ASNT Fall 2021

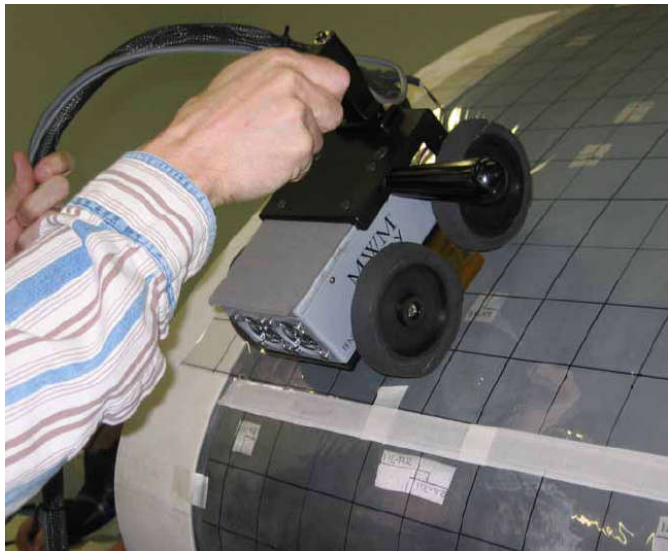
Progress in Aircraft and Spacecraft NDT with ET-Arrays

N. Goldfine, T. Dunford, S. Chaplan, J. Nelms, Z. Thomas, A. Washabaugh

Jenteksensors.com

Presenting New MWM-Array Advances…

…Built on Historical Successes such as for the Space Shuttle Leading Edge



Outline of Presentation

- MWM-Array Technology Background & Advances
- Currently Funded Transition Programs
  - **Bolt-Hole inspection for aircraft (New capability)**
  - Surface and buried crack detection away from holes
  - Corrosion imaging for aircraft
  - Weld inspection for spacecraft
  - **In-Situ layer-by-layer sensing for Additive Manufacturing (New capability)**
  - Cold Spray coating characterization
  - Upgrades to engine component inspections

MWM-Array Technology: Parallel Architecture Instruments

jET® Hand-Held

- 7 Simultaneous Impedance Measurements
- 3 Frequencies Simultaneously
- Supports the MWM and MWM-Array Sensor Technologies
- Weight less than 1 pound
- Best of class impedance measurement

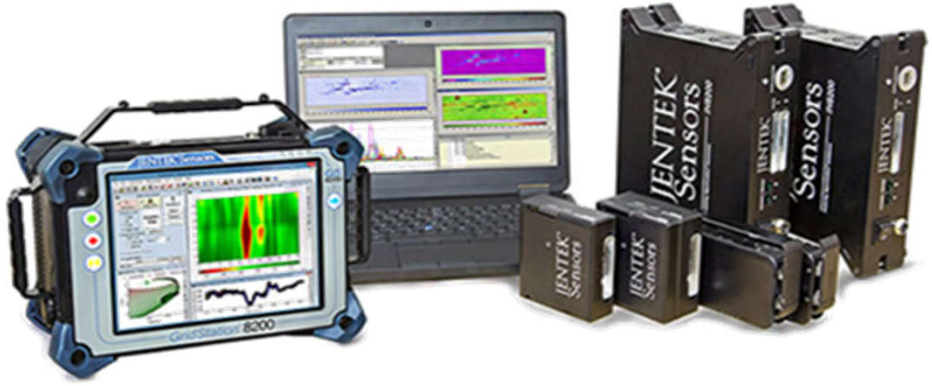
Periodic MWM

Deep Penetration MWM-Array

Near Surface MWM-Array

7-Channel MWM & MWM-Arrays

GridStation® GS8200



- Standard 19 and 39 Channel Systems standard
- Stackable up to 119 Channels
- 3 frequencies simultaneously
- All channel impedances and real and imaginary parts (or mag. & phase) recorded simultaneously
- Support for both inductive and magnetoresistive (MR) sensing element arrays

39-Channel MWM-Array

MWM-Array Technology: Available & Planned System Upgrades

jET® Hand-Held

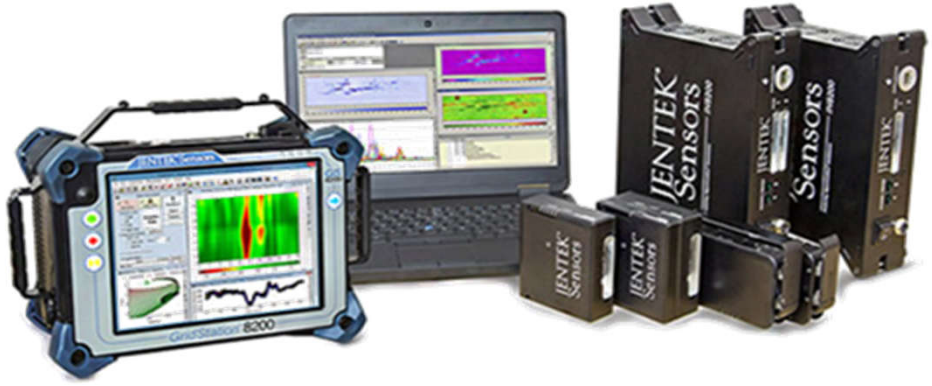
Available Upgrades

- 7-Channel 5 ft. flexible extension cable
- Data access at all levels for 3rd party development
- Improved intelligent filtering and signature libraries
- Improved user interface with tabs and automated reporting

Planned Upgrades

- **New D2P2 SBIR for field hardened solution and bolt-hole inspection**
- Integrated larger touch screen
- Improved battery pack

GridStation® GS8200



Available Upgrades

- 39- Ch 5 ft. flexible extension cable
- Data access at all levels for 3rd party development
- Improved intelligent filtering and signature libraries
- Improved user interface with tabs and automated reporting

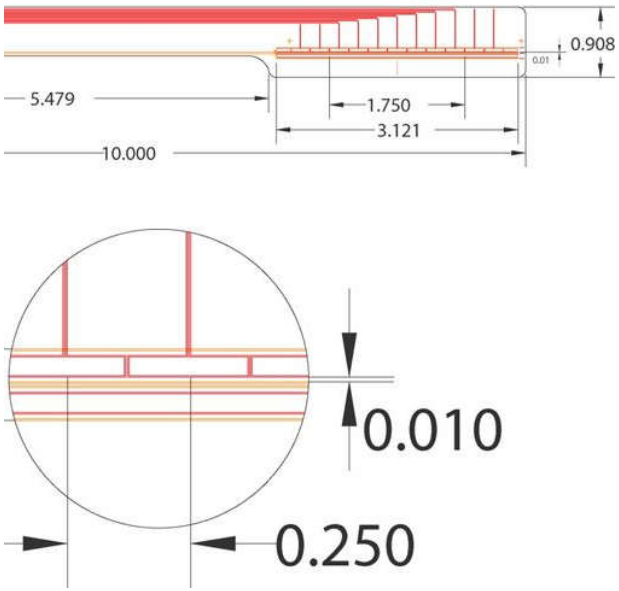
Planned Upgrades

- **New Phase 2.5 SBIR to develop "backpack portable" unit**
- Improved battery pack
- 79 and 119 Channel commercial systems

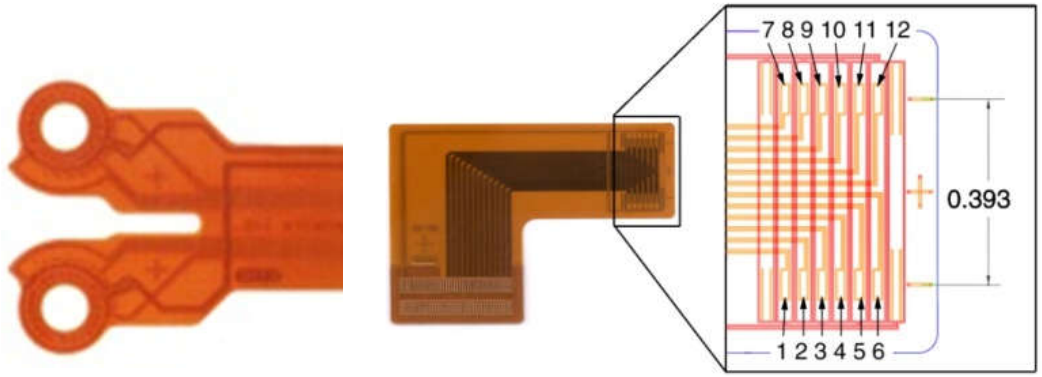
MWM-Array Technology: Designed for Model-Based Analytics

unique approach to sensor design
first eliminates unmodeled behavior
to empower physics model based data analytics

NDT Sensors



SHM Sensors



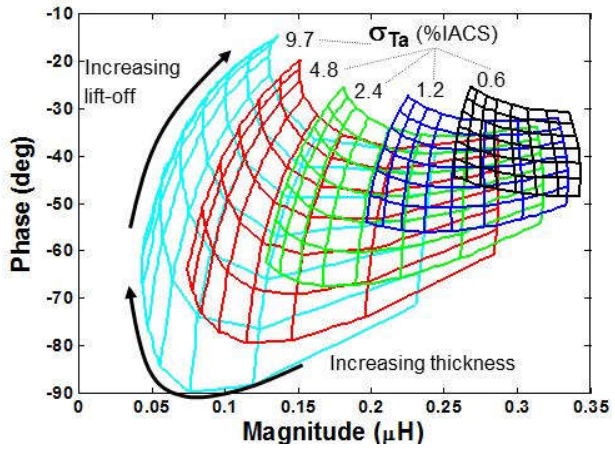
- MWM-Arrays input a current through a unique single or dual rectangle drive construct to produce a time varying magnetic filed at up to three frequencies simultaneously, and measure voltage at a linear array of sensing elements to provide imaging of material conditions and detection of defects

- Simultaneous measurement at neighboring channels (and for both the real and imaginary parts, or magnitude and phase, of the impedance) enables both high speed scanning and intelligent filtering

MWM-Array Technology: Rapid Analytics & Intelligent Filtering

Multiple Simultaneous Property Measurement: Using Model-Based Multivariate Inverse Methods

- Rapid conversion of sensor data into material properties
  - Electrical conductivity
  - Magnetic Permeability
  - Layer Thickness
  - Intelligent filtering with signature libraries for defect detection and sizing



Intelligent Filtering: Using Spatial and Temporal Signatures and Signature Libraries

- Rapid conversion of material property data at multiple sensing elements to defect responses (including sizing) with reduced false indications
  - Crack detection and sizing
  - Corrosion imaging and sizing for multiple layered constructs
  - Geometric feature estimation and accommodation
  - Signature library training and management for rapid data analysis and portability to new applications
  - Targeted anomaly suppression for reduced false indications and improved signal-to-noise performance

Ease of Use: (ASTM E2338; ASTM E2884)

- Air and Reference Calibration – to reduce burden on inspectors and improve reliability
- Intuitive Digital Data Visualization Tools – to empower customers and decision makers
- Immediate Calibration and Inspection Performance Verification – to build confidence and reduce uncertainty
- Targeted user interfaces for large ongoing transition opportunities:
  - ➢ Bolt-Hole Inspection
  - ➢ Gun Barrel Inspection
  - ➢ Aircraft Corrosion Imaging
  - ➢ Pipeline and Riser Inspection
  - ➢ Land-Based Turbine Inspection
  - ➢ In-Process Sensing for AM (Additive Manufacturing)

Picking the Right MWM-Array Sensor
(Depth of Penetration is NOT Depth of Sensitivity)

