

# Eddy Current Array In Lieu of PT and MT for Aerospace Inspection

2019 A4A NDT Forum

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# Agenda

- Liquid Penetrant Testing (PT)
- Magnetic Particle Testing (MT)
- Eddy Current Testing (ECT)
- Eddy Current Array Testing (ECA)
- PT Aerospace Applications
- MT Aerospace Applications
- Conclusions

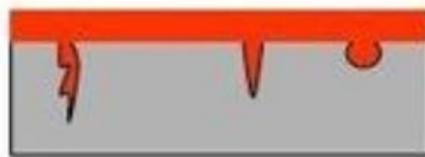
# Liquid Penetrant Testing (PT)

- Liquid or Dye Penetrant Testing (PT)
  - Liquid is drawn into surface openings by capillary action
  - Defects become visible from the dye or under UV light
- Identify surface-breaking defects and discontinuities in metal and other nonporous materials

Sequence of actions when performing penetrant testing



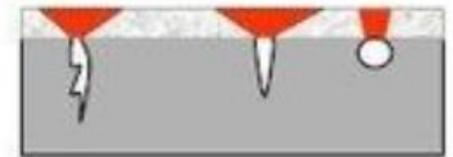
Surface cleaning



Surface covering with penetrant



Removal of exceeding penetrant



Surface covering with developer and area inspection

# Liquid Penetrant Testing (PT)



- Indication types:
  - Surface-Breaking Cracks and Discontinuities, Nicks, Cuts, Gouges, Scratches, Corrosion
- Aerospace applications:
  - Structural parts – Multiple Materials, Bridges, Flanges, Frames, Fuselage Parts, Supports, Ribs, Skins
  - Engine parts – Propellers, Turbine Rotor Blades, Nozzles, Valves, Gear Boxes
  - Helicopter parts – Spars

# Liquid Penetrant Testing (PT)



- Advantages:
  - Complex shapes can be tested
  - Conductive and nonconductive materials
  - Large numbers of similar parts can be rapidly tested/automated
  - Small fine surface cracks can be detected
  - Estimate crack size
  - Easy to perform
  - Relatively low cost

# Liquid Penetrant Testing (PT)

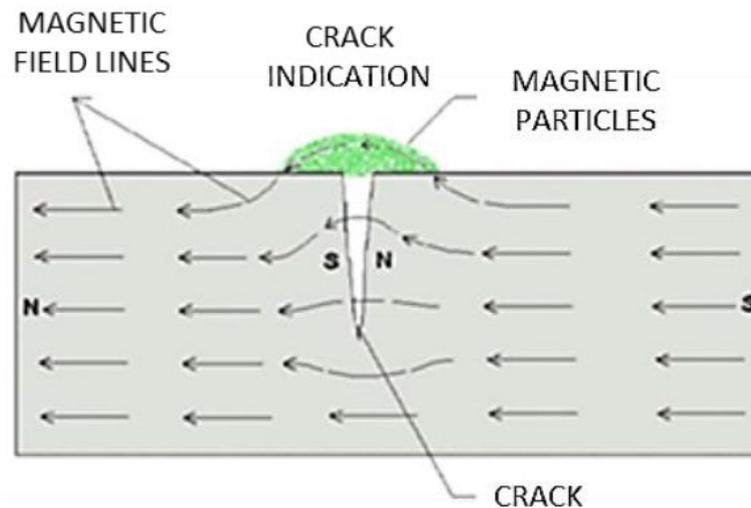


- Disadvantages:

- Requires removal of paint and other coatings
- Surface coatings can be hard to fully remove
- Porous materials cannot be tested
- Can't detect subsurface indications that can hide just below surface
- Limitations at low and high temperature
- Possibility of fire or explosion
- Penetrants may be toxic or hazardous
- Cleaning required after test
- Requires reapplying paint or coatings to go back into service

