Mapping & Tracking Properties of Next Generation Space Vehicle Materials

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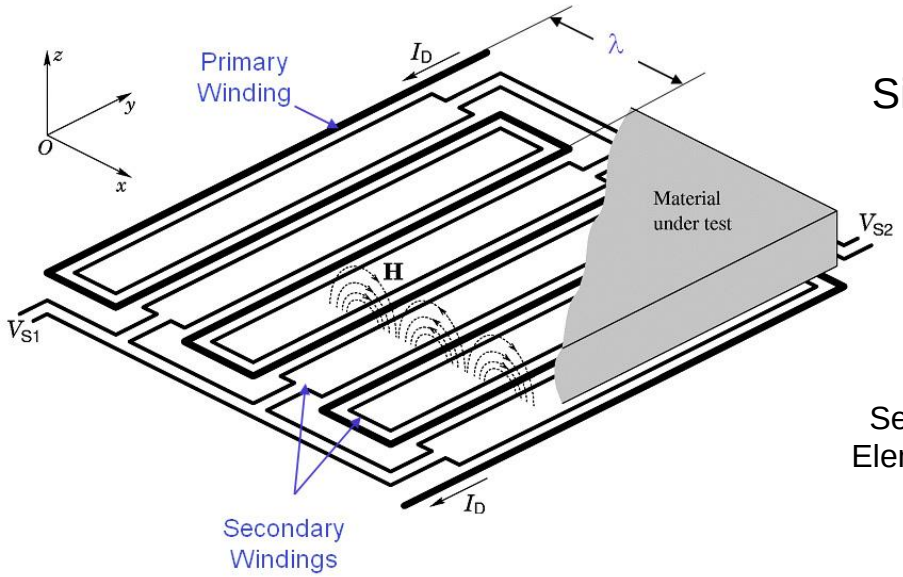
Outline

- MWM®-Array Imaging
- New Magneto-Thermography™ Method (Patents pending)
- Mapping & Tracking using Time-Sequenced Imaging
- Case Studies
  - Titanium Fatigue
    - Cracks at Mechanical Damage Site
    - Bolt Hole Inspection
  - Reinforced Carbon-Carbon Composite
  - Graphite Fiber Composite Damage
    - MWM-Arrays for Disbonds/Delaminations/Fiber Damage
  - Steel Fatigue and Stress Corrosion Cracking (SCC)
- Summary and Future Work

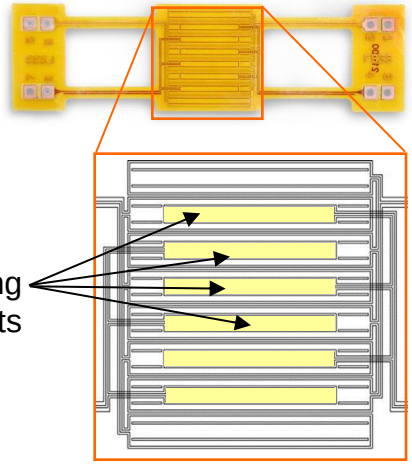
MWM® and MWM®-Array Sensors

Meandering Winding Magnetometer (MWM)