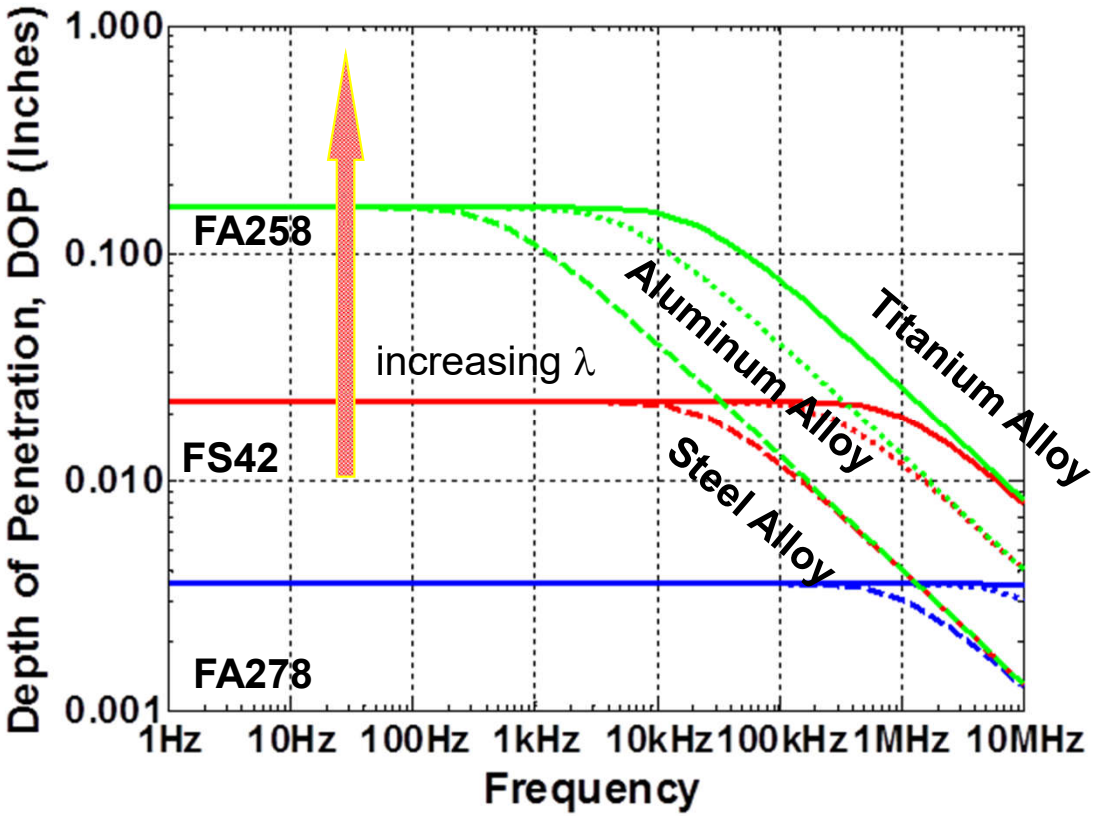
Field Variation with Depth ≈ $e^{-\Gamma_n z}$

$$\Gamma_n = \sqrt{(2\pi n/\lambda)^2 + j2/\delta^2}$$

Spatial Fourier Mode Depth of Penetration = $1/\mathrm{Re}(G_n)$

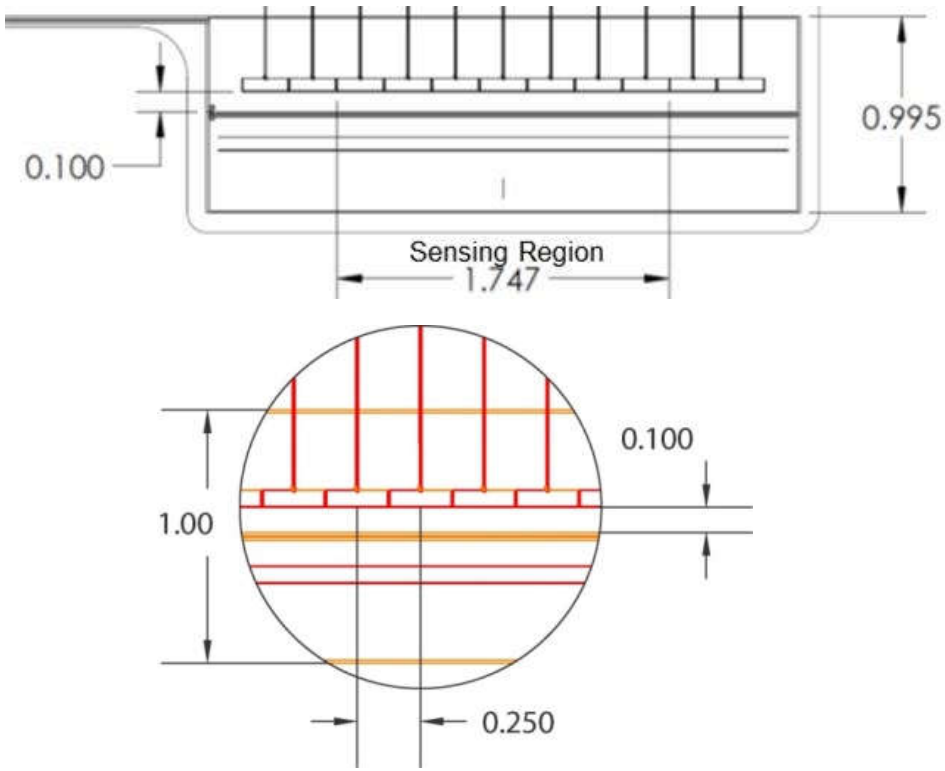
Low frequency asymptote = $\lambda/2\pi$

Skin depth: $\delta = \sqrt{\frac{1}{\pi f \mu \sigma}}$

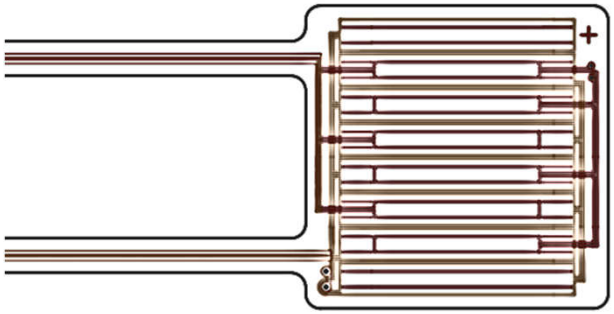


MWM®-Array

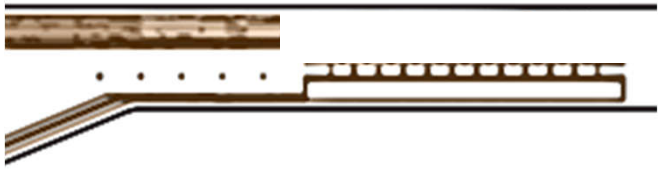
FA258



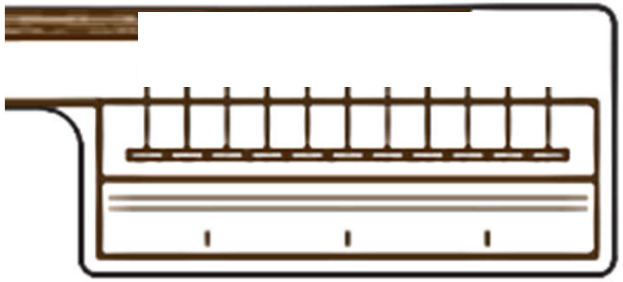
MWM and MWM-Array Sensors



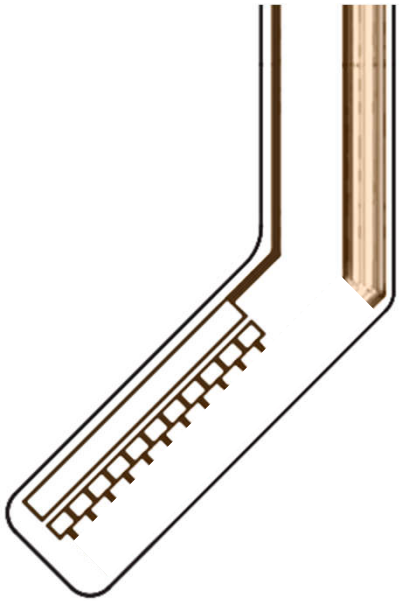
MWM® (FS42)



MWM®-Array (FA260)
Sense Elements Outside Drive



MWM®-Array (FA296)
Dual Rectangle Drive



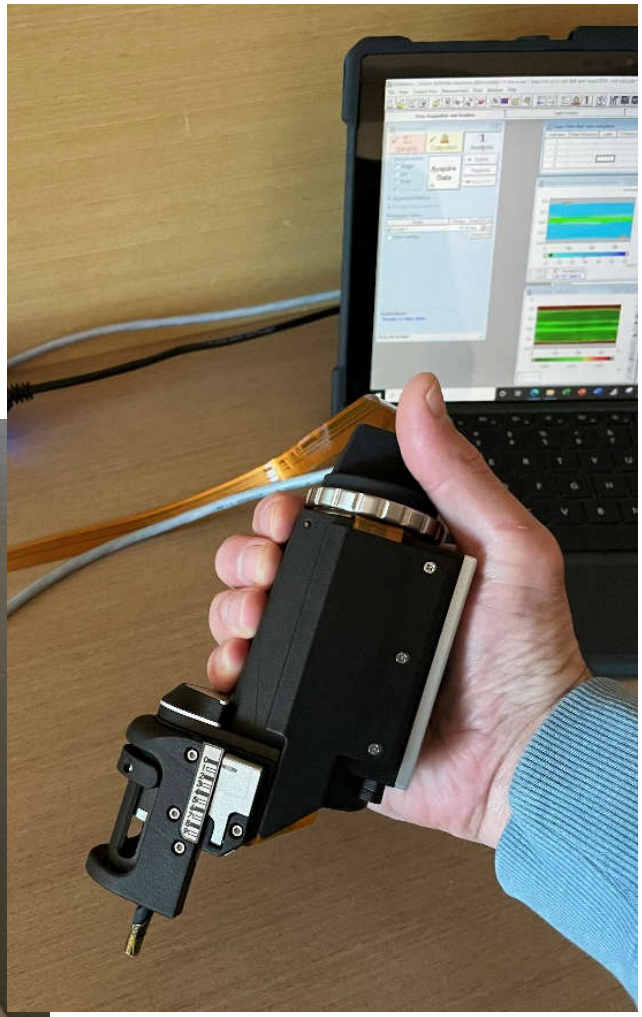
MWM®-Array (FA314) for Bolt Hole
(Older version than FA318 currently in use)

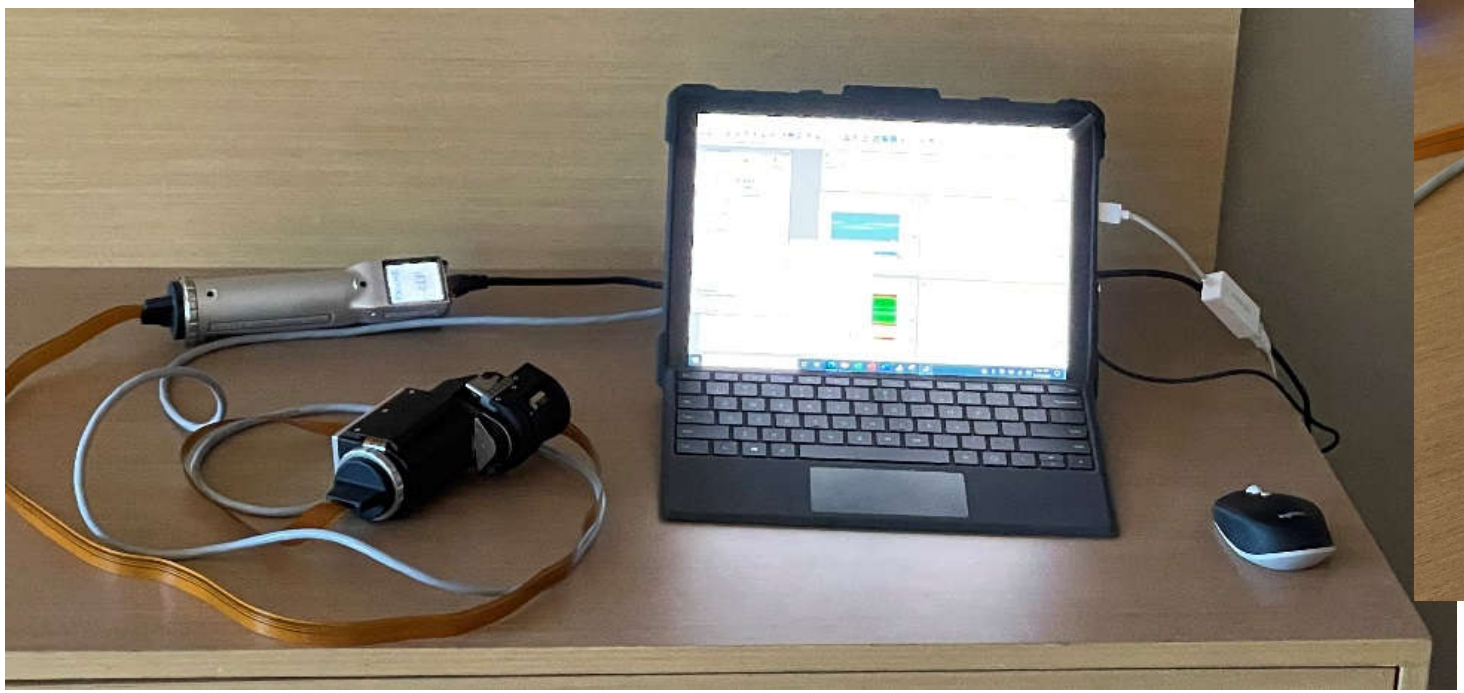
Currently Funded Transition Programs

- **Bolt-Hole inspection for aircraft**
- **Surface and buried crack detection for structures and engines**
- **Corrosion imaging for aircraft**
- Weld inspection for spacecraft
- In-Situ layer-by-layer sensing for Additive Manufacturing
- Cold Spray coating characterization
- Upgrades to engine component inspections