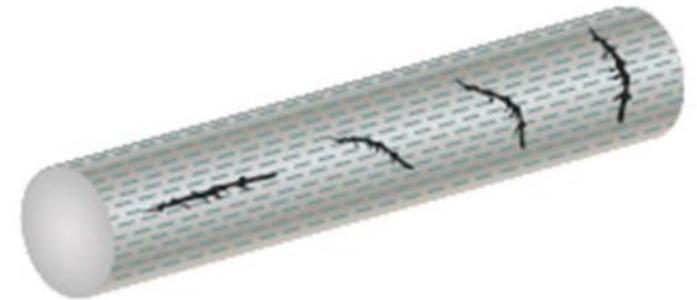
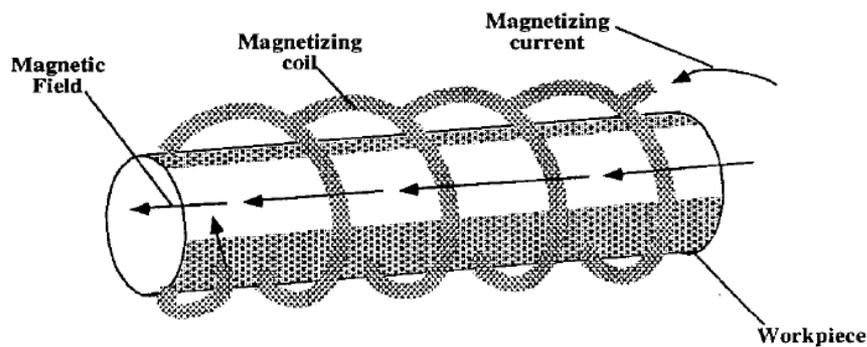
# Magnetic Particle Testing (MT)

- Magnetic Particle Test (MT)
  - Very fine ferromagnetic particles are applied to the metal
  - Particles are drawn into flaws which indicates their presence
- Locate surface and near-surface crack indications in ferromagnetic material



# Magnetic Particle Testing (MT)

- Longitudinal magnetization
- Indications 45° to 90° with respect to axis give best response



Poor

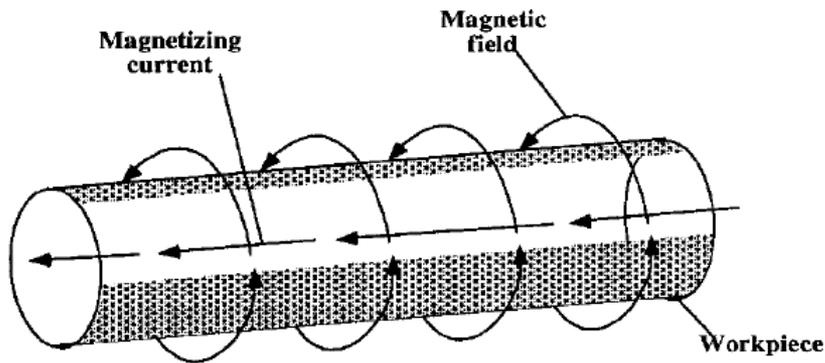
Fair

Good

Best

# Magnetic Particle Testing (MT)

- Circular magnetization
- Indications 0° to 45° with respect to axis give best response



Best

Good

Fair

Poor

# Magnetic Particle Testing (MT)



- Indication types:
  - Cracks, Laps, Seams, Inclusions, Other Discontinuities
- Aerospace applications:
  - Engine parts – Crankshafts, Connecting Rods, Engine Mounts, Low Pressure Turbine Shafts, Gear Box Assemblies, Gear Reduction Components, Compressor Discs
  - Structural parts – Under Carriage, Landing Gear
  - Other parts – Bolts, Nuts, Washers

# Magnetic Particle Testing (MT)



- Advantages:
  - Complex shapes can be tested
  - Cracks filled with paint or other foreign material can be detected
  - Large numbers of similar parts can be rapidly tested/automated
  - Small fine cracks can be detected
  - Subsurface discontinuities can be located
  - Cracks can be located through thin nonmetallic coatings
  - Estimate crack depth
  - Easily learned
  - Relatively low cost

# Magnetic Particle Testing (MT)



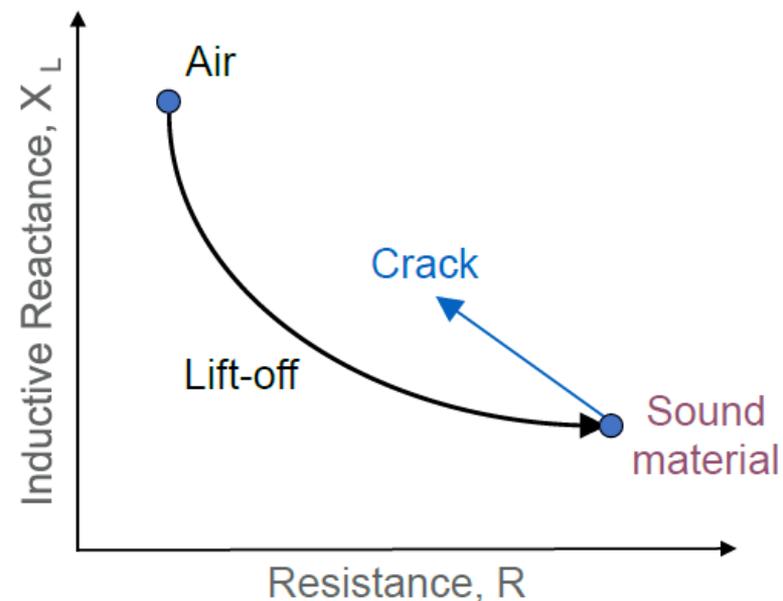
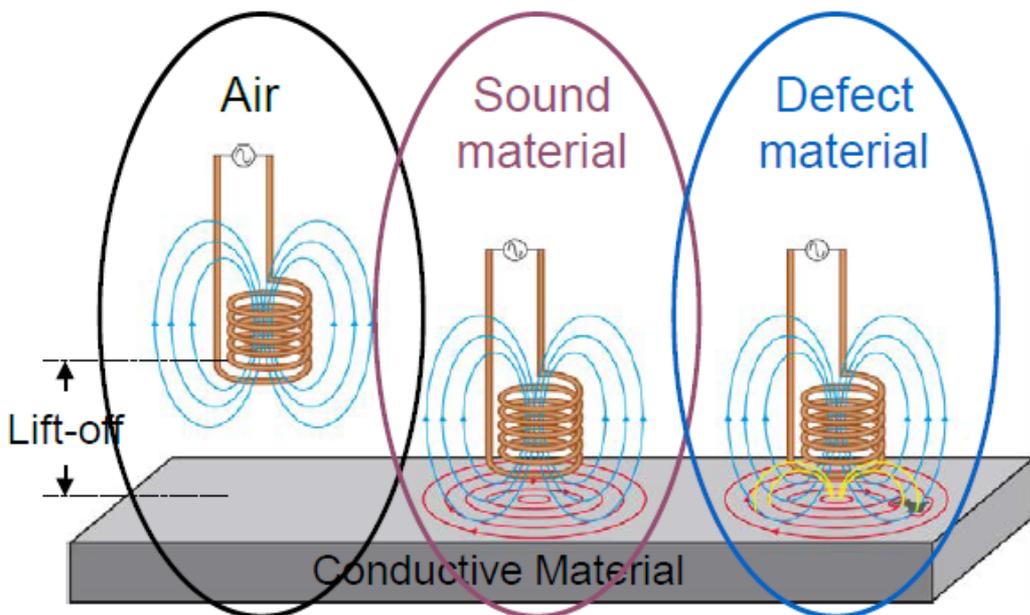
- Disadvantages:
  - Only ferromagnetic materials can be tested
  - High electric current required to magnetize
  - Demagnetization required in some instances
  - Extreme care to avoid burn spots
  - Difficult to detect small defects below the surface
  - Cleaning required after test
  - Complex shapes may require more than two magnetizations
  - Takes multiple magnetization orientations for full coverage

# Eddy Current Testing (ECT)



- Eddy Current Test (ECT)
  - Coils apply EM field into metal, indications disrupt EC flow
  - Can find indications in ferrous and non-ferrous materials
  - Detects through nonconductive coatings
- Generally no surface prep or chemicals are required
- Computerized record of the inspection
- There is high dependence on the user training
- Speed is slow due to limitation of only inspecting one spot at a time

# Eddy Current Testing (ECT)



# Eddy Current Testing (ECT)

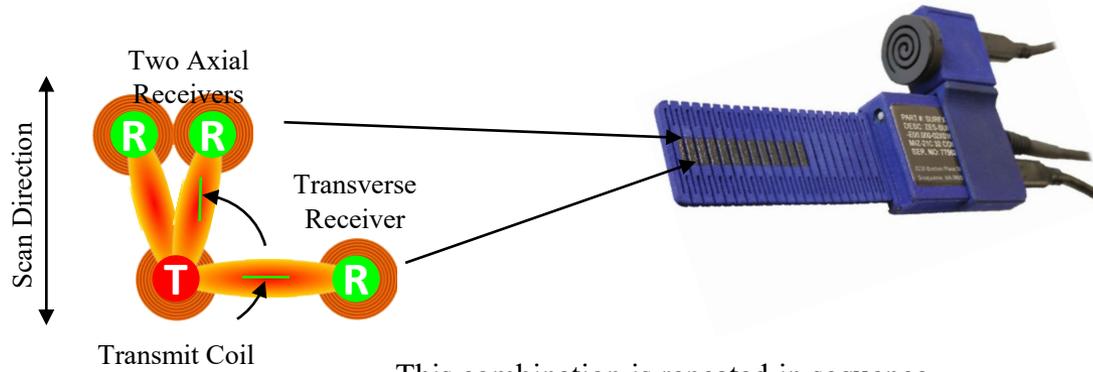


# Eddy Current Array Testing (ECA)

