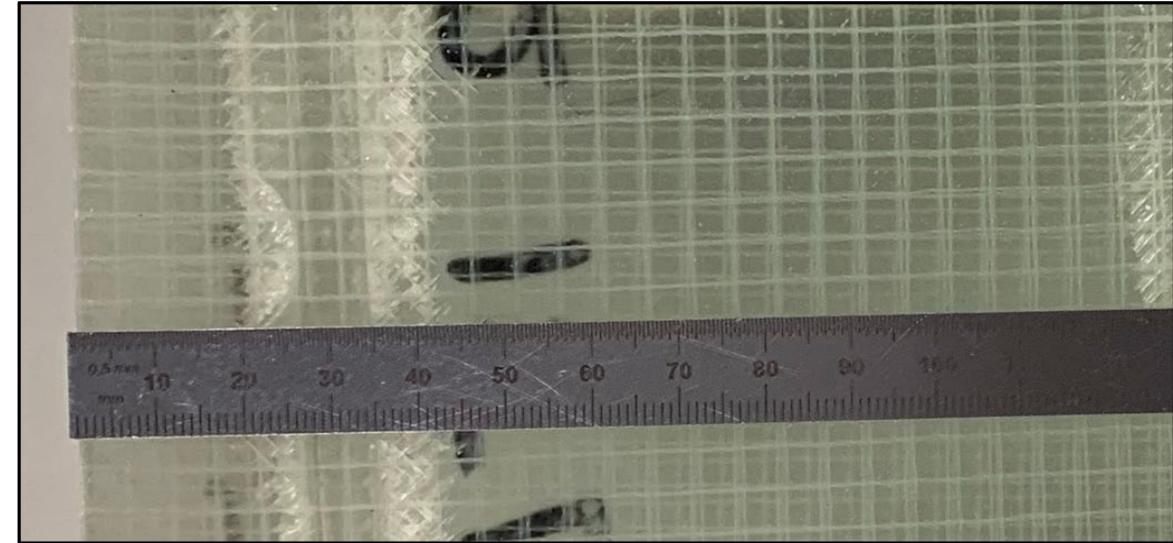
Glass fibre plate (270×245×5)mm with four $\varnothing 3\text{mm}$ glass rods to effect wrinkling



One-Line FMC/TFM at 10MHz (cont'd)

Glass Fibre Plate with Wrinkles

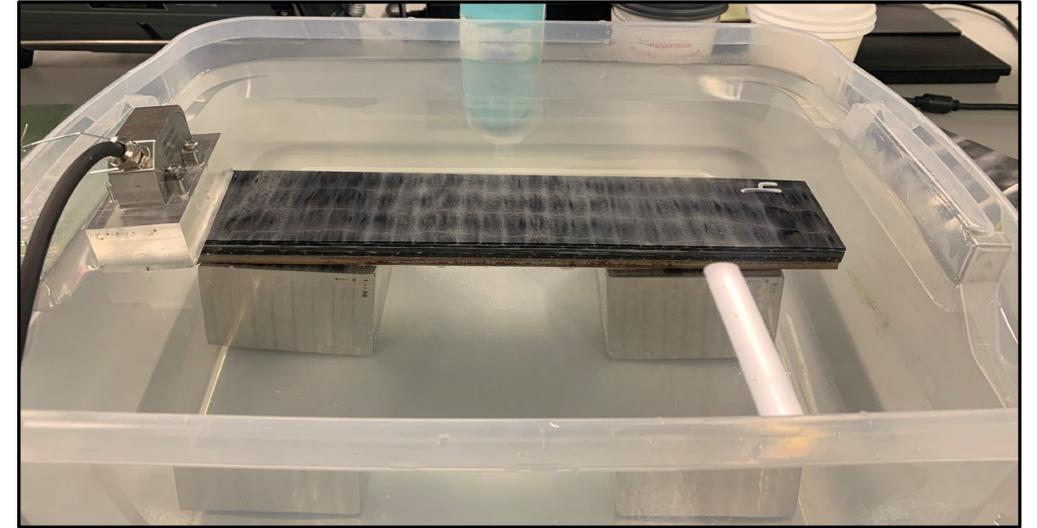
- Fibre pitch $\approx 5\text{mm}$
- Individually identifiable on bottom right zoom view
 - Added lines to indicate 5mm intervals
- But for the heavy noise at top surface, same pattern too might be visible at earlier depths