Prototype jET Handheld Scanner for Bolt-Hole Inspection

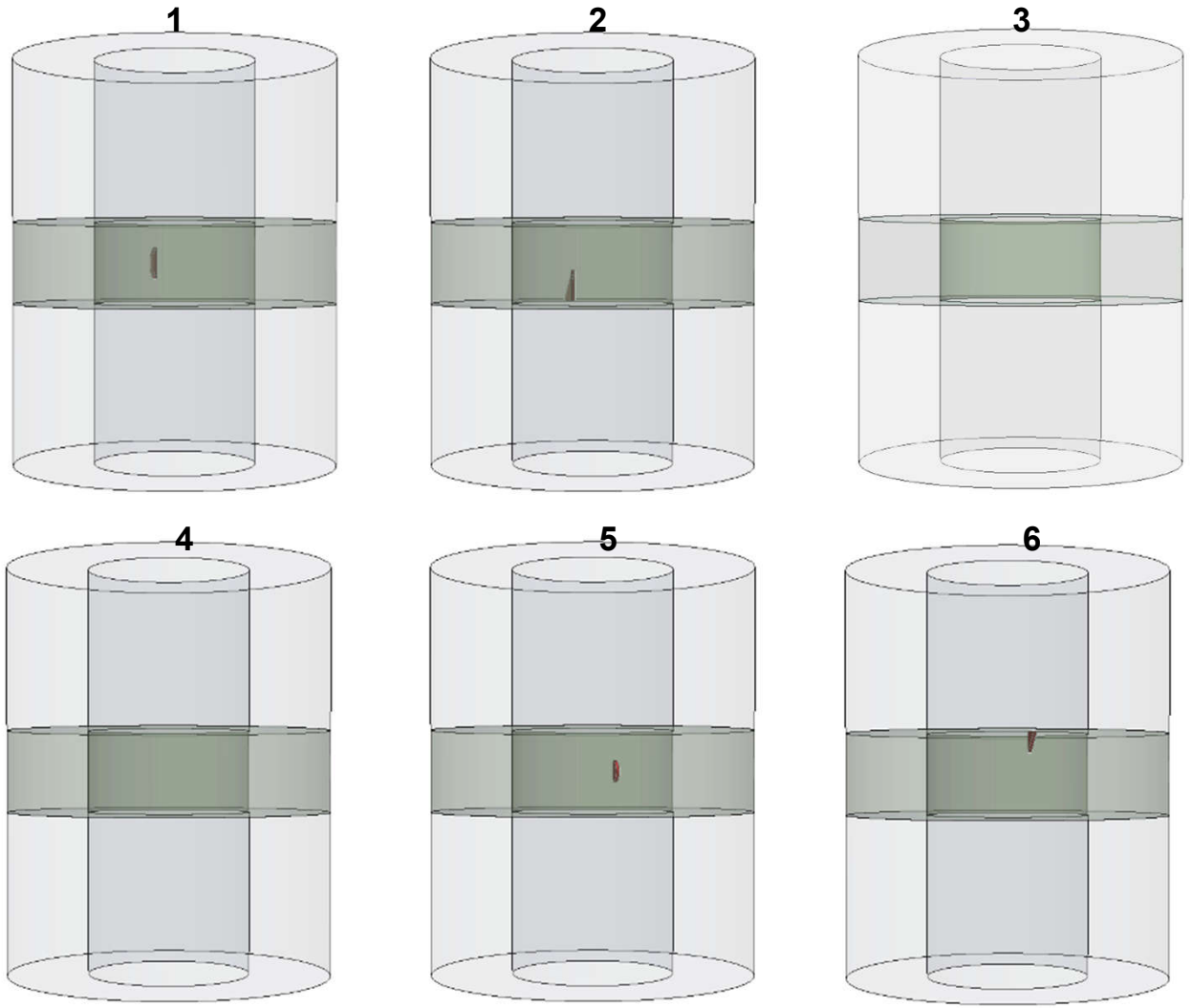
- Current prototype of “wrapping-lead” bolt hole scanner
- A new more compact version is under development with an alternative internal configuration
- 5 ft. flexible lead enables more convenient scanning
- GridStation software performs multi-variate inverse methods and intelligent filtering





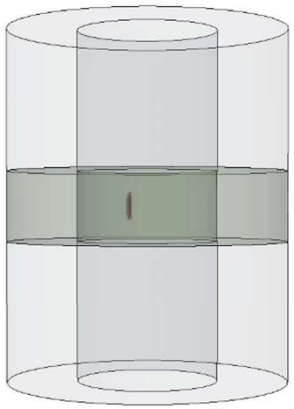
6 Holes per Sample; Multi-layer; Multi-material

- Corner EDM notches
- Mid-wall EDM notches
- Real crack samples can be inserted in material stack-ups

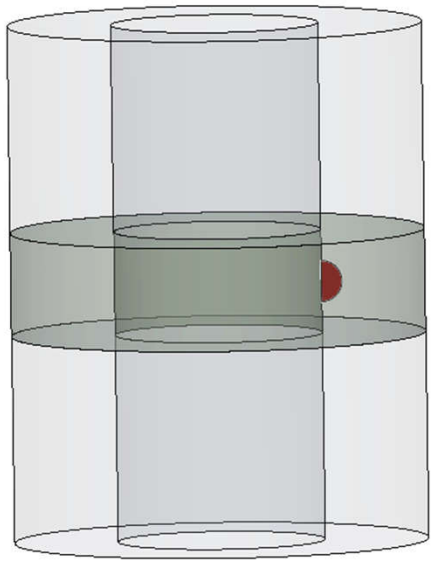


Example Result: 3 Layer Stack-up

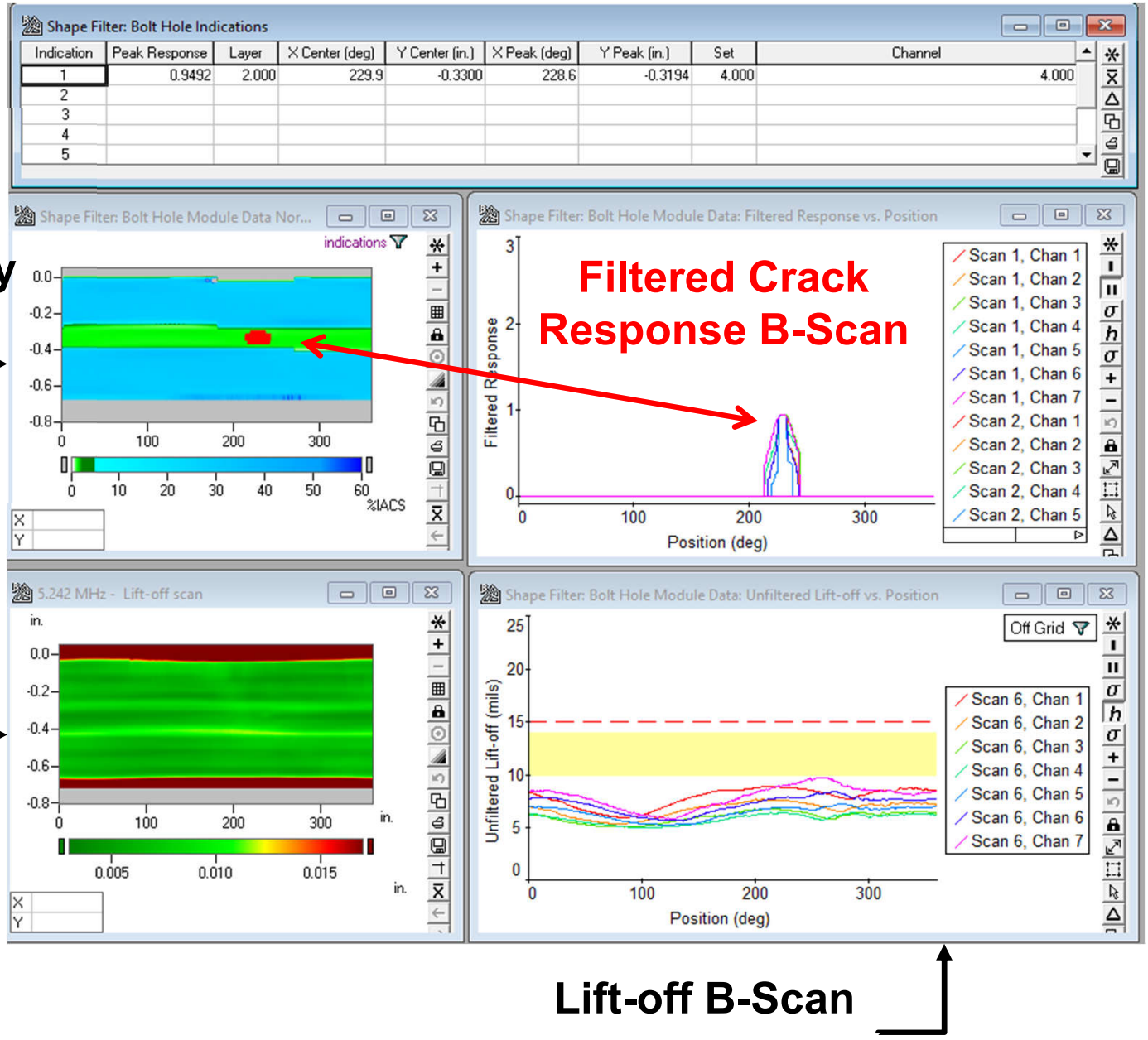
Automatic Reporting



Conductivity C-Scan



Lift-off C-Scan



Lift-off B-Scan

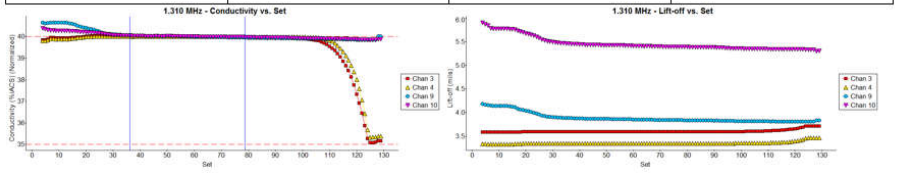
Real Crack Specimen Fabrication

Material	Thickness (in)	Hole Diameter (in)
6061-T6	0.125	¼ (0.250)

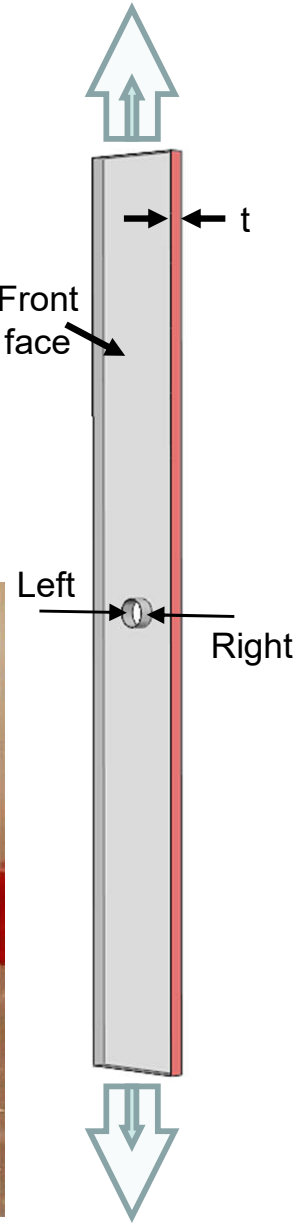
Note: Conductivity measurements are **NOT** consistent with 6061-T6

Maximum Load (lbs)	Minimum Load (lbs)	Frequency (Typical)	Max. # Cycles
3000	300	25Hz	19,773

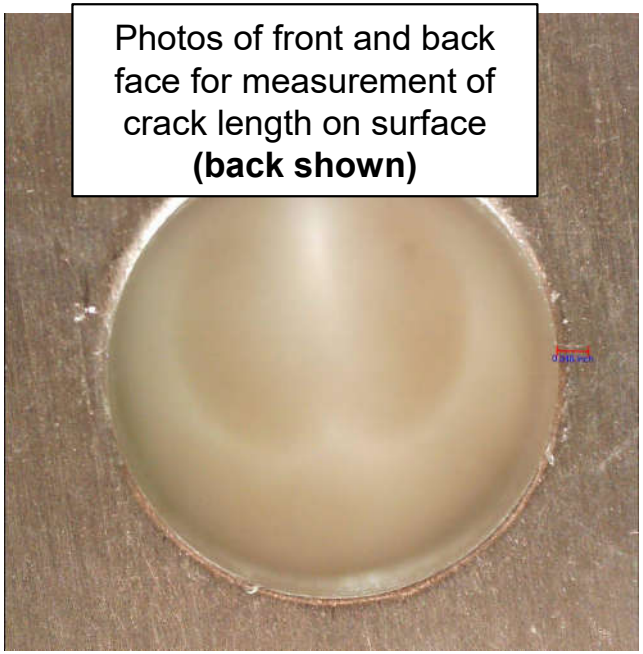
Left		Right	
Length in Hole (in)	Length on Surface (in)	Length in Hole (in)	Length on Surface (in)
0.000	0.000	0.044	0.018



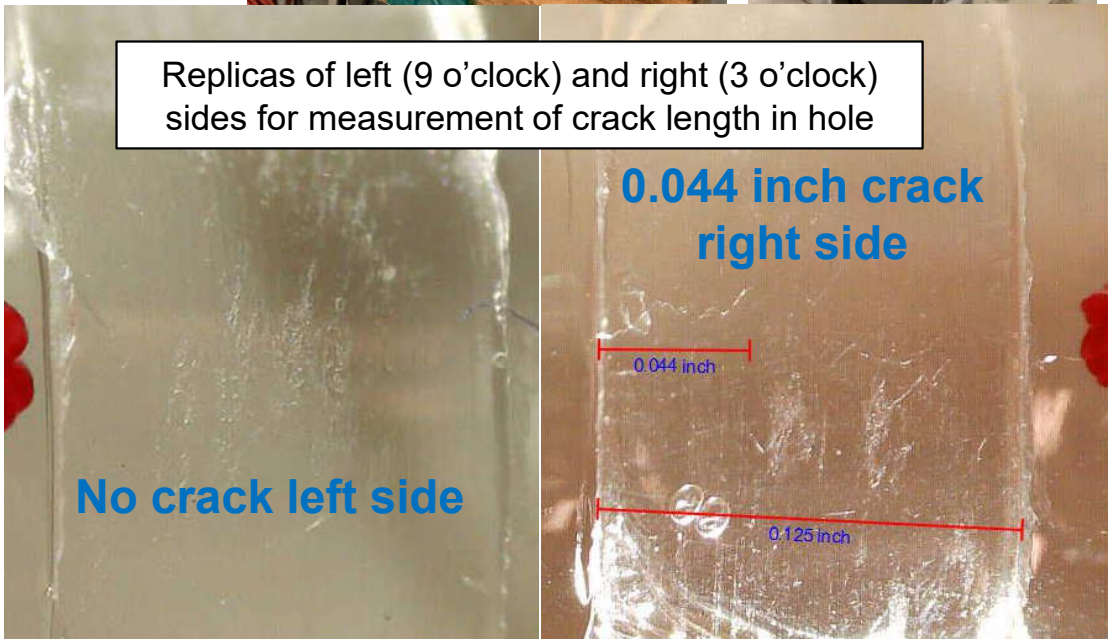
Sample **1**



Photos of front and back face for measurement of crack length on surface **(back shown)**



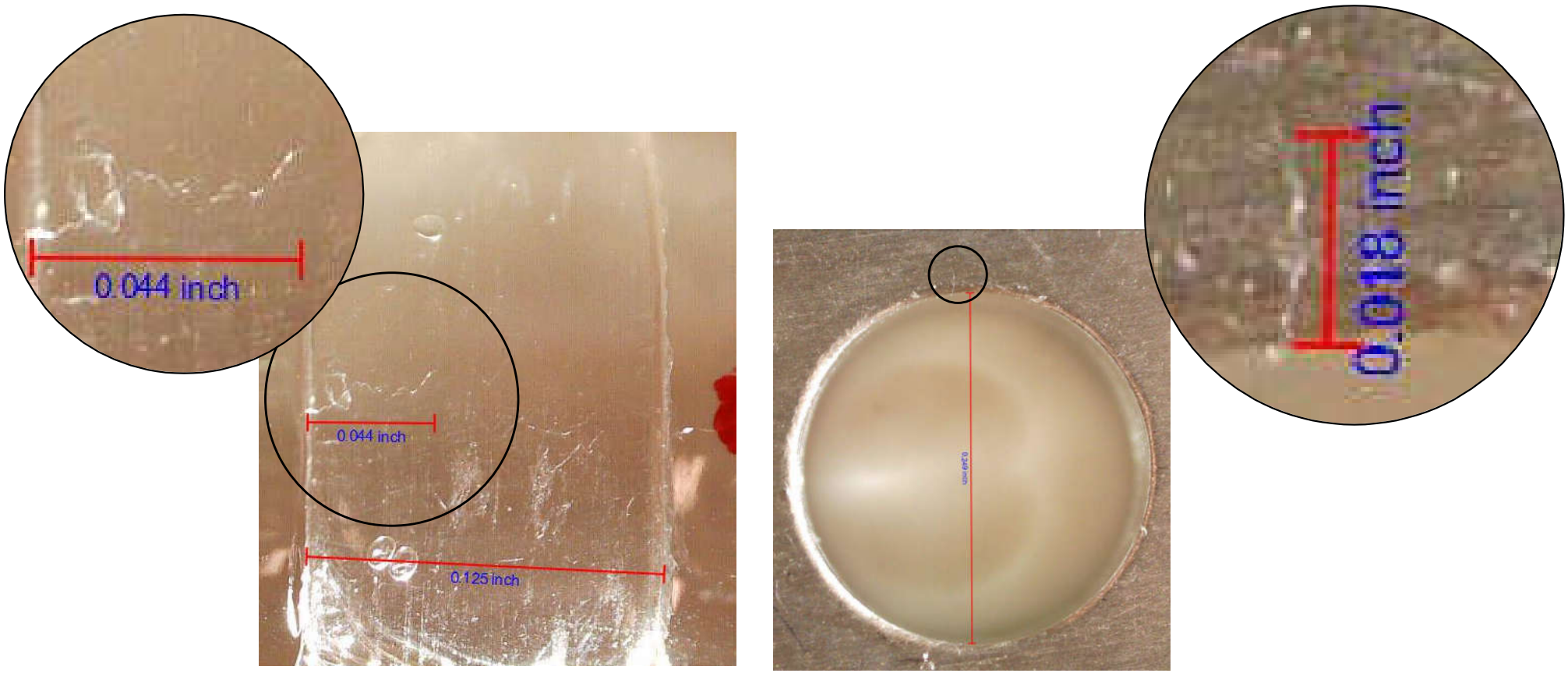
Replicas of left (9 o'clock) and right (3 o'clock) sides for measurement of crack length in hole



Real Crack Specimen 1

- ¼ in. hole; Al alloy
- Left inside: No defect
- Right inside: 0.044 in. corner crack (0.018 in. external surface crack)

Right Side

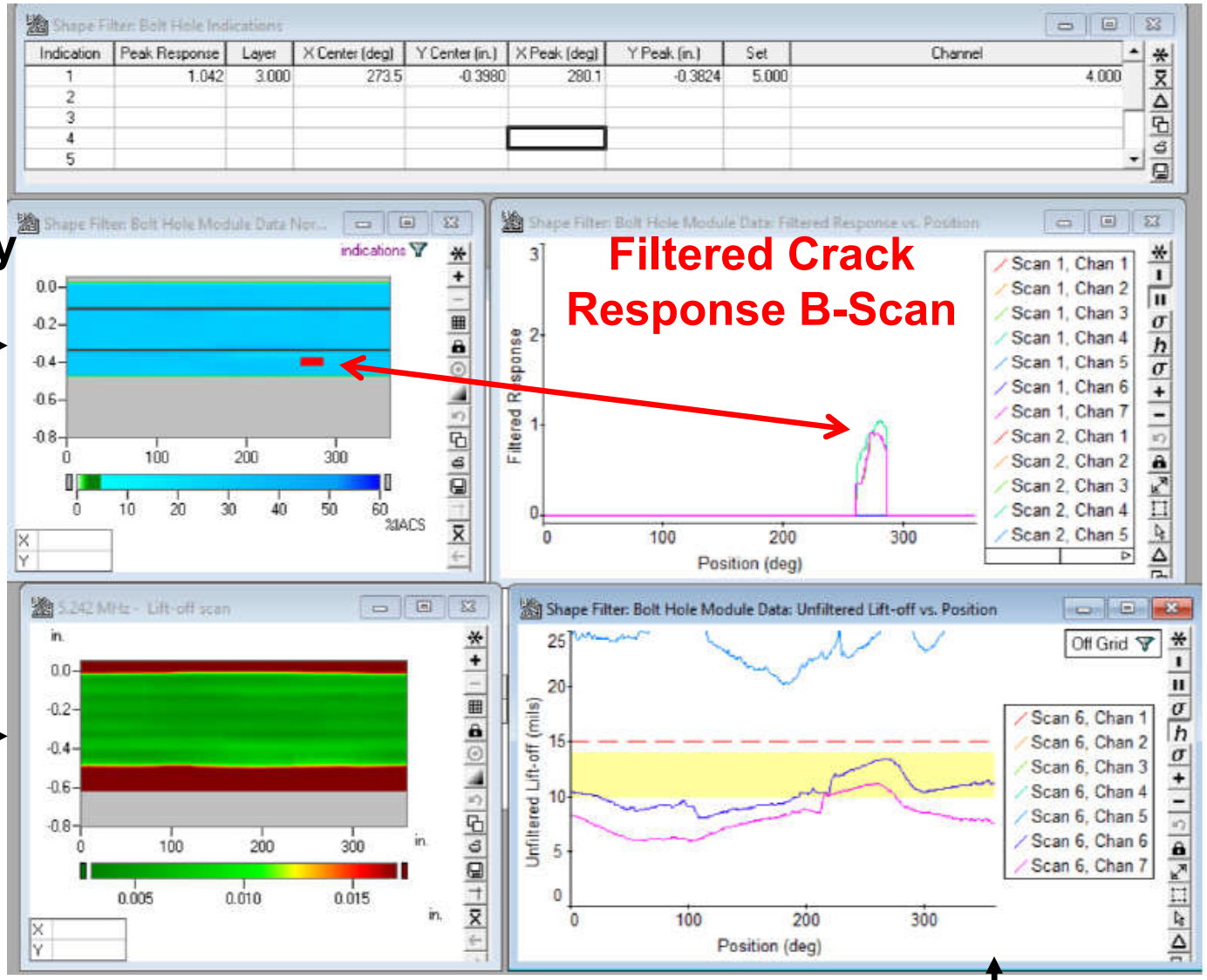


Real Crack Specimen 1 – Sample scan result

Automatic Reporting

Conductivity C-Scan

Lift-off C-Scan

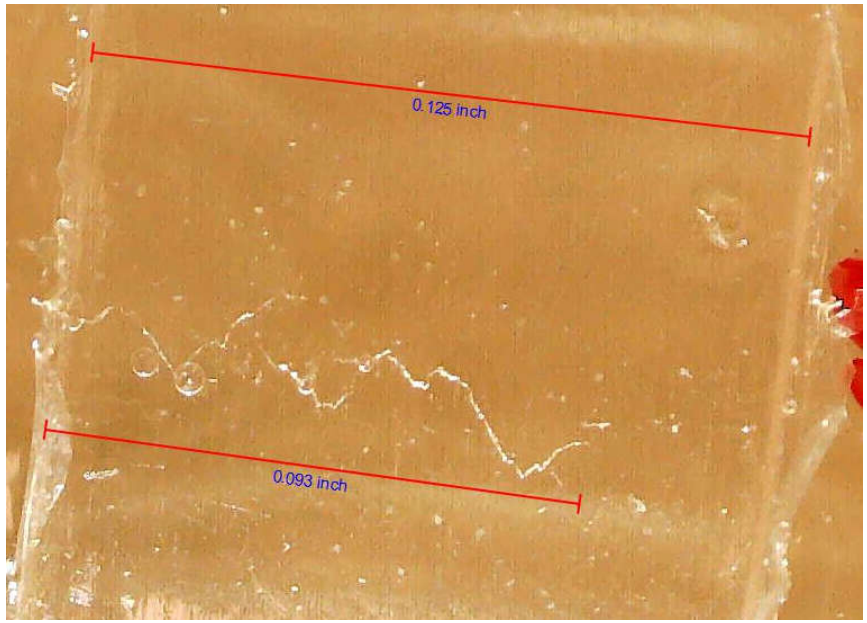


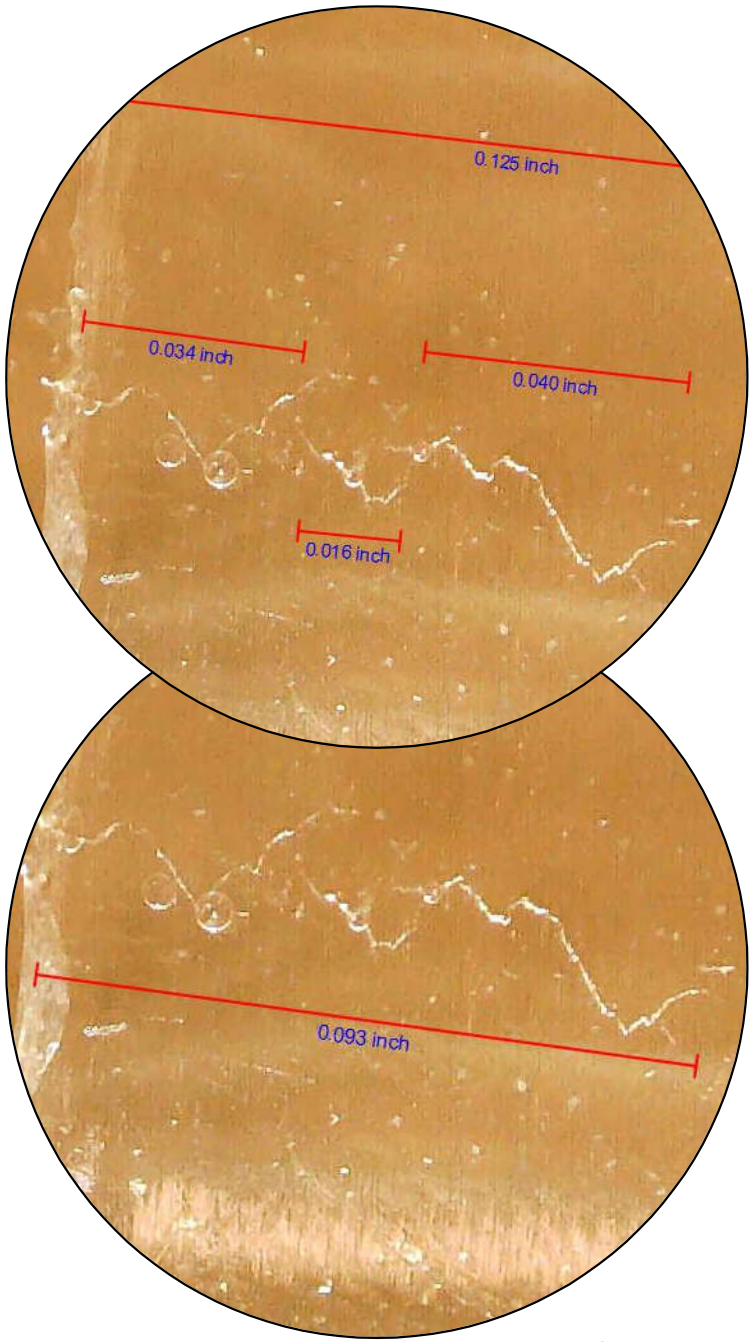
Lift-off B-Scan

Real Crack Specimen 2

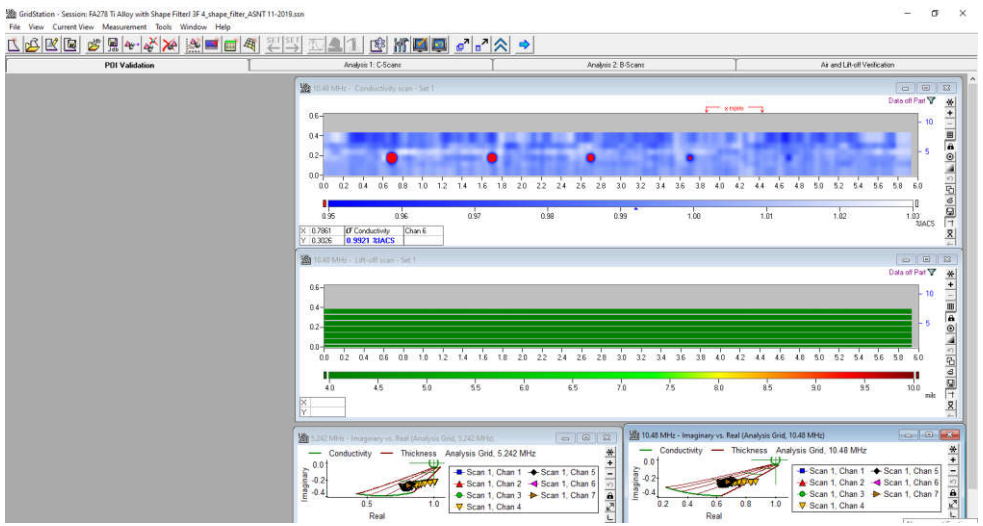
- ¼ in. hole; Al alloy
- Left inside: No defect
- Right inside: 0.093 in. crack near edge (no external surface crack visible)
- Appears to be three nearly coalesced cracks of lengths 0.040 in., 0.016 in., and 0.034 in.

Right Side

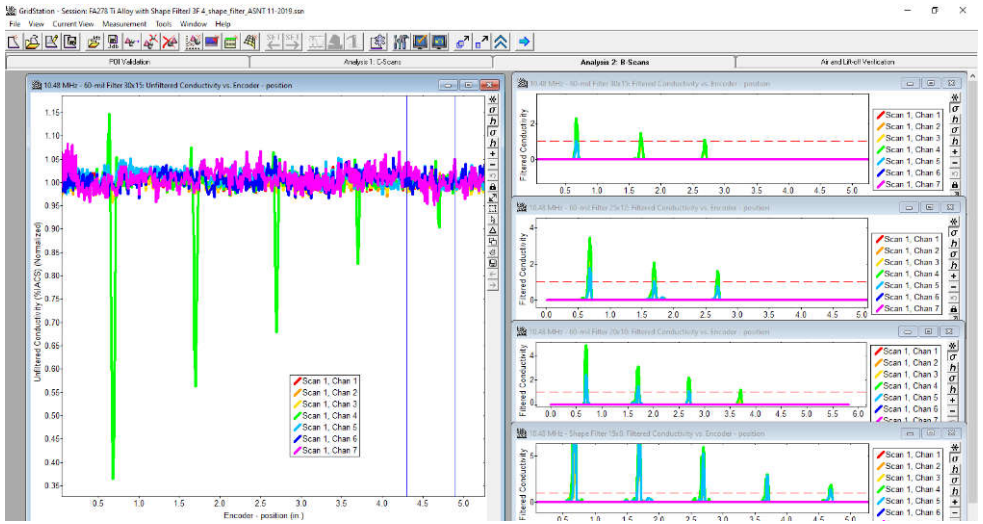




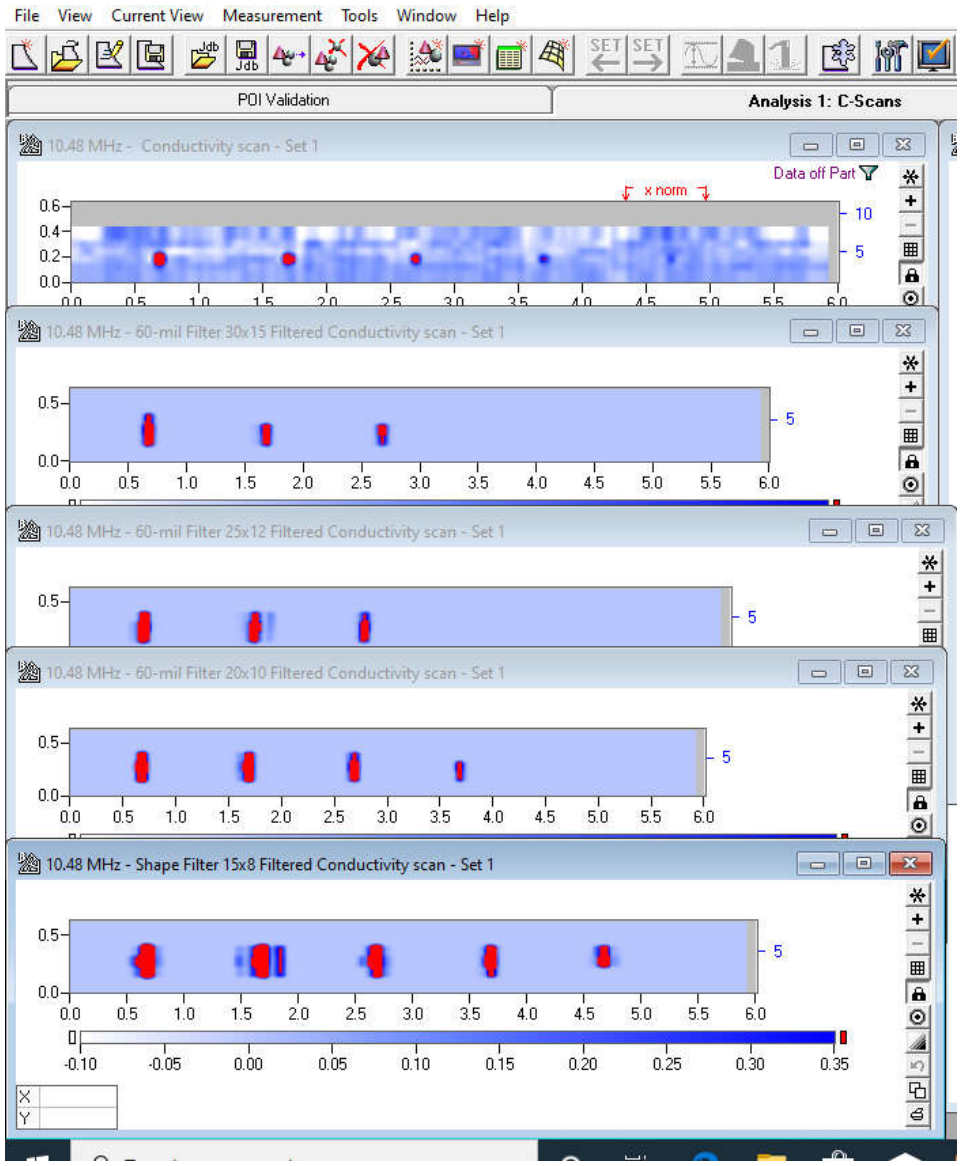
Surface Crack Detection Interface for POD verification and Inspection



Liftoff & coverage verification

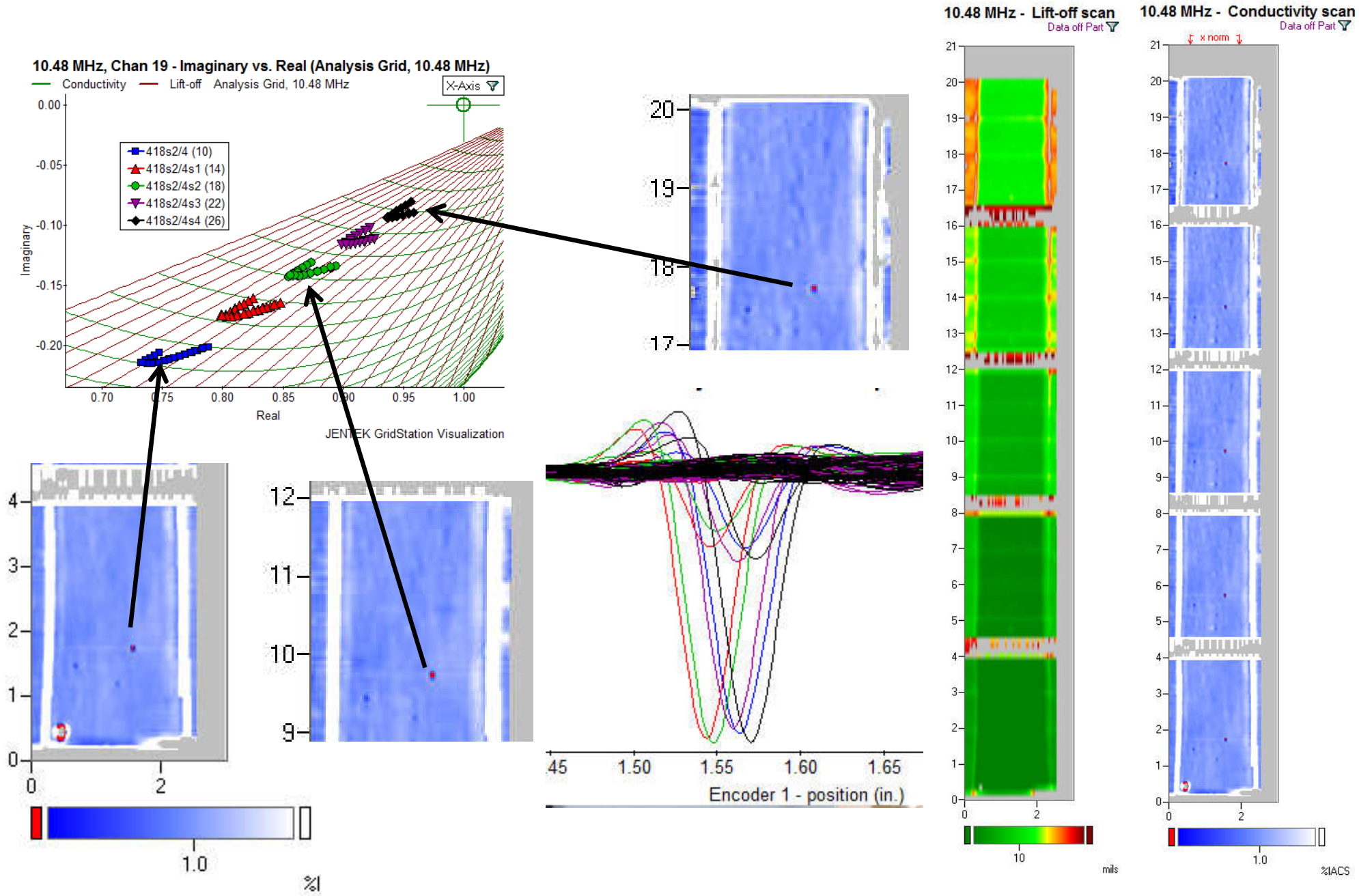


Unfiltered and Filtered B-Scans

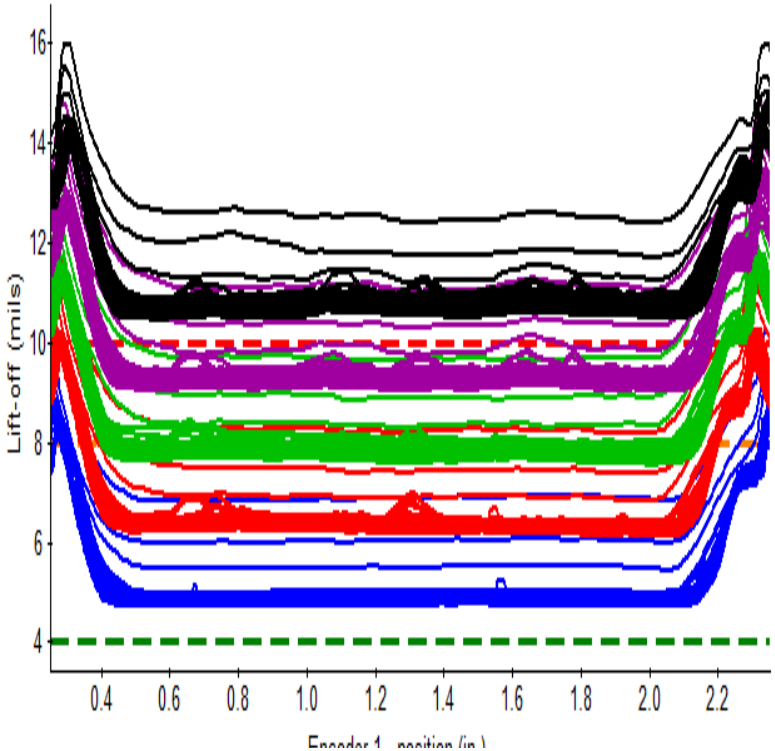


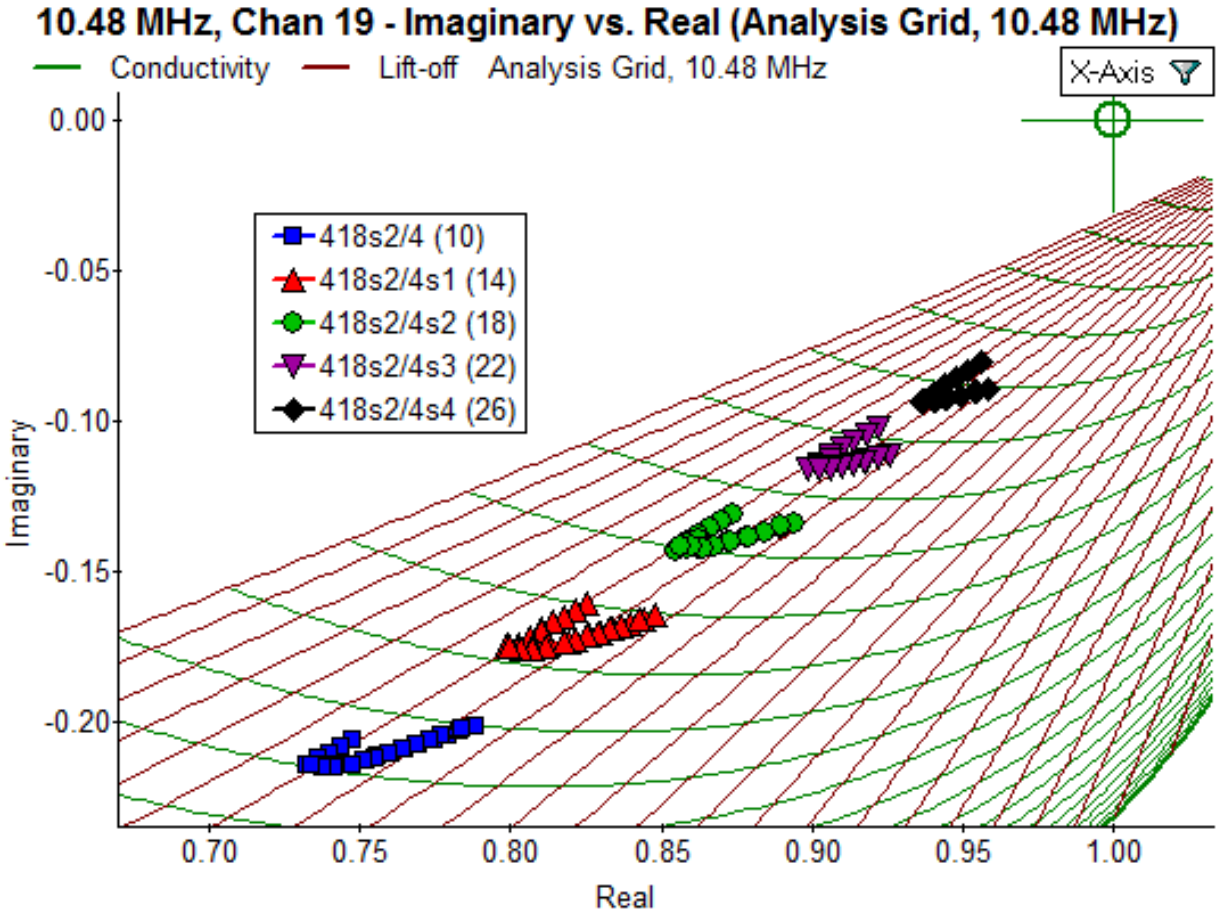
Unfiltered and Filtered C-Scans

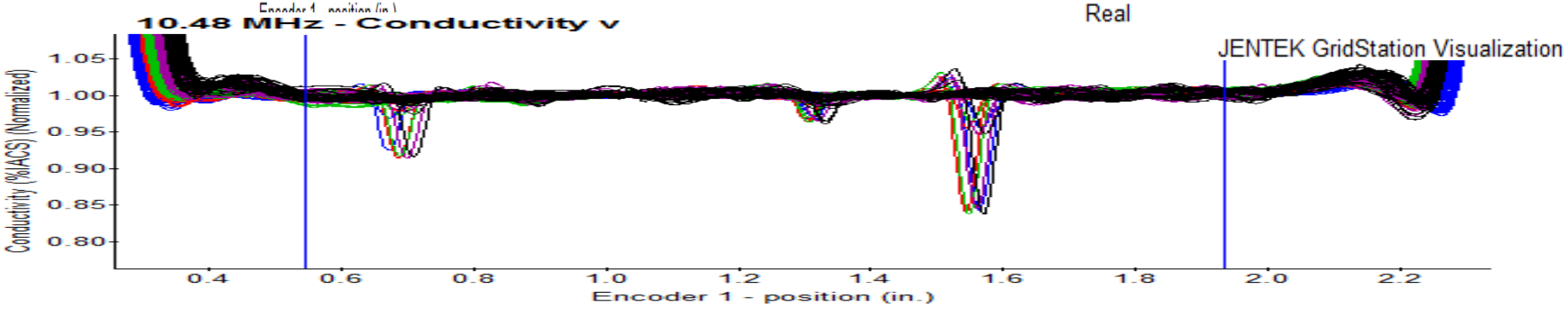
Surface Cracks: Rescaling of Conductivity Response



Surface Cracks: Rescaling of Conductivity Response

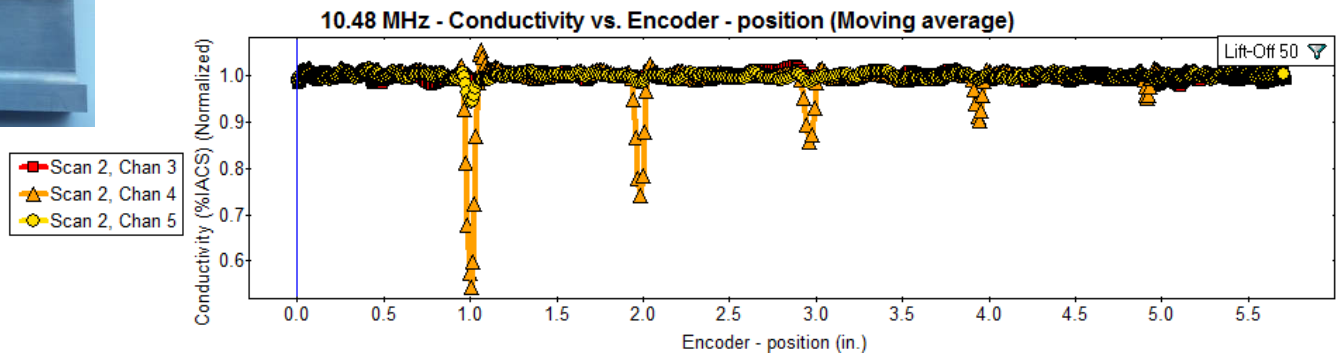


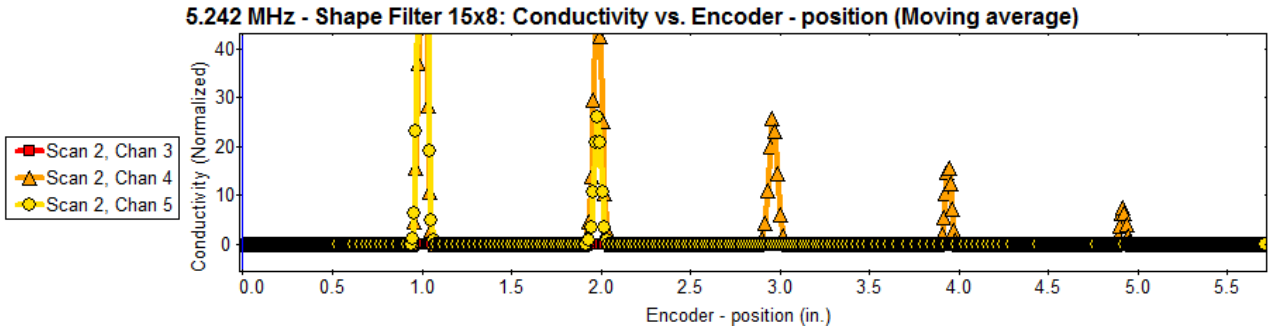


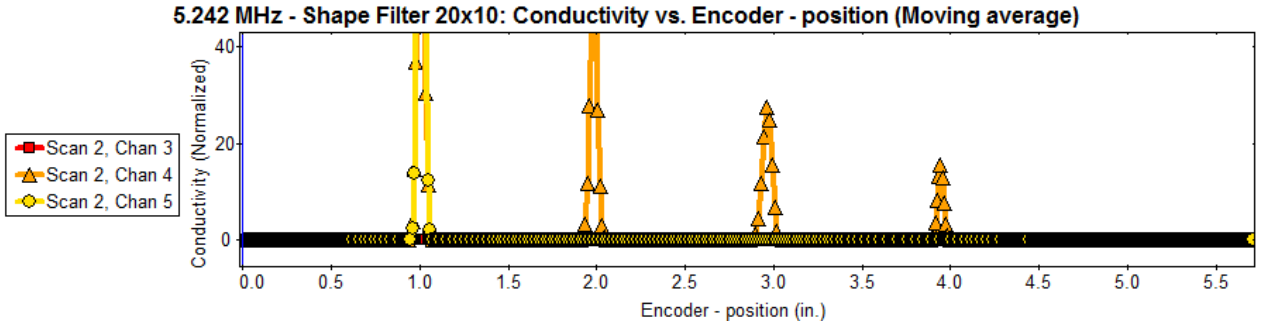


Titanium Alloy Unfiltered and Shape Filtered Results

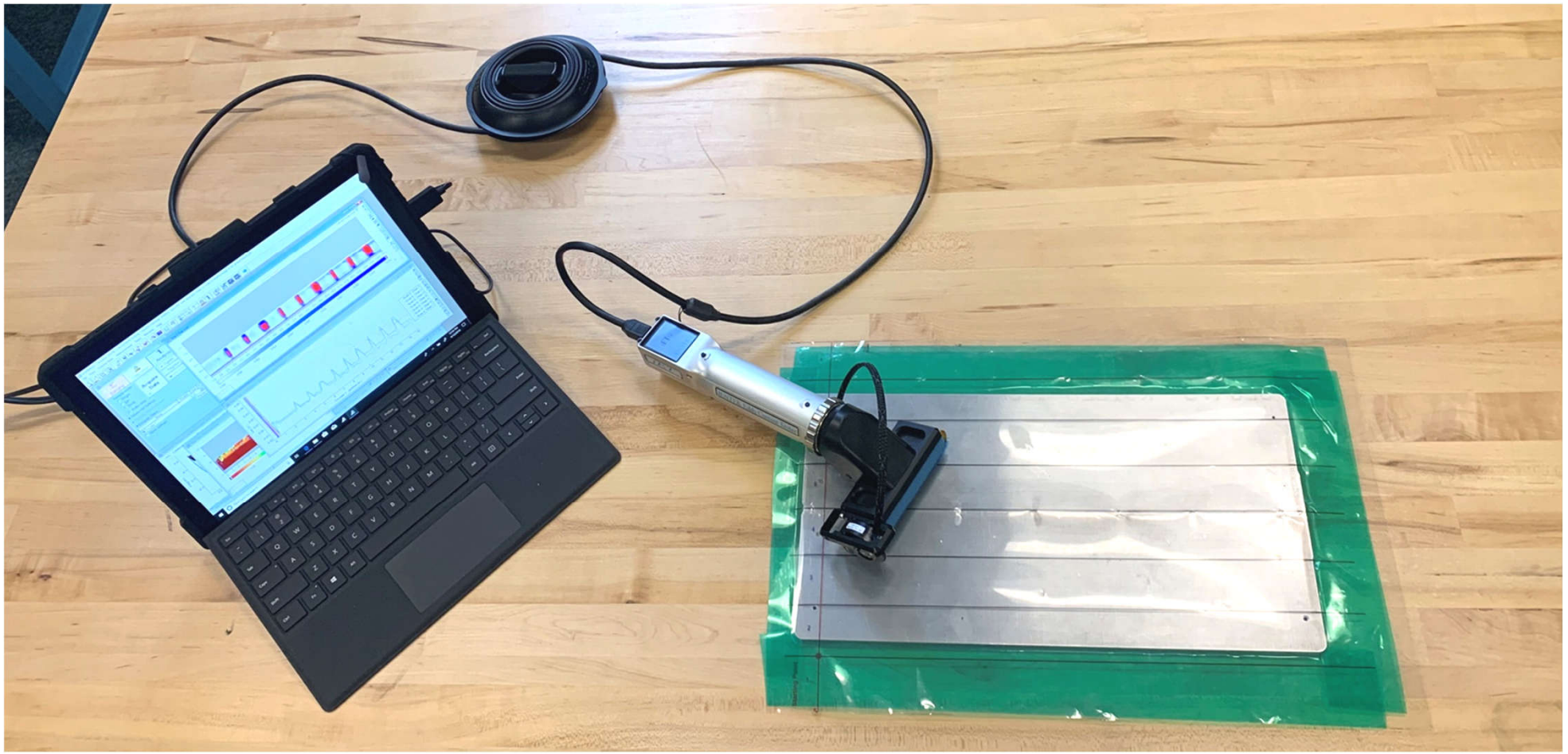
EDM Notch Sizes:	length	0.06	0.04	0.03	0.02	0.015
	depth	x0.03	x0.02	x0.015	x0.01	x0.0075



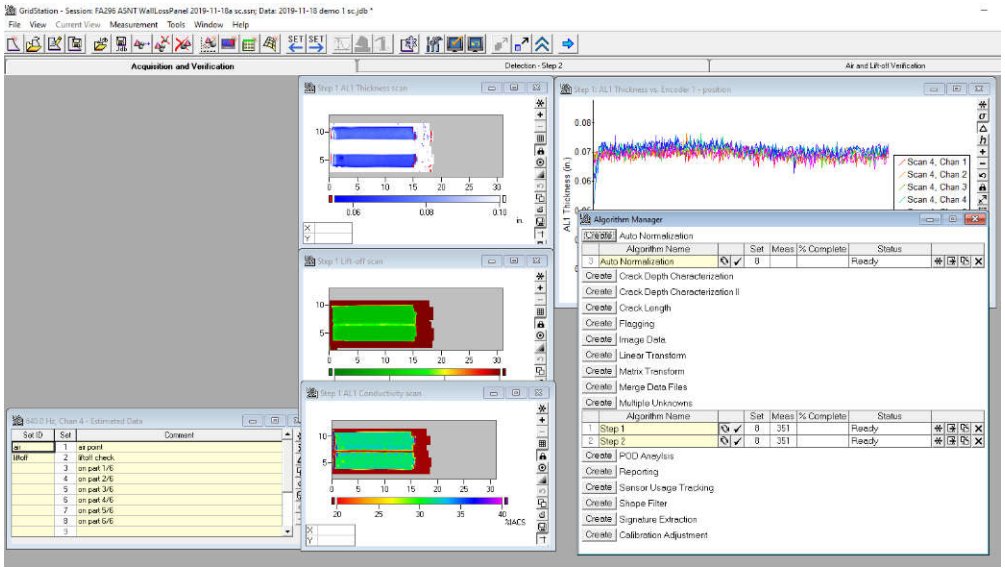




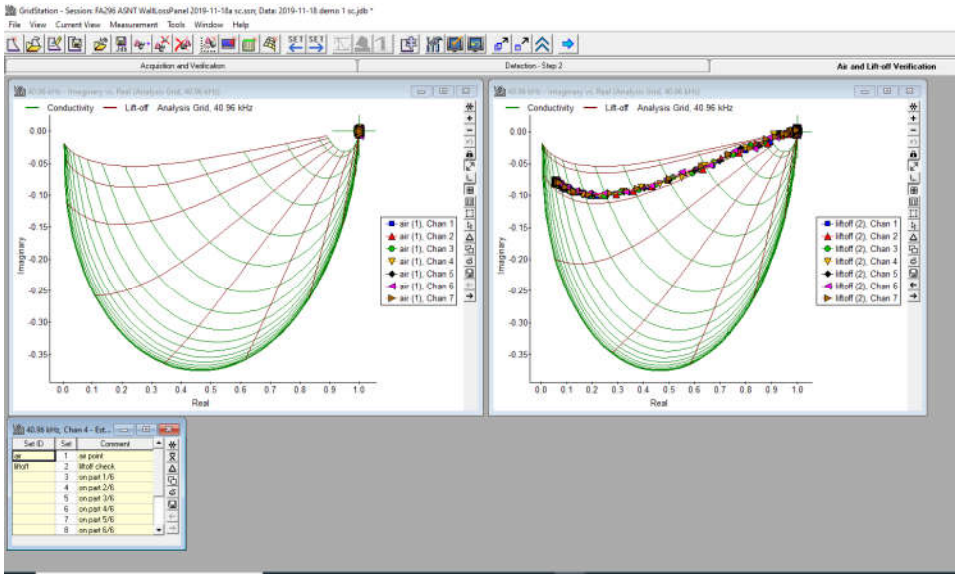
I.6: Corrosion Imaging Performance Study Ongoing



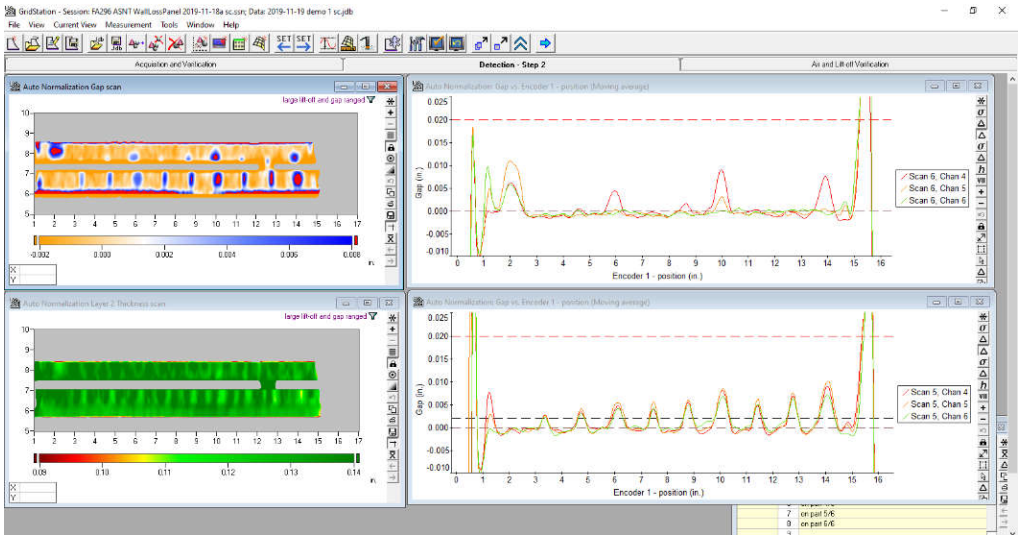
I.6: Corrosion Loss Imaging and POI Verification



Liftoff & coverage verification

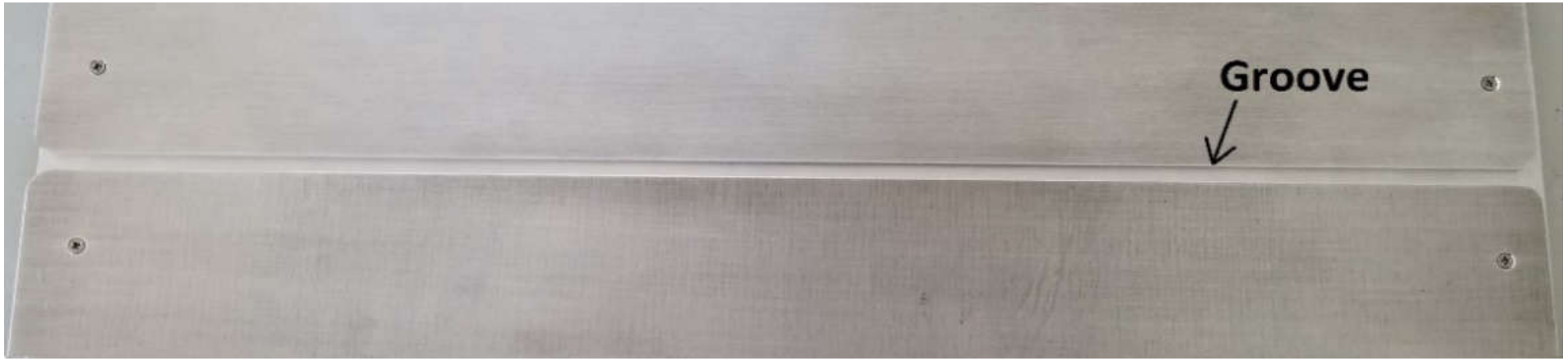


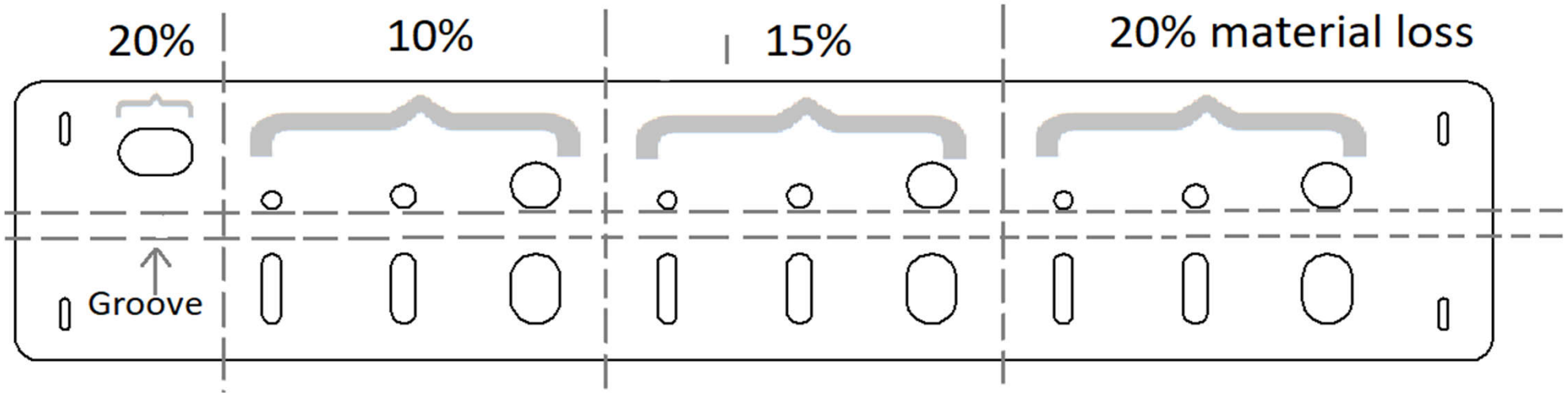
Air Calibration & Cal Check (Air and liftoff)



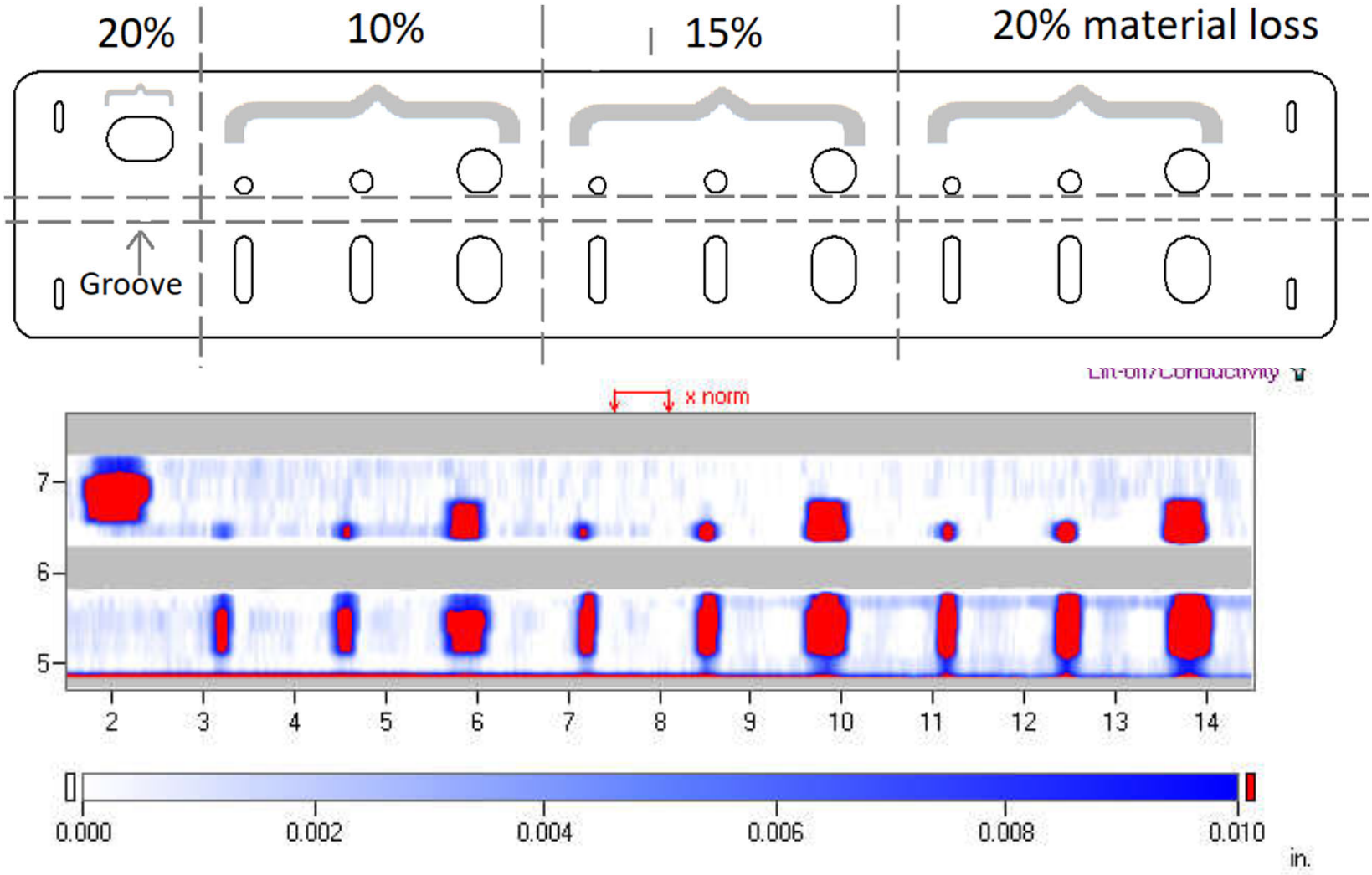
C-Scan and B-Scan data visualizations

I.6: 15 inch Corrosion Loss Sample



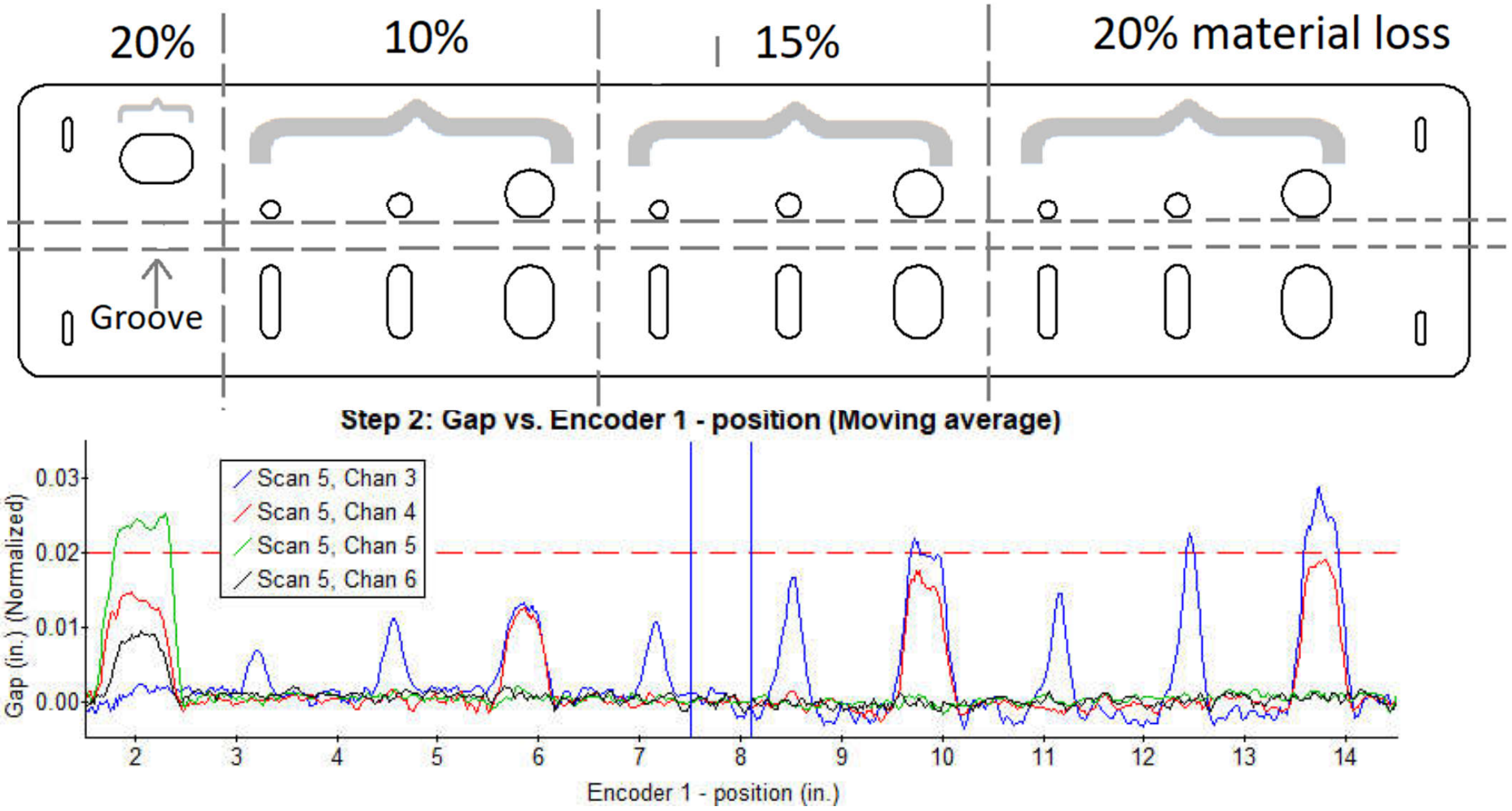


I.6: FA296: 15 inch Corrosion Loss Sample (1)



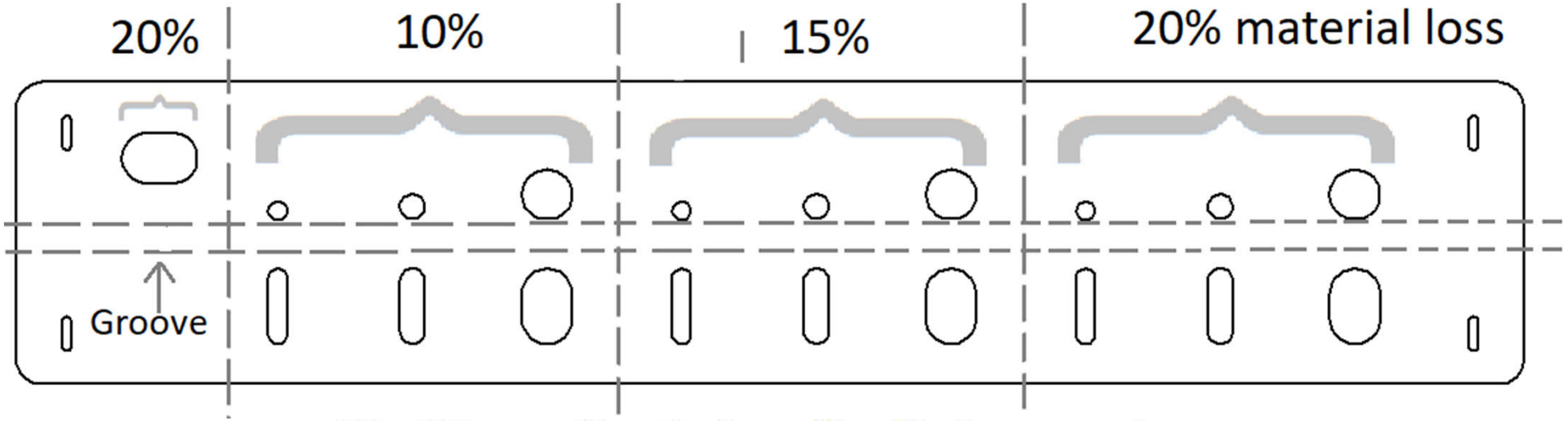
Filtered and normalized C-scan of Gap data across the corrosion defect locations.

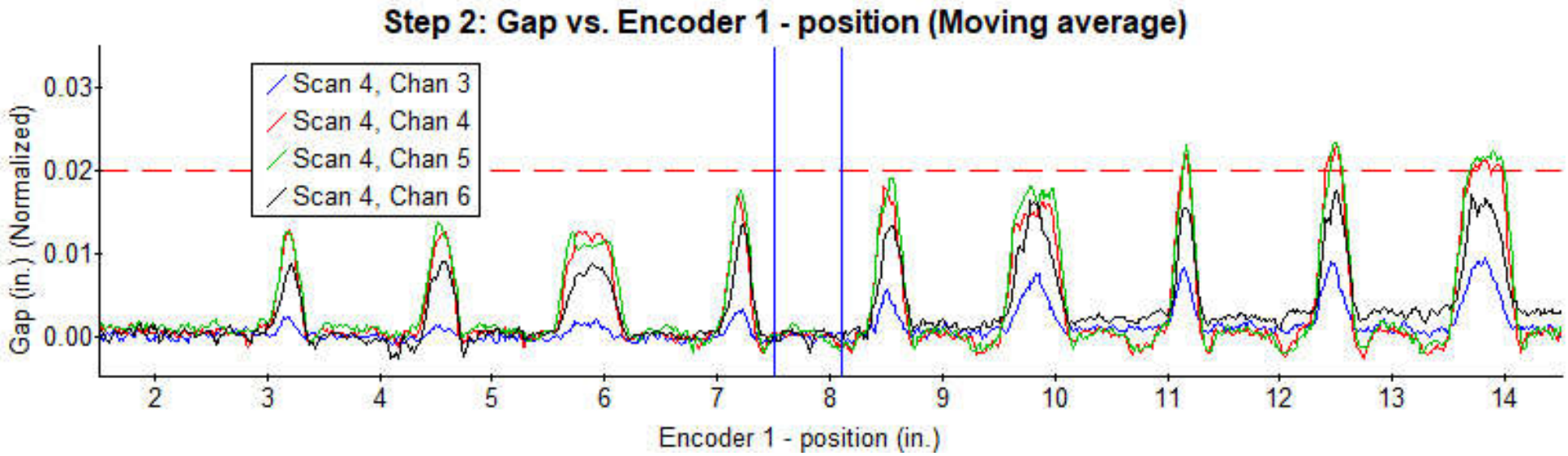
I.6: FA296: 15 inch Corrosion Loss Sample Holes (2)



Normalized B-scan of Gap data across the flat bottom hole defect locations.

I.6: FA296: 15 inch Corrosion Loss Sample Slots (3)





Normalized B-scan of Gap data across the flat bottom slot defect locations.

Currently Funded Transition Programs (continued)

- Weld inspection for spacecraft
  - Friction Stir Welds
    - POD studies completed at scan speeds up to 10 in./second
    - Replacement for LPI
  - Volumetric Weld Inspection
    - For complex geometries
    - Surface and buried defects
  - Enhanced Portability of GS8200 (“Backpack Portable”)

Currently Funded Transition Programs (continued)

- In-Situ layer-by-layer sensing for Additive Manufacturing
  - Two customer funded initiatives ongoing (LPBF, DED)
  - Fully integrated pilot line testing planned for 2022
- Cold Spray coating characterization
  - Production qualification completed for one application
  - Sustainment application development ongoign
- Upgrades to engine component inspections
  - jET validation ongoing for propeller cold work upgrade
  - GS8200 upgrade pending for disk slot inspections

Summary

- Substantial upgrades are ongoing to the MWM-Array for depot/production, field and embedded applications
- Currently Funded Transition Programs include
  - **Bolt-Hole inspection for aircraft (New capability)**
  - Surface and buried crack detection away from holes
  - Corrosion imaging for aircraft
  - Weld inspection for spacecraft
  - **In-Situ layer-by-layer sensing for Additive Manufacturing (New capability)**
  - Cold Spray coating characterization
  - Upgrades to engine component inspections