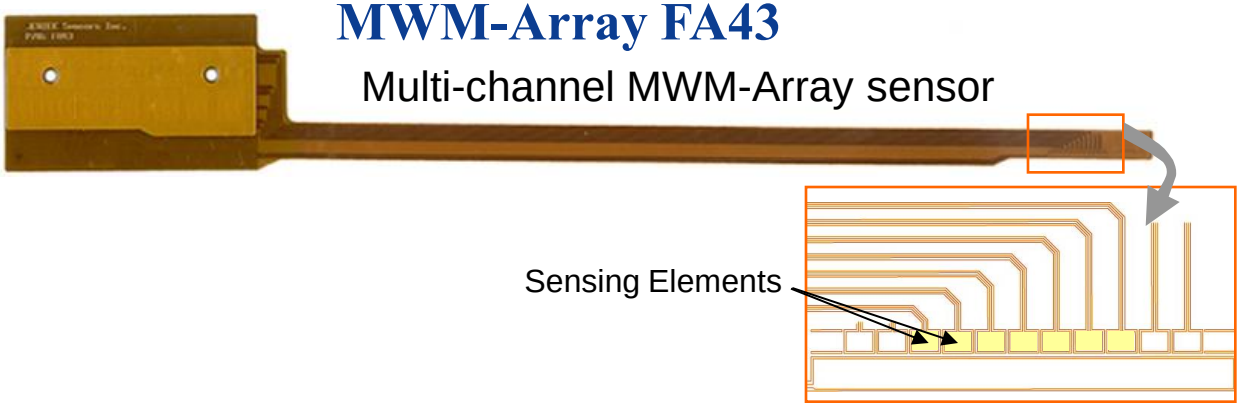
MWM FS33

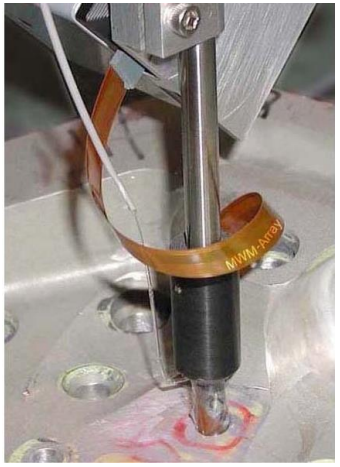
Single-channel MWM sensor



MWM-Array FA43

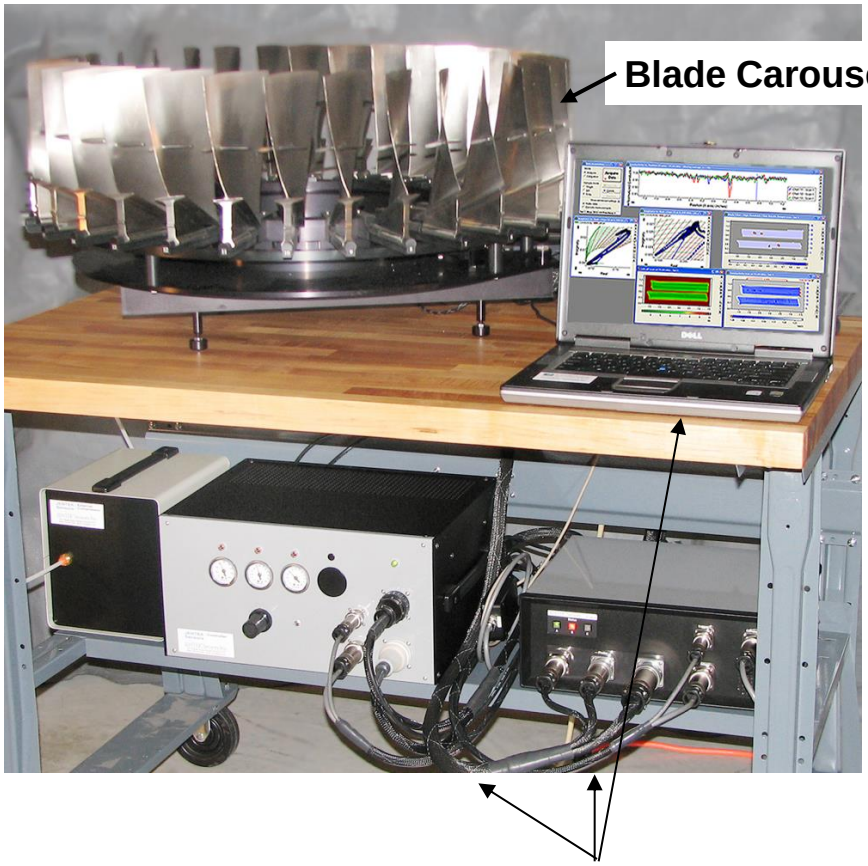
Multi-channel MWM-Array sensor



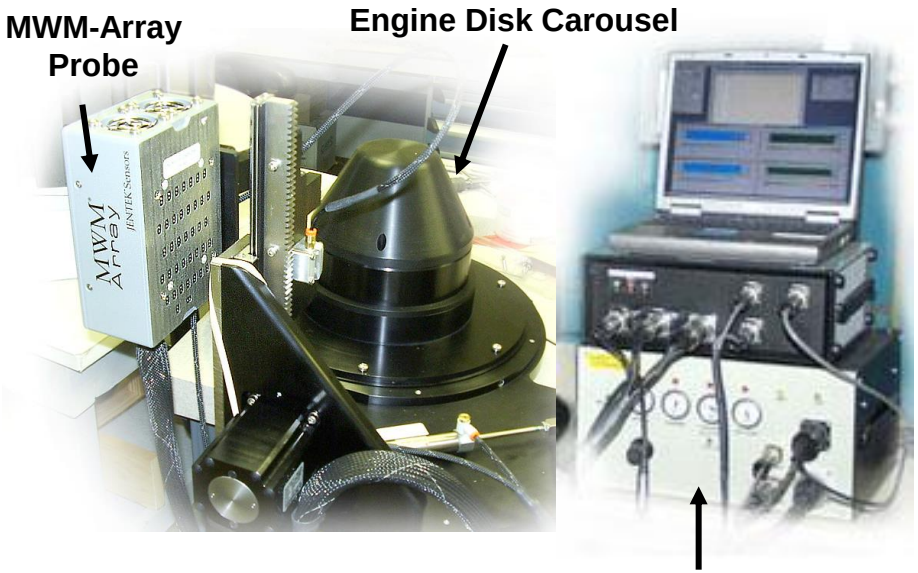


High Resolution MWM-Array Scanning for Engine Components

Blade Dovetail Inspection



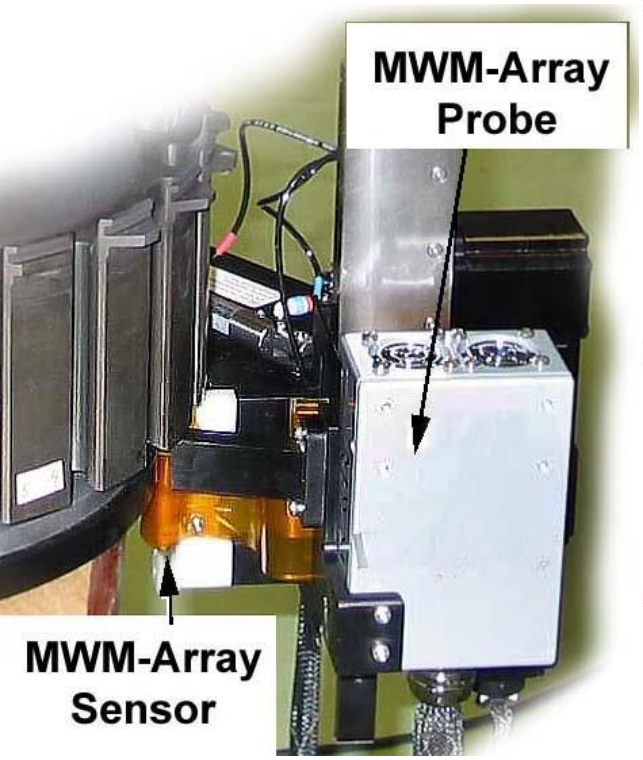
Engine Disk Slot Inspection



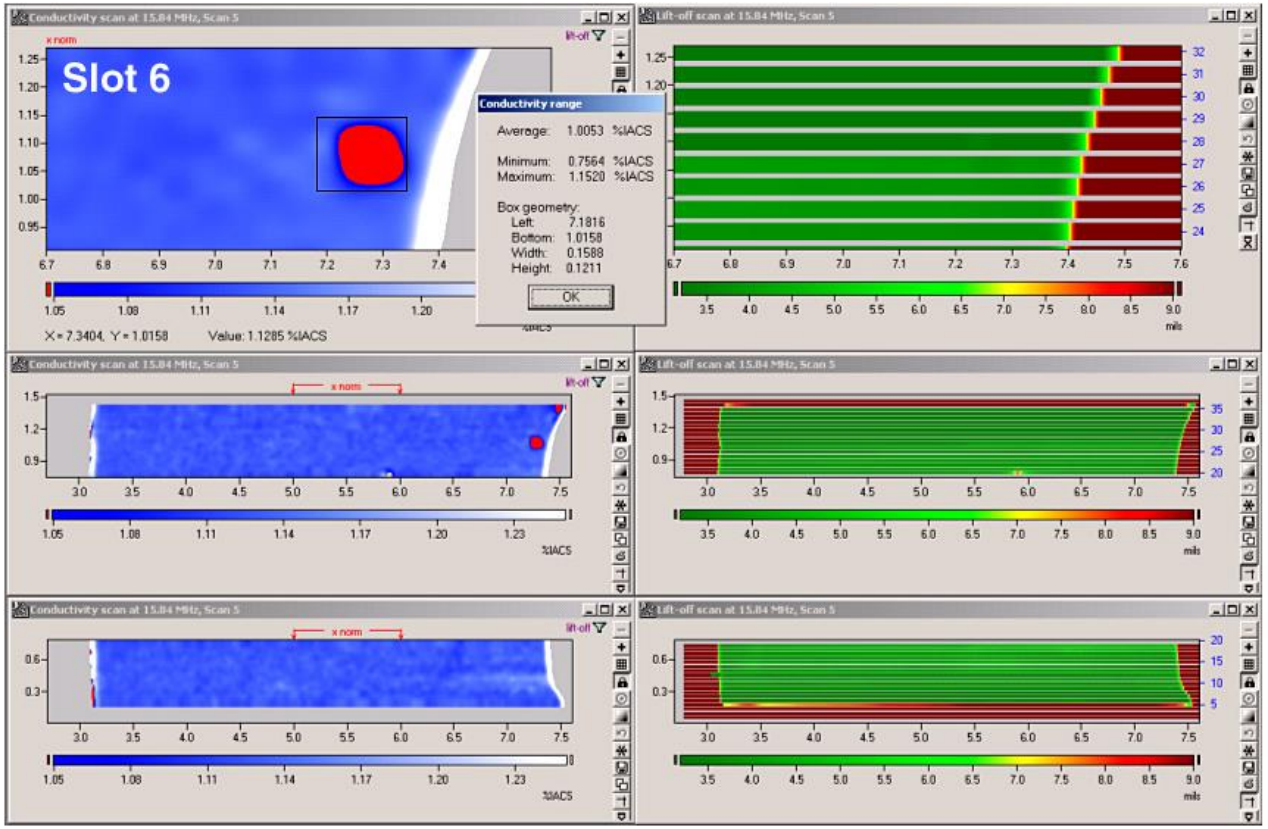
Automated Engine Disk Inspection System

Presented at ASNT Fall, Oct 2006

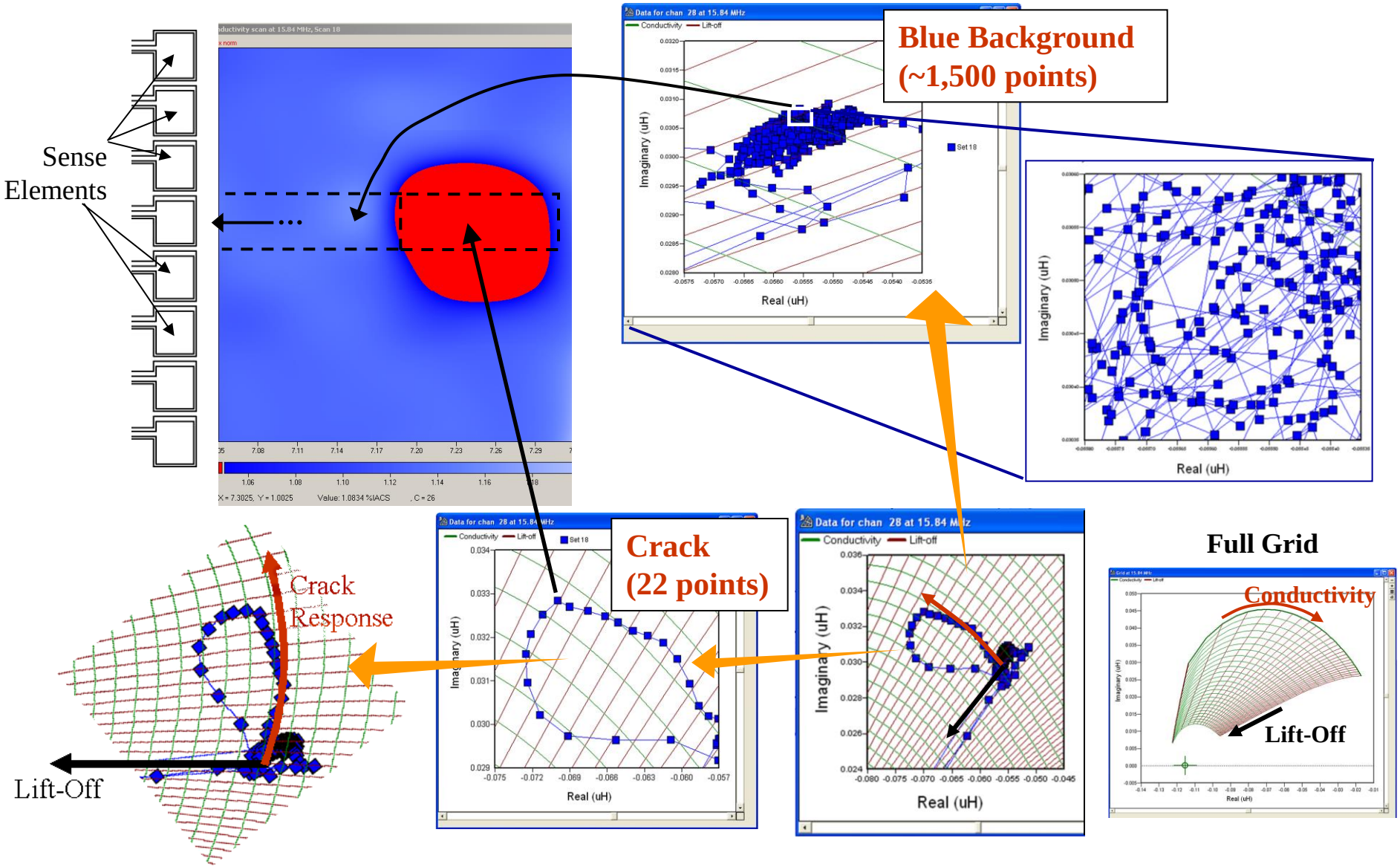
- In-use at NAVAIR Depot since April 2005
- Nine disks with verified cracks detected, several of these large and small cracks not detected by conventional ET and LPT
- No false indications (over 3000 slots inspected), false indication rate <0.04



Conductivity **Lift-Off**



Rapid Data Processing with Grid Methods and "Air" Calibration



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New Magneto-Thermography™ Method

- Developed by JENTEK (patents issued and pending)
- New Phase I SBIR (ongoing for composites)
- JENTEK IR&D (ongoing for metals)

New Magneto-Thermography Method
(Patents pending)

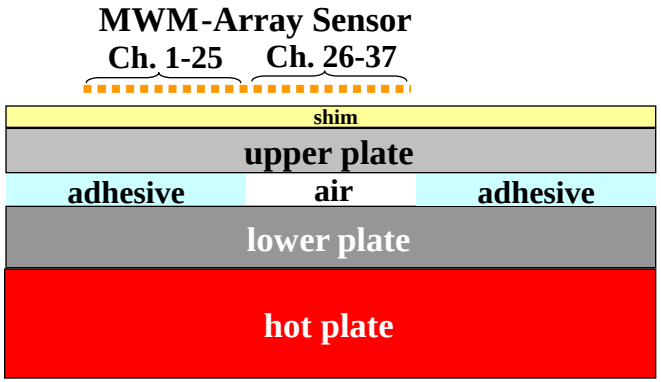
- Monitor subsurface temperatures and temperatures at buried interfaces
- Reduced cost and improved portability over IR cameras
- Capability to inspect thicker structures, up to 0.75 in. or more, with higher sensitivity than conventional thermography
- Capability to inspect curved and complex structures
- Capability to measure temperatures at different depths by varying frequencies
- Capability to inspect through air gaps and coatings, for multi-layered structures

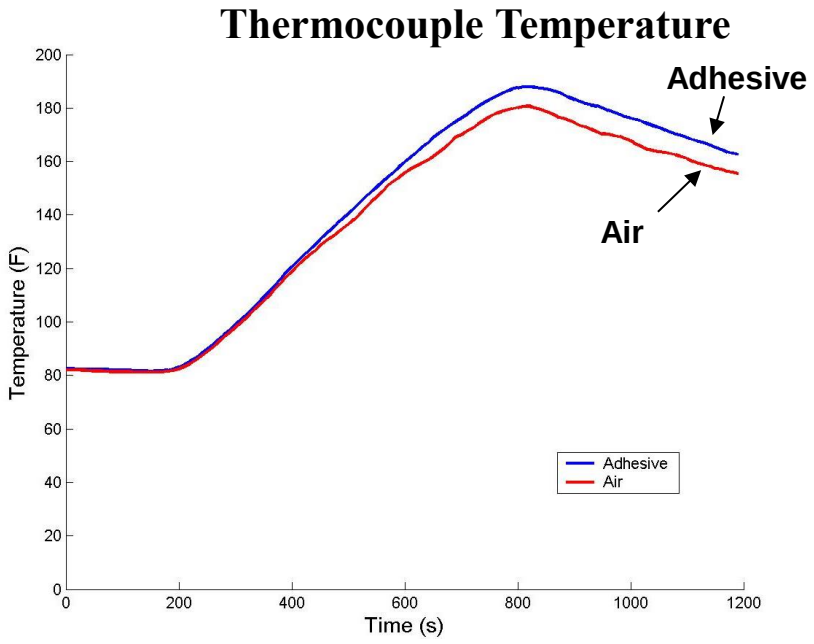
Magneto-Thermography Capability Demonstration: Metal-Metal Joint (JENTEK IR&D Project)

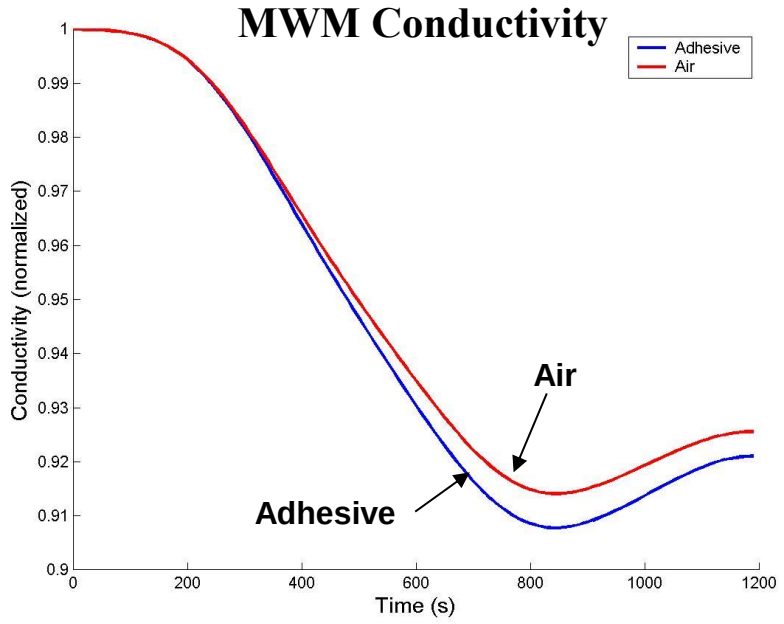
- Hot plate provides heat
- The temperature difference along the upper plate part over the adhesive and the part over air simulates a disbond
- Differences in temp. lead to differences in material conductivity
- Conductivities of both upper plate areas are measured using mounted MWM-Array sensor

$$\sigma = \frac{\sigma_0}{1 + k_c(T - T_0)}$$

k_c=thermal coefficient of resistance (/K)



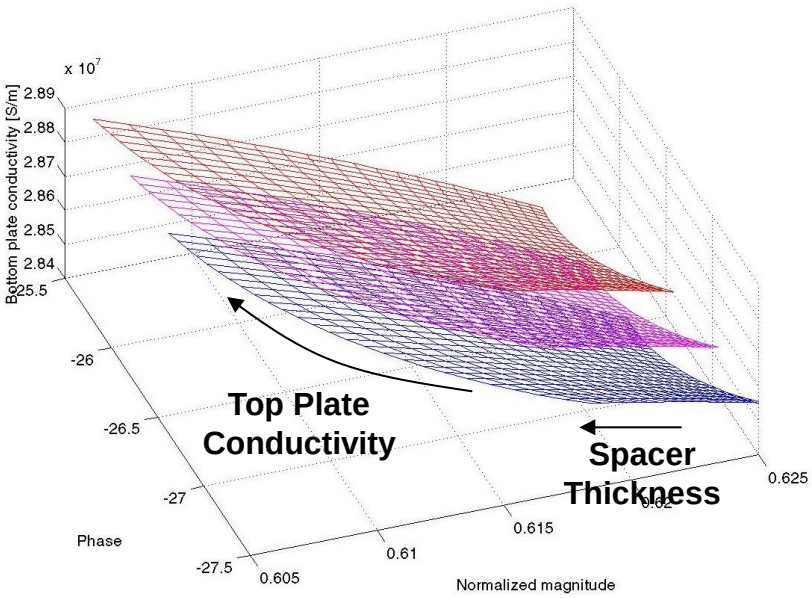


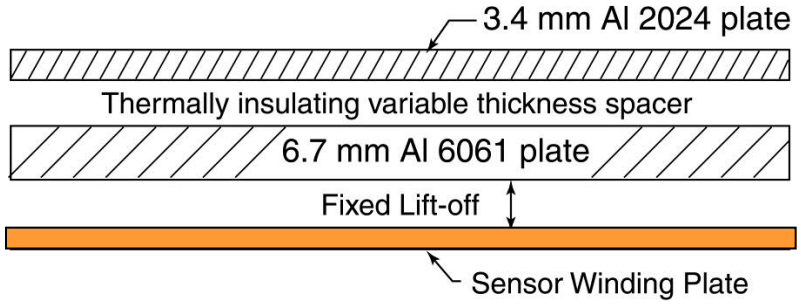


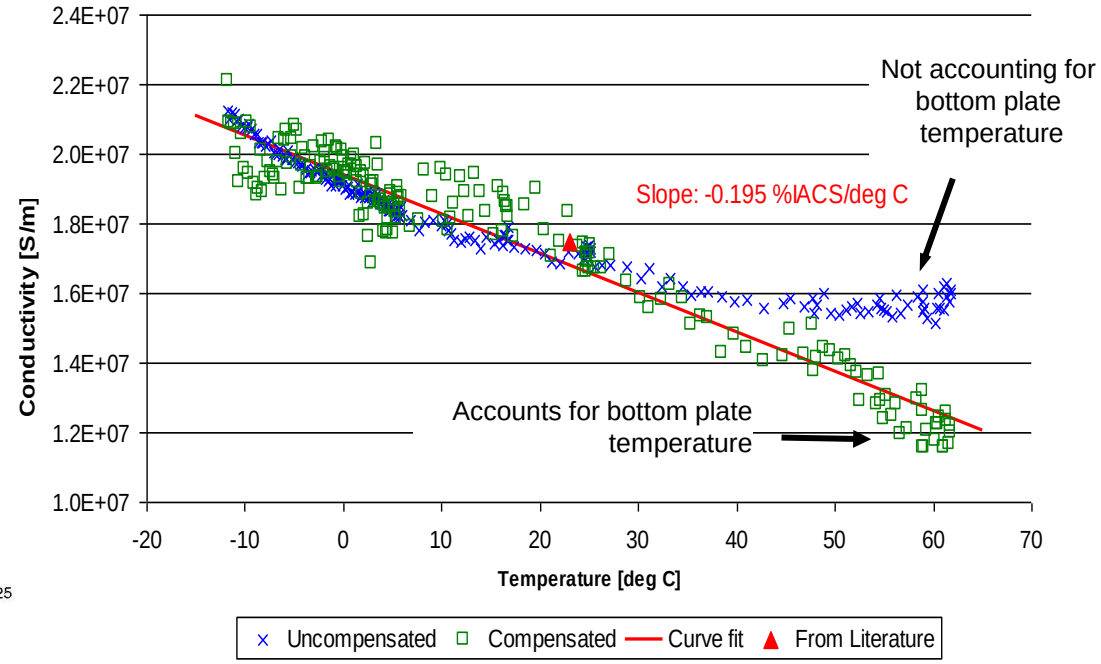
Through-Wall Temperature Monitoring

Need: Non-invasive through-wall temperature measurement at inaccessible locations

ONLY Known Solution for this Problem

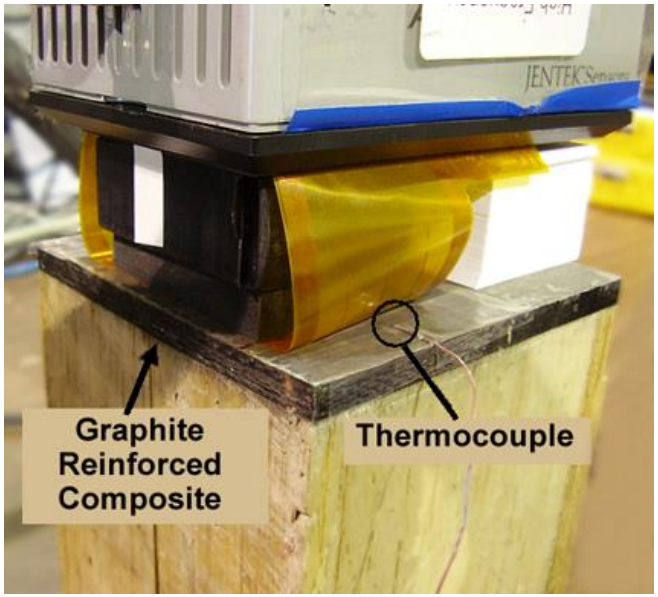


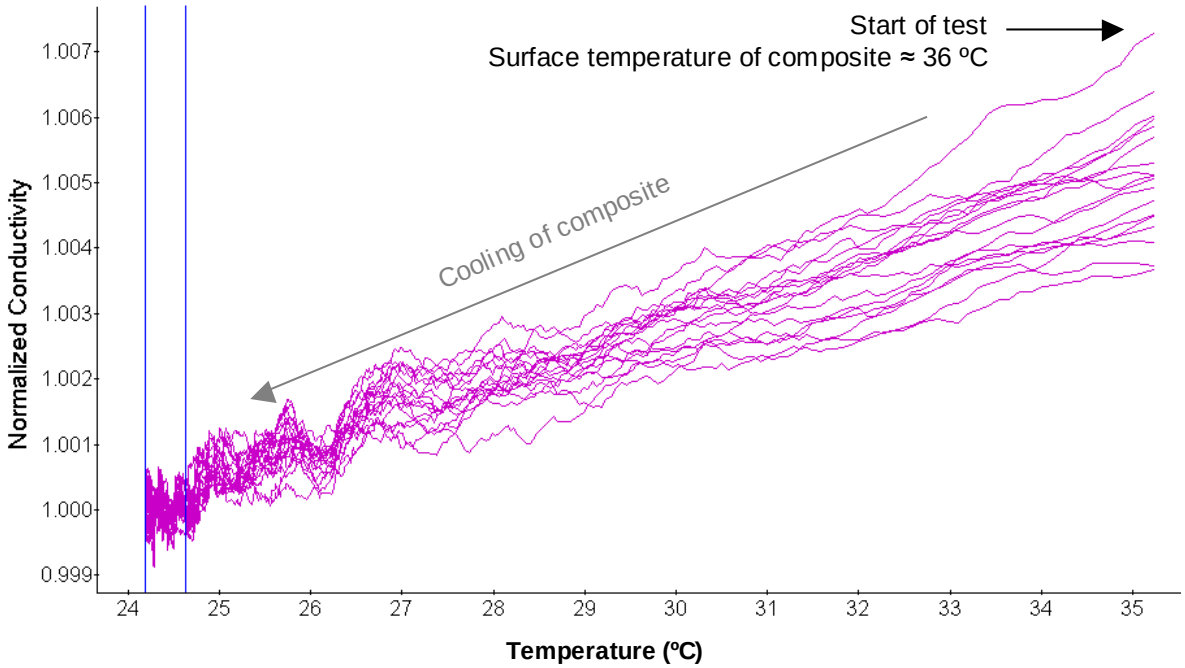




Composite Fiber Temperature Monitoring

Magneto-Thermography Feasibility Tests





Measured Temperature of Buried Fibers

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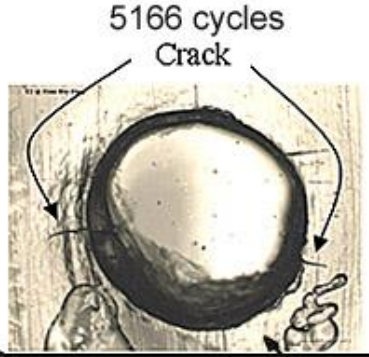
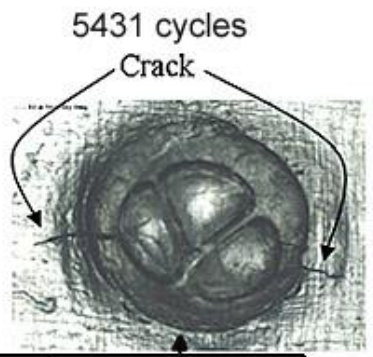
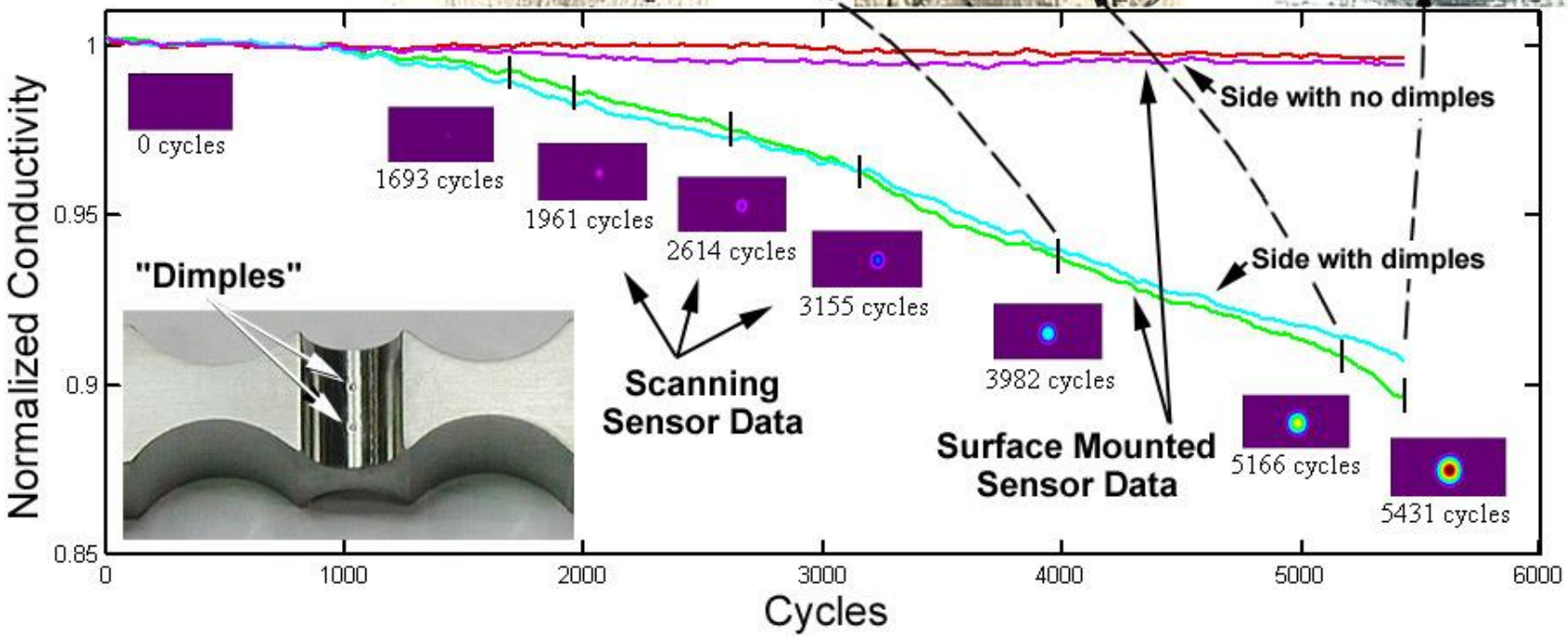
Requirements for Mapping & Tracking of Damage Initiation and Growth

- Reliable and reproducible images
- High resolution
- Position registration
- Fast
- Low cost
- Easy to use in field and depot

Mapping and Tracking of Crack Initiation and Growth at "Dings" in Ti-6Al-4V

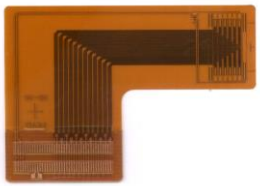


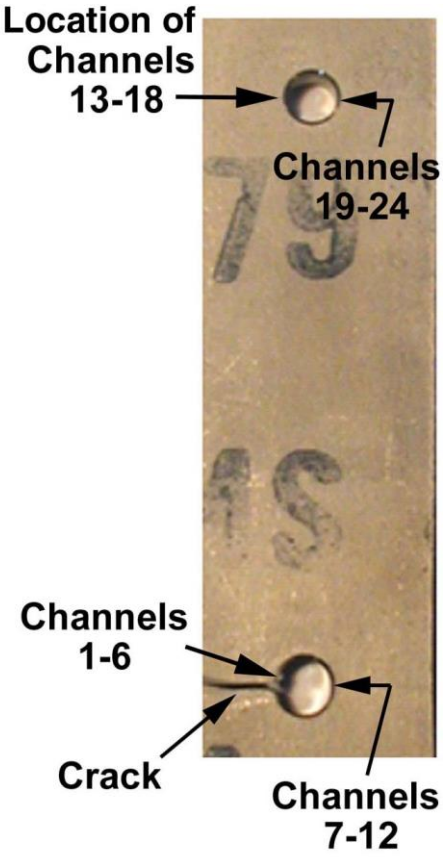


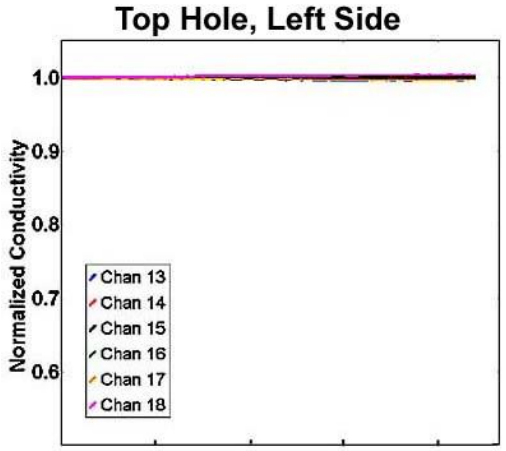


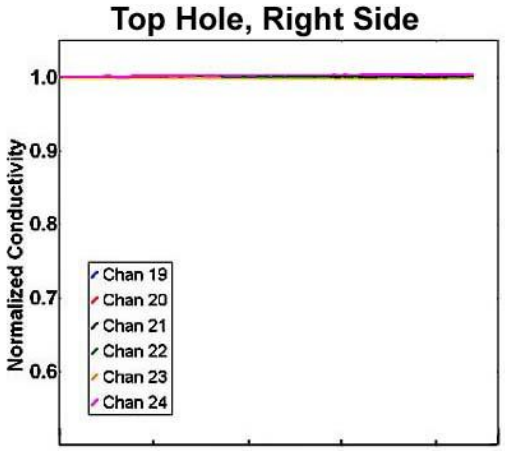
Generation of "Real Crack" Specimens

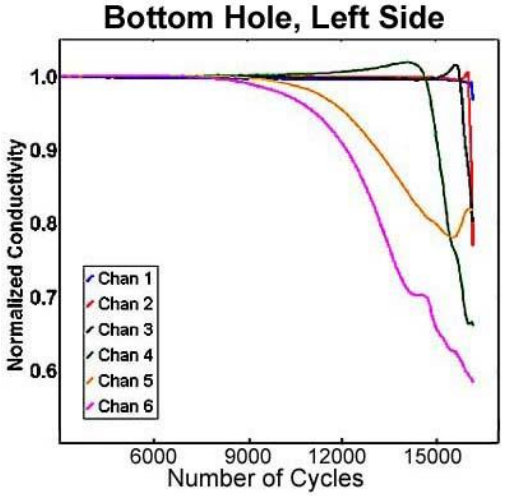
MWM-Array
FA75

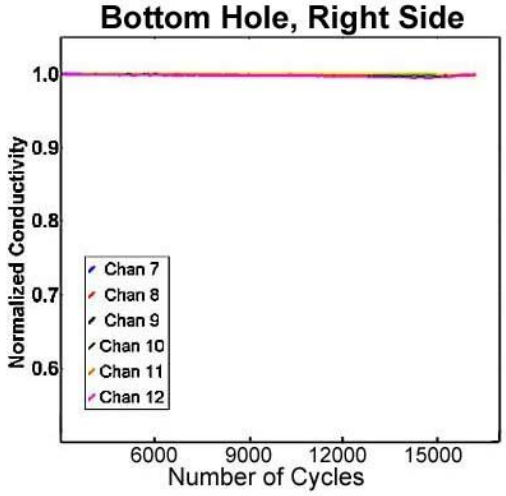




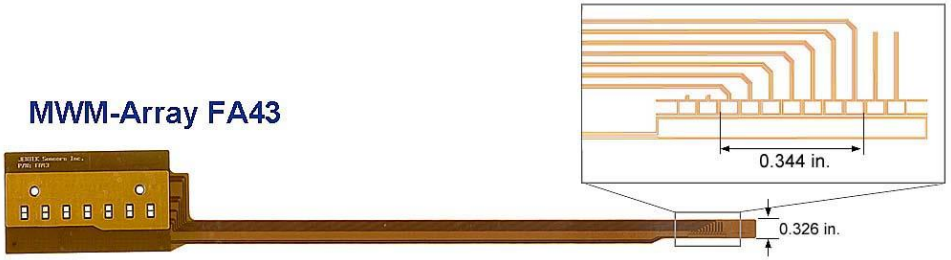


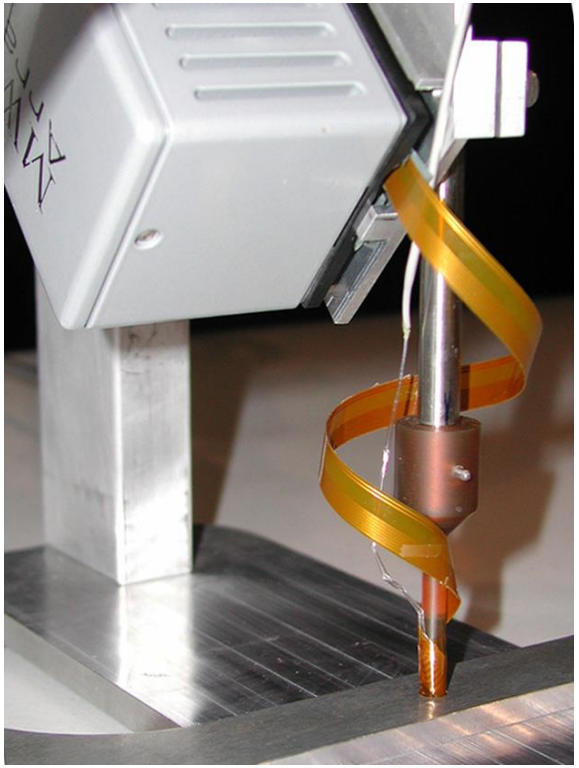


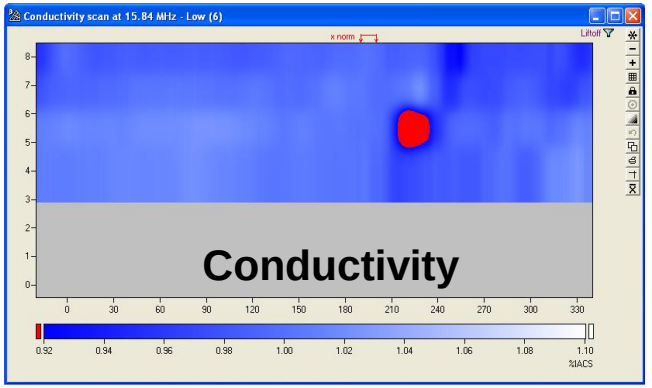


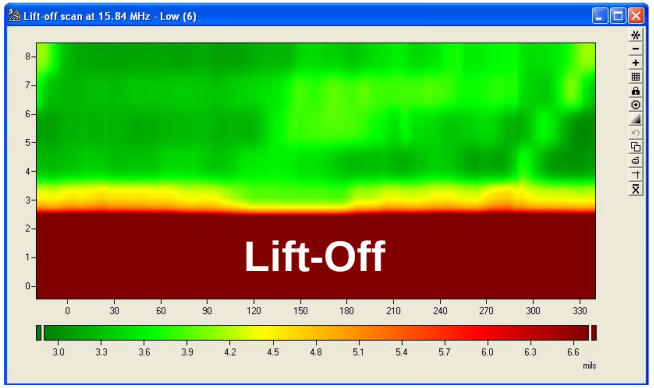


MWM-Array Scans for Bolt Hole Inspection



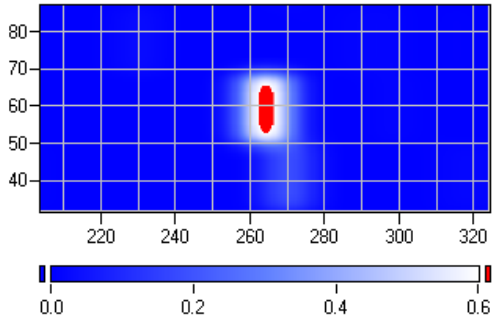


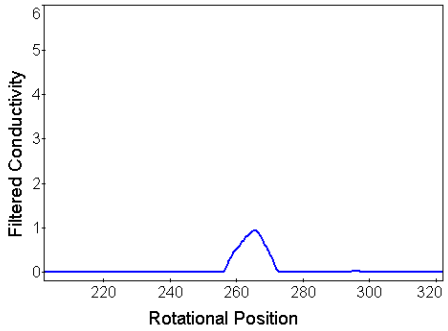




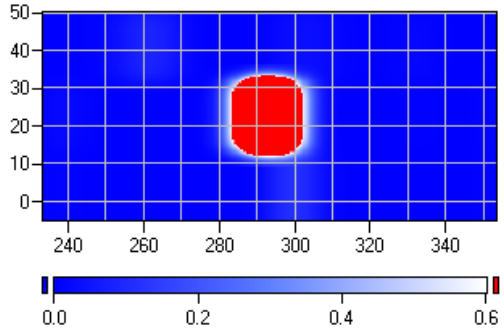
Time Sequenced Images of Crack Growth

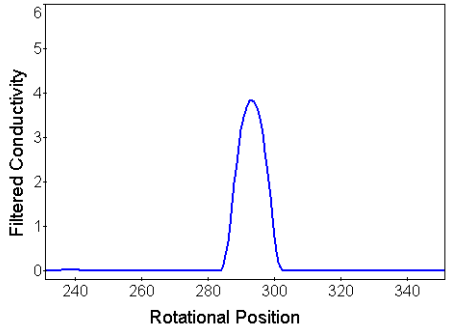
24,840 cycles
0.017 in.



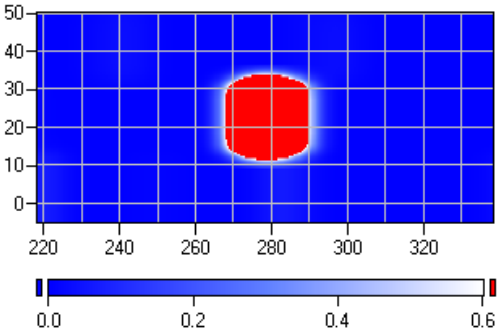


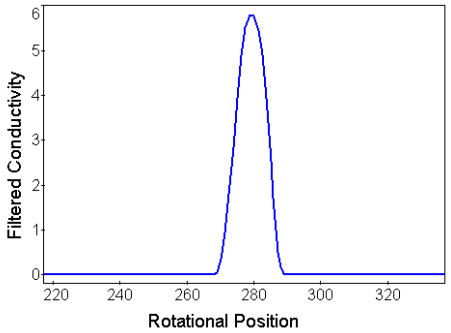
25,348 cycles
0.0205 in.





25,907 cycles
0.0259 in.





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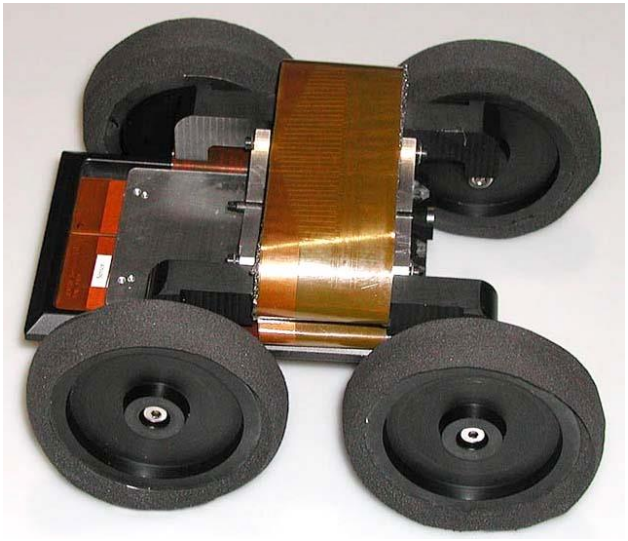
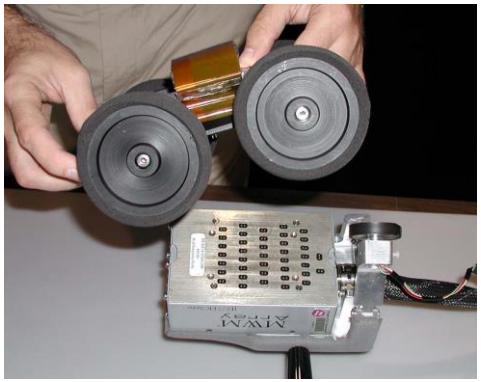
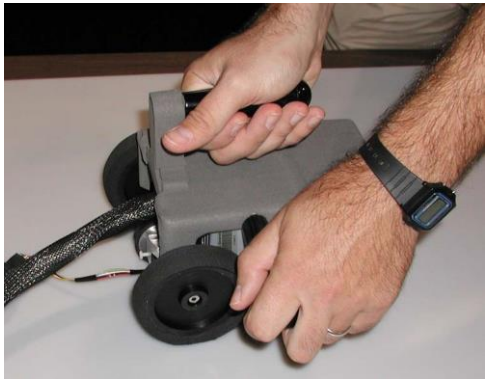
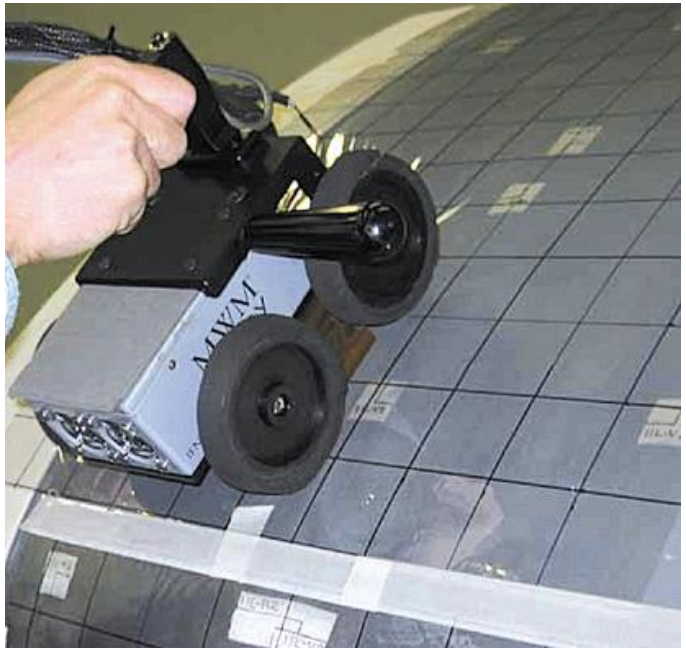
Inspection of Complex Composite Surfaces with Variable Curvatures



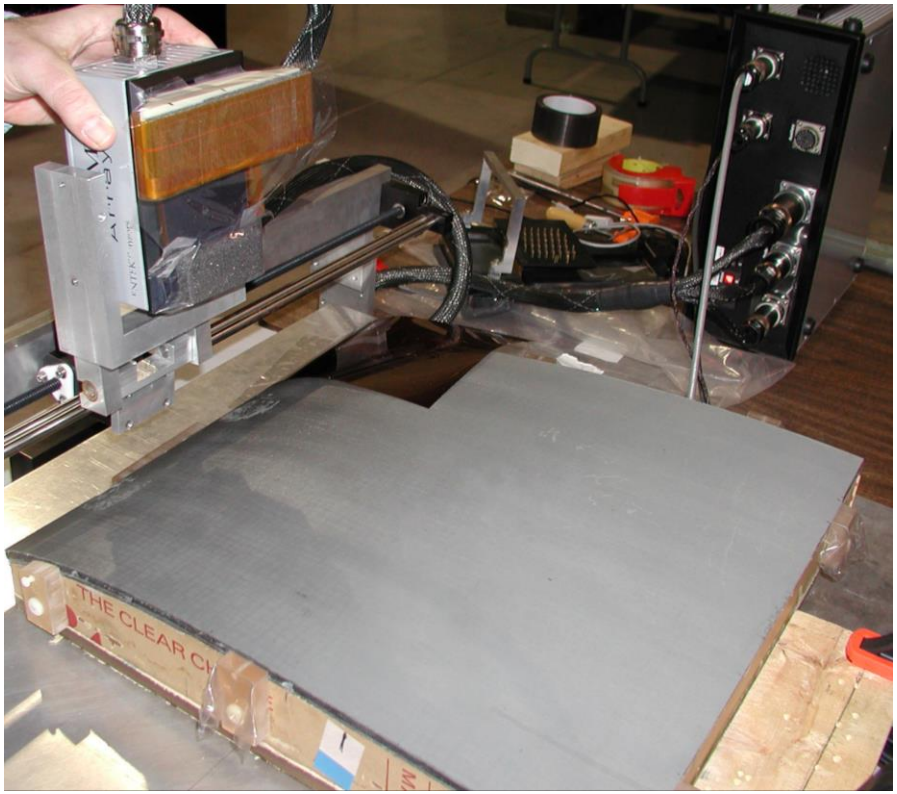




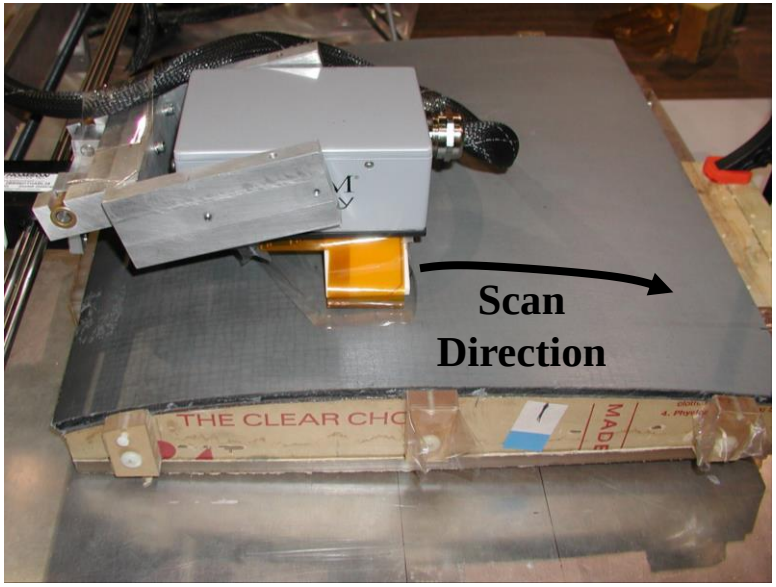


- Foam wheels protect surface
- Manual scanning for complex surfaces
- C-Scan images of wide areas built from multiple passes
- Adapts automatically to varied curvatures

Test Setup for MWM-Array RCC Inspection Validation

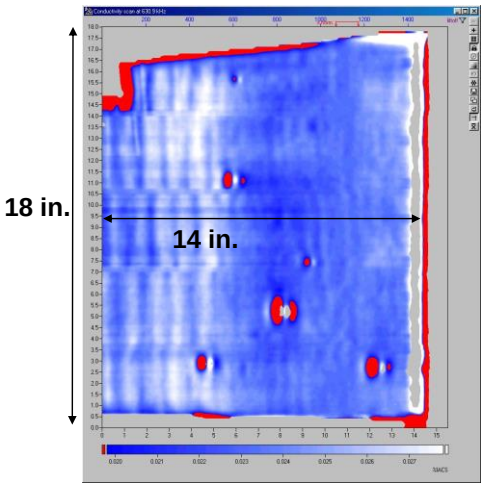


Blind Test RCC Sample Provided by NASA Langley Research Center

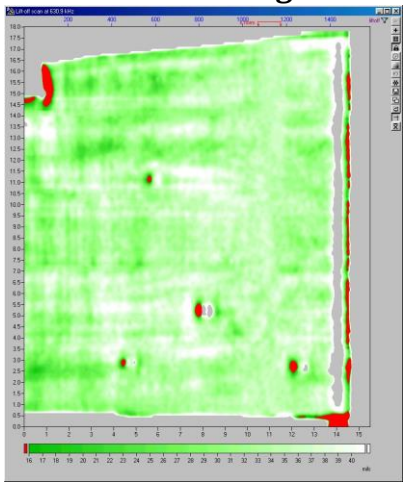


MWM-Array FA24 single-frequency scan at 1 in./sec

Conductivity Image



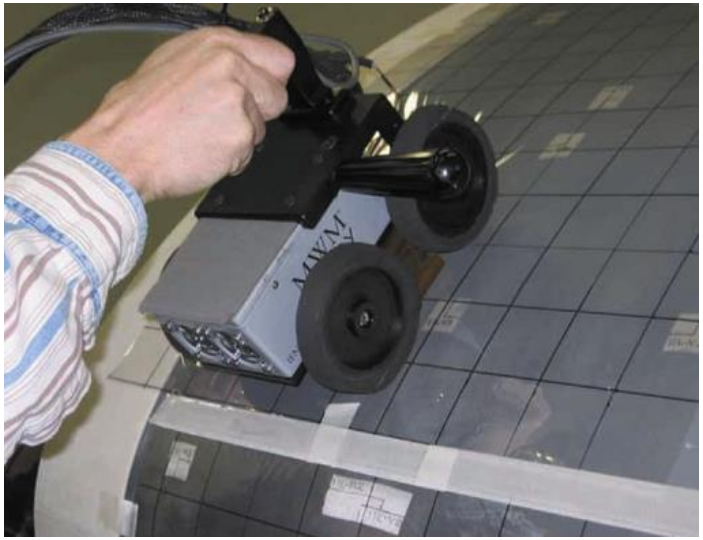
Lift-Off Image

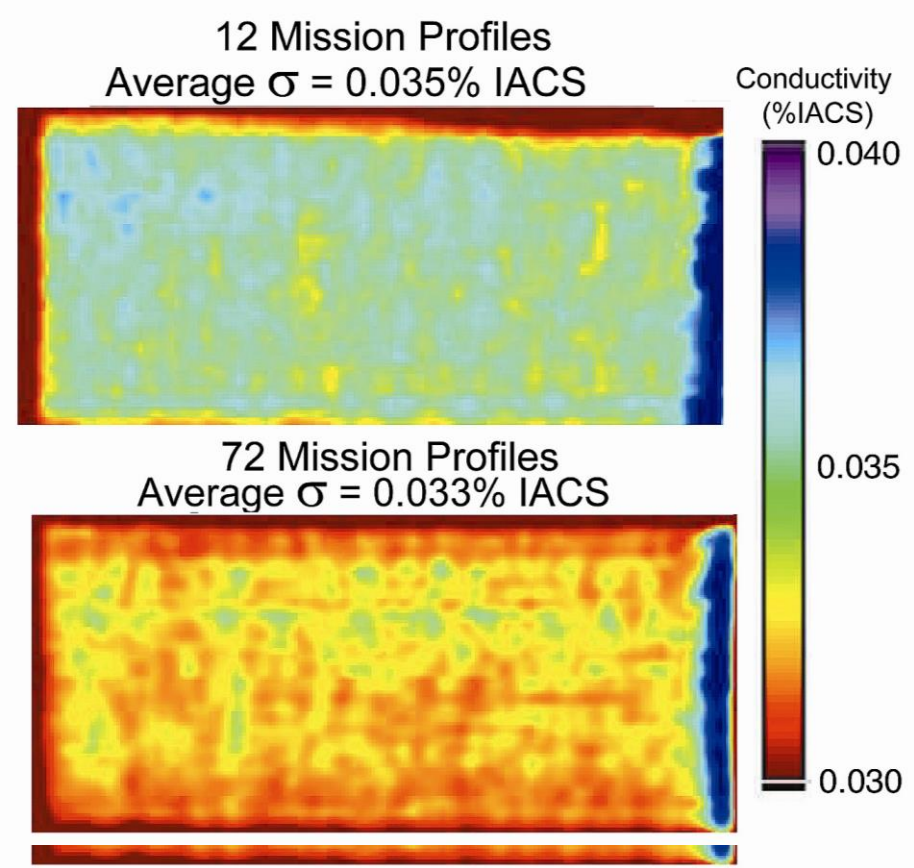


Scan Performed in 2 Minutes.

Space Shuttle Leading Edge Conductivity Mapping of RCC

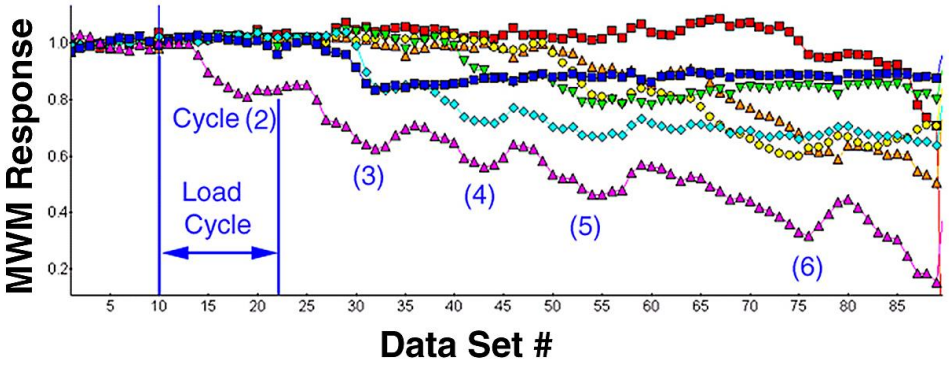
MWM-Array for Inspecting Complex Composite Surfaces with Variable Curvature



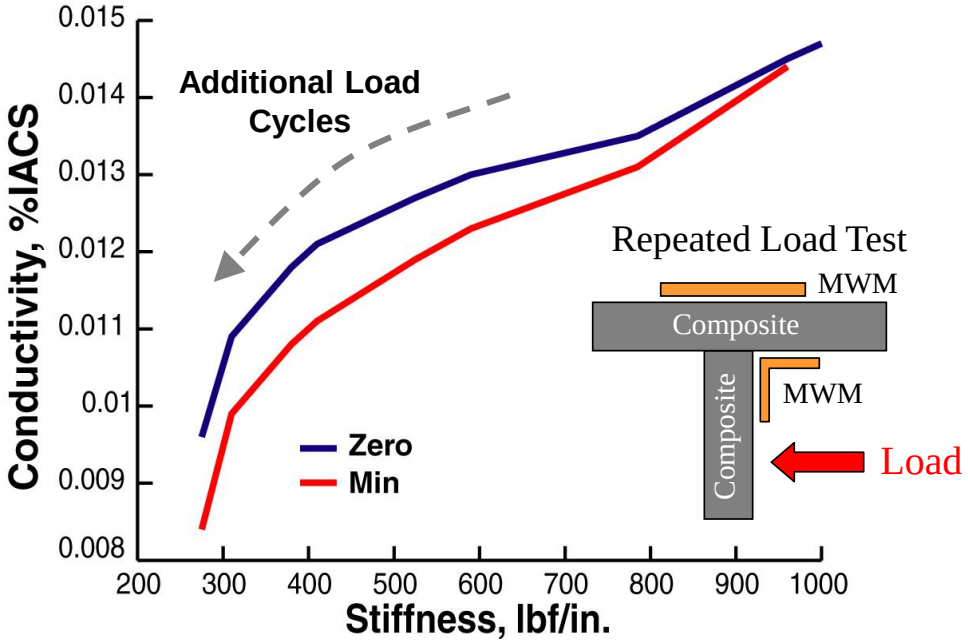


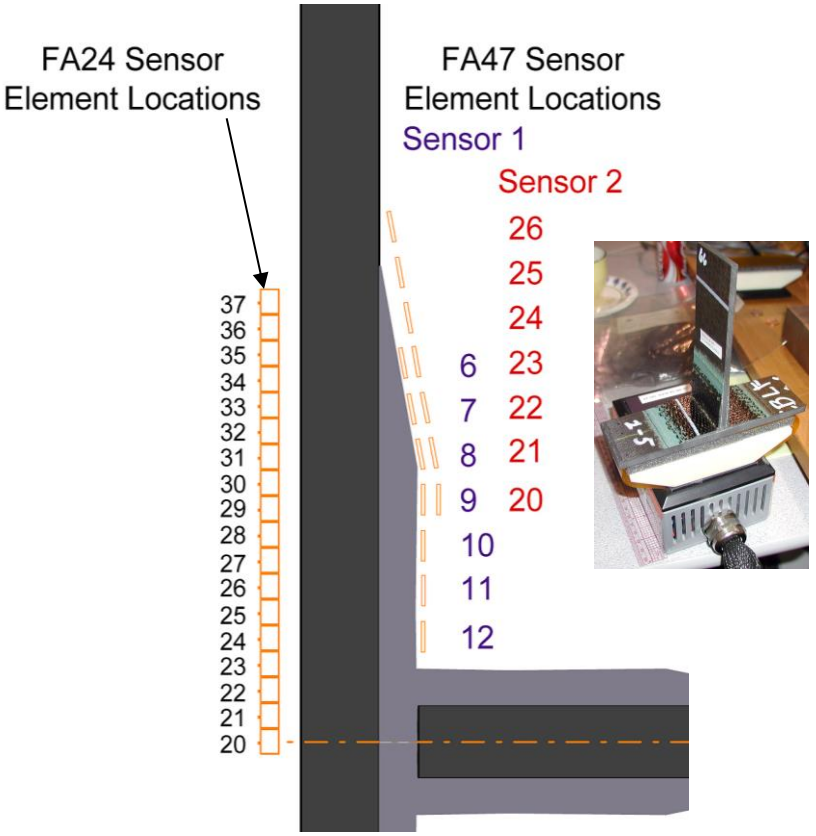
For as-manufactured RCC specimens and the same specimens exposed to thermal cycling equivalent to 12 and 72 shuttle missions

Composite (Buried) Disbond Growth Mapping and Tracking



- Surface mounted sensors
- Scanning sensors (not shown here)





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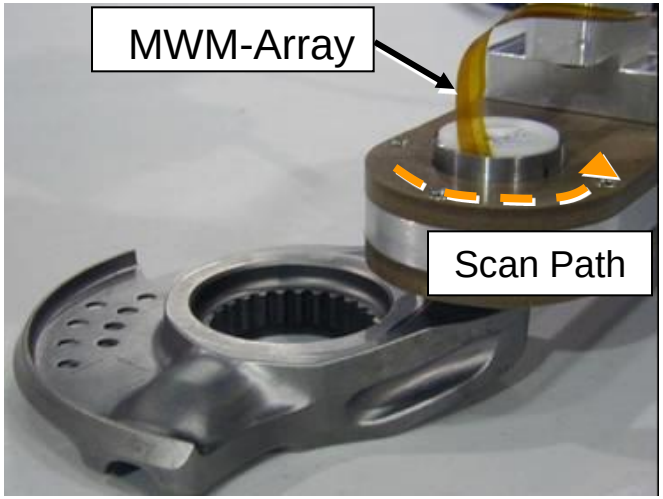
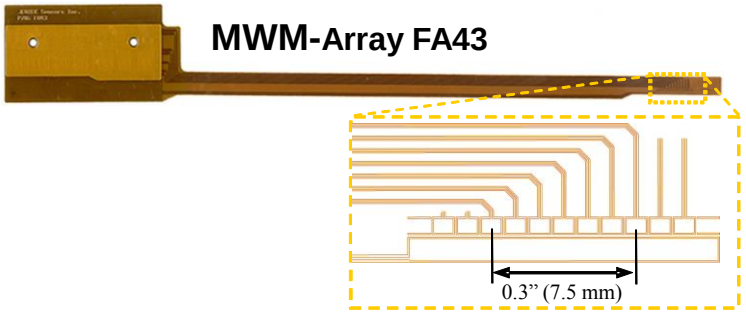
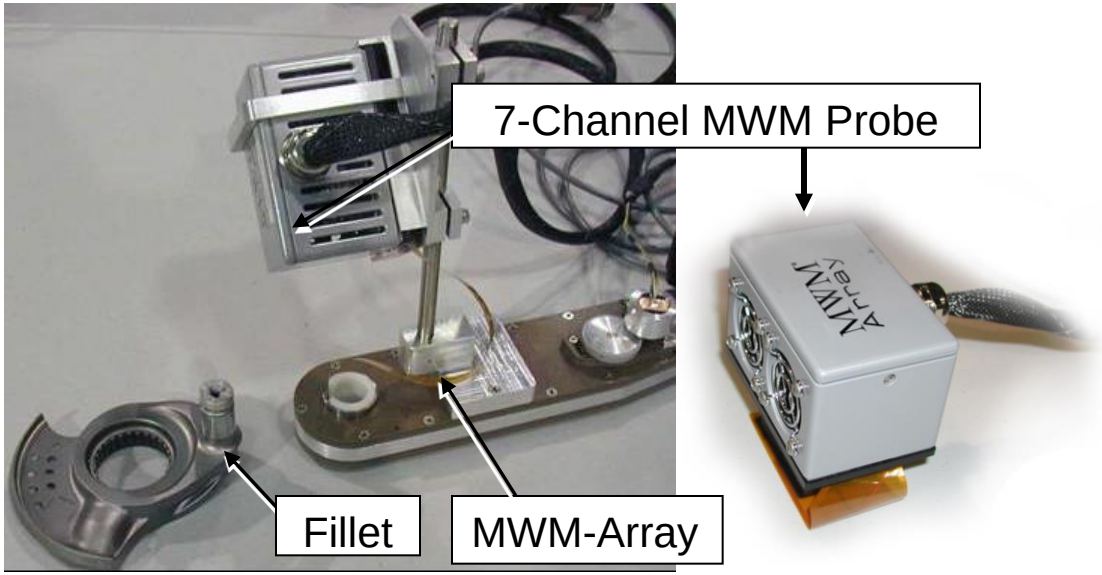
Fighter Aircraft Steering Crank Inspection Using MWM-Arrays

- Prototype fixture for scanning with an FA43 MWM-Array sensor
- Multi-frequency calibration and measurement procedure using a 3-unknown method:
  - plating thickness (assuming a conductivity)
  - lift-off
  - substrate magnetic permeability
- Magnetic permeability images provide both crack and overload detection capability

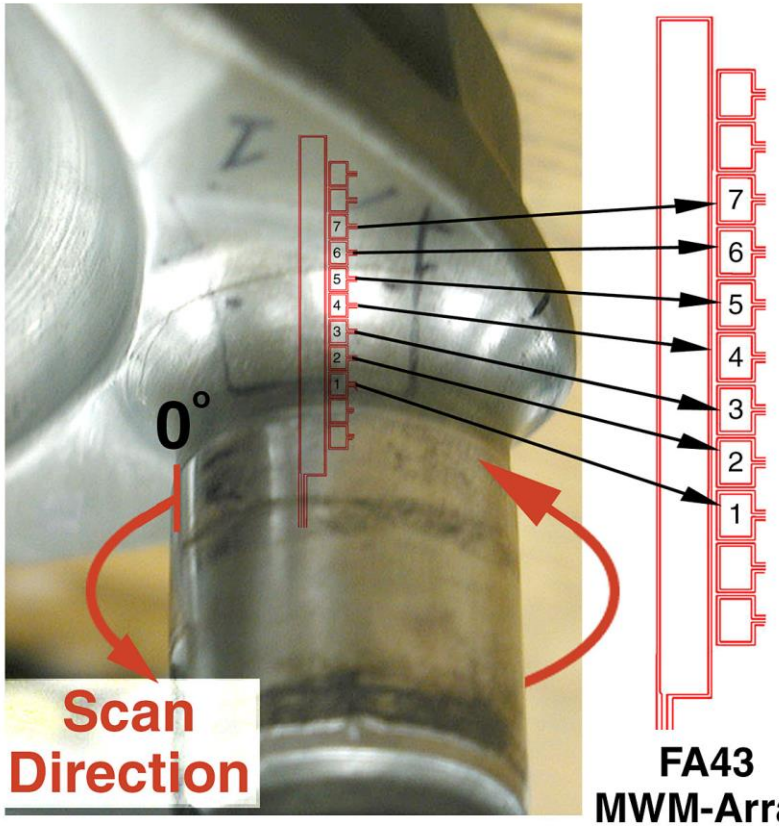


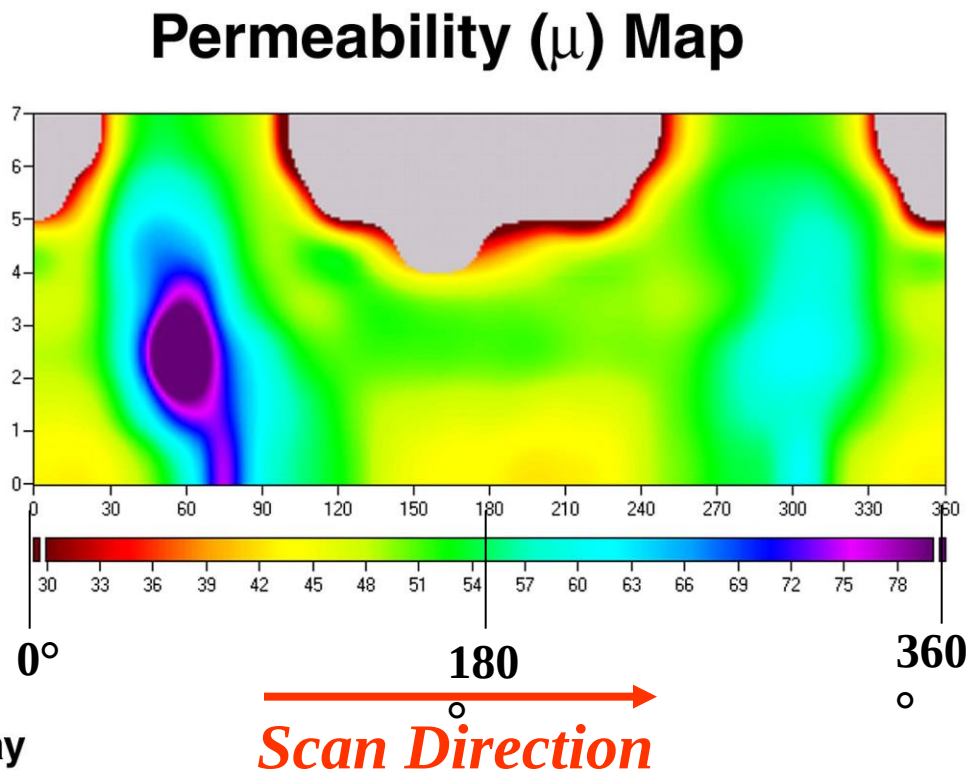




Fighter Aircraft Steering Crank Inspection

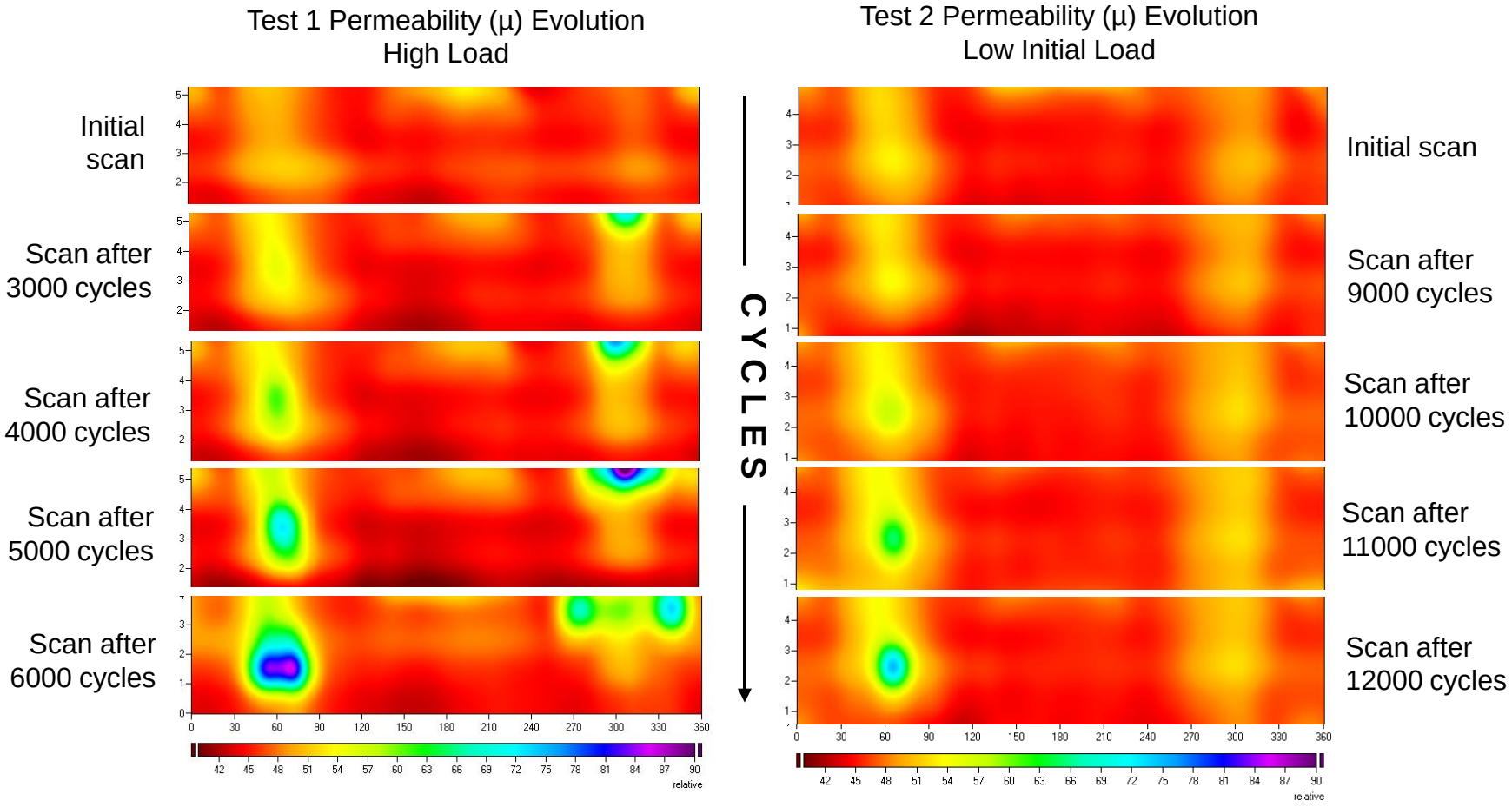
Sensor placement and permeability map produced





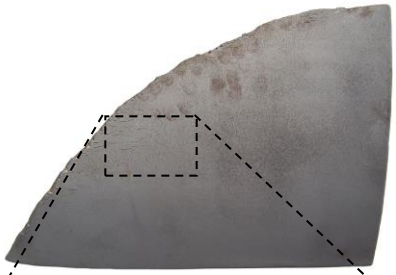
C-Scan Images of MWM-Array Measured Magnetic Permeability

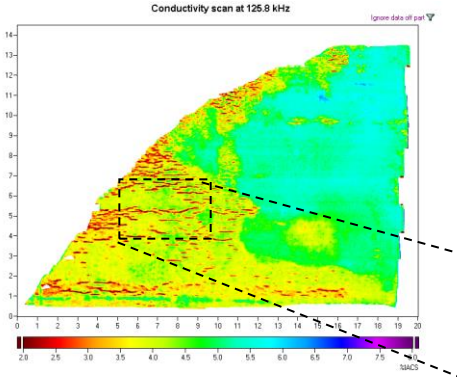
Acquired during periodic interruptions of two fatigue tests



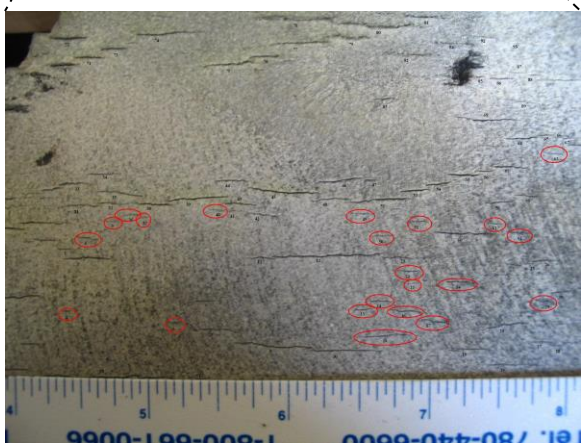
Imaging of SCC in Pipeline Sample

Establishing Detection Criteria

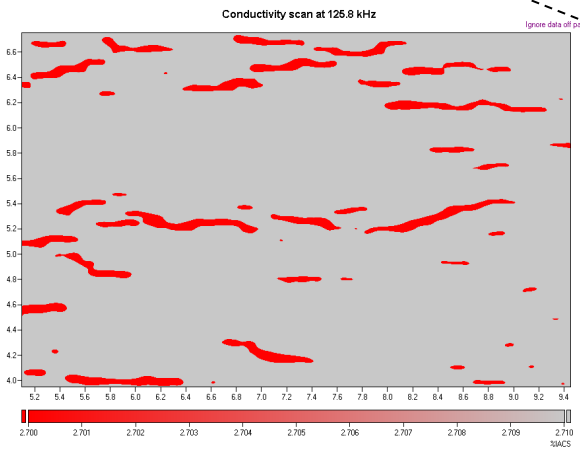




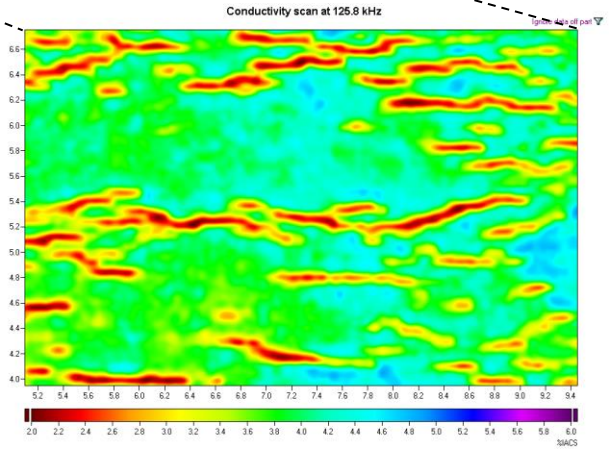
- Simple image thresholding may not be sufficient
- Multiple frequency measurements with filtering can improve detection



MPI Analysis by RTD. Circled cracks do not appear in MWM thresholded image.



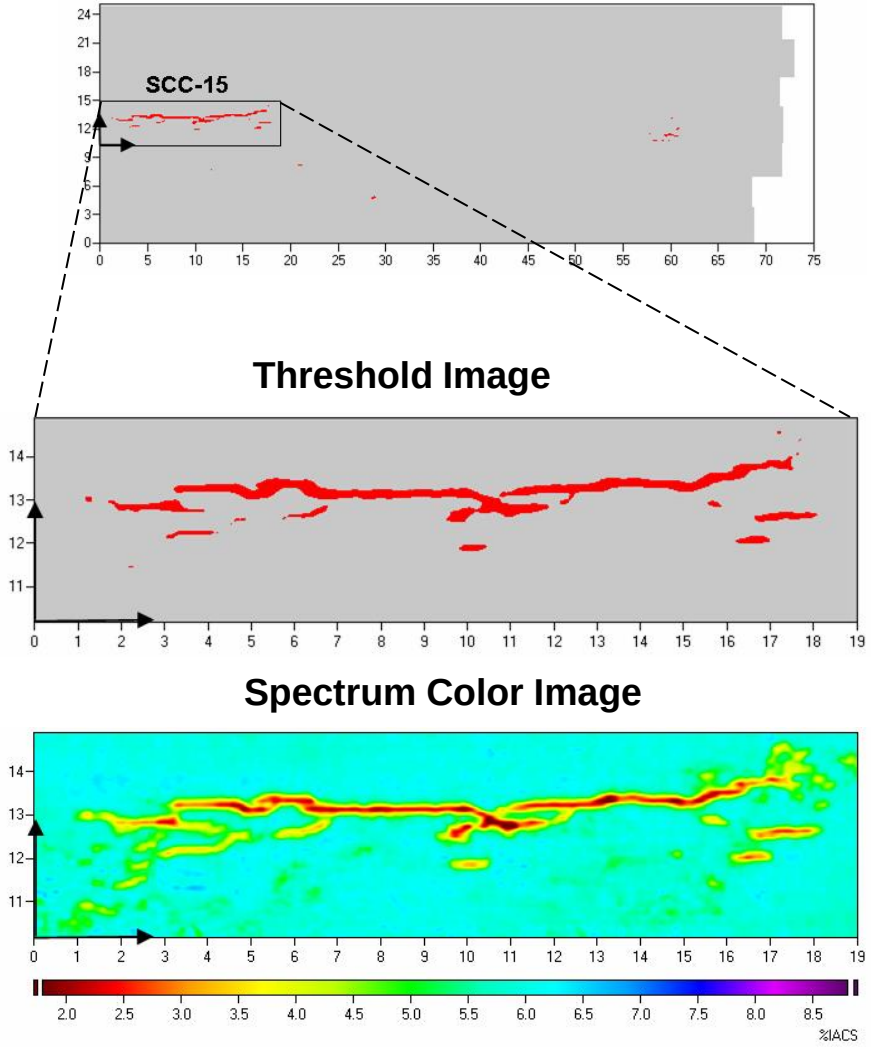
MWM threshold image.



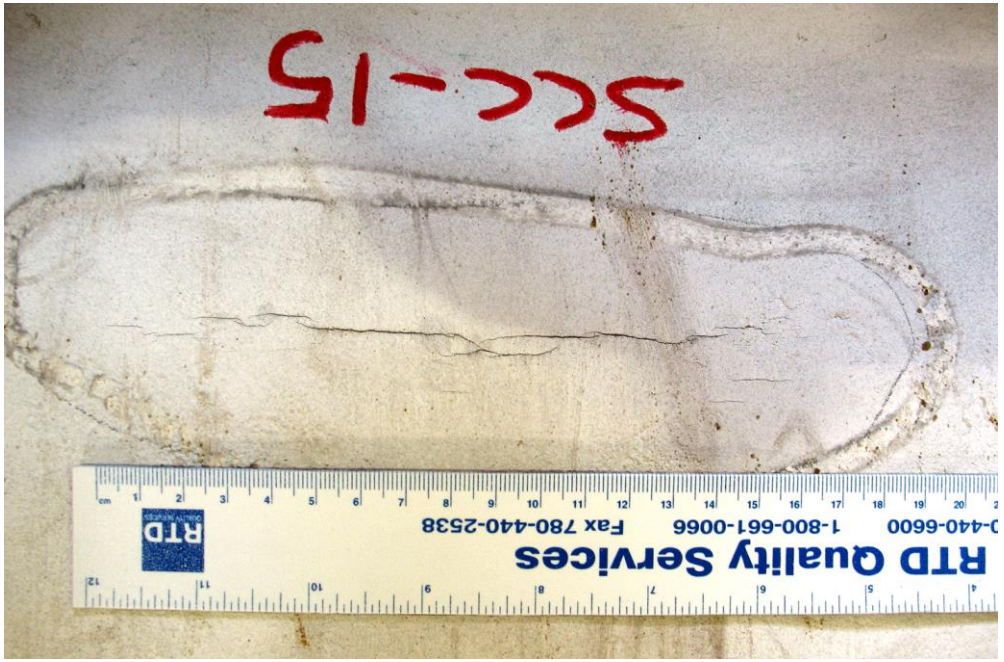
MWM spectrum image. ***All cracks identified by MPI were detected.***

Imaging of SCC in Pipeline Sample

Scans of Pup Section With Identified SCC



(RTD p/n NPS34 #1)



Summary and Future Work

- Mapping and tracking feasibility demonstrated for:
  - Titanium
  - Gr/Epoxy Composites
  - RCC
  - Steel
- Future Work
- Time space filtering methods
- Adaptive life management (ongoing SBIR for NAVAIR)