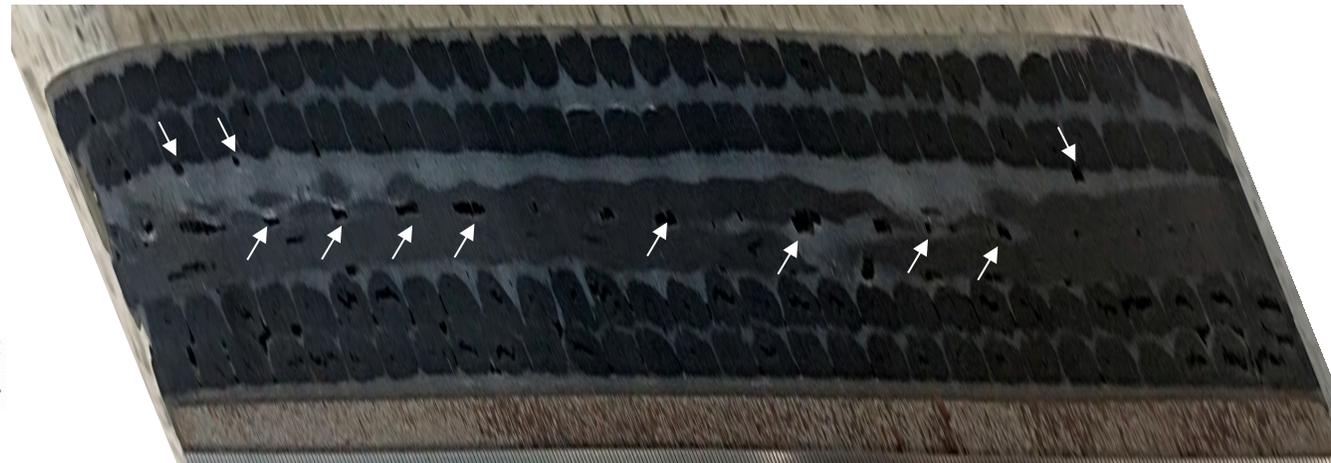
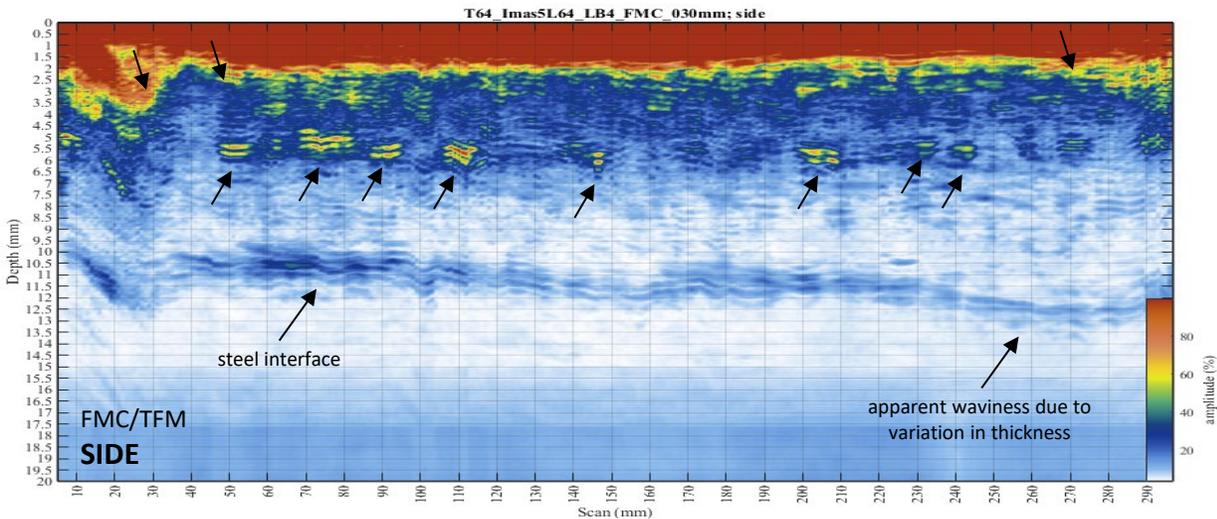
One-Line FMC/TFM at 5MHz

Small CFRP Strip

- Structure:
 - Six laminar layers ($\approx 12\text{mm}$)
 - Steel substrate ($\approx 7\text{mm}$)
- TFM highlights voids observed at mid-depth; some possible correspondence with the observed distribution, though the voids may not be consistent with depth
 - Steel interface is seen clearly, showing variation in height of the CFRP material
 - Unfortunately, wedge entry noise is significant



Small specimen (304×60×18)mm in immersion tank



Summary

- Manual tap testing found practical in identifying embedded gas bubble flaws in mockups
- Electronic tap testing demonstrated reliable detection of gas bubbles
- DRS demonstrated strong detection capabilities
 - May need further evaluation for effective interpretation of the binary results
- Conventional UT:
 - 1MHz and under showed capability in distinguishing and characterising many of the gas voids
 - Performance above 1MHz was not strong and usually did not yield useful data
 - Volumetric nature of the acquired data requires skill to evaluate and interpret
- TFM-based UT at 5MHz and 10MHz on various specimens
 - Performance highly dependent on material, specimen and structure
 - Scope for further technique development to address understanding gaps
- Perspectives for 2026-2027:
 - Continue UT technique development to identify and assess the performance of different TFM algorithms and UT apparatus for characterisation of the bulk material
 - Address NDE knowledge gaps for CFRP with emphasis on the following critical flaw types:
 - Poor adhesion to the substrate
 - Delamination between deposited layers
 - Void clusters and other imperfections of the epoxy
 - Supplement the mockup inventory as required with procured plate/pipe flawed specimens with different surface types

EPRI report #3002032154 (2025) available from [epri.com](https://www.epri.com)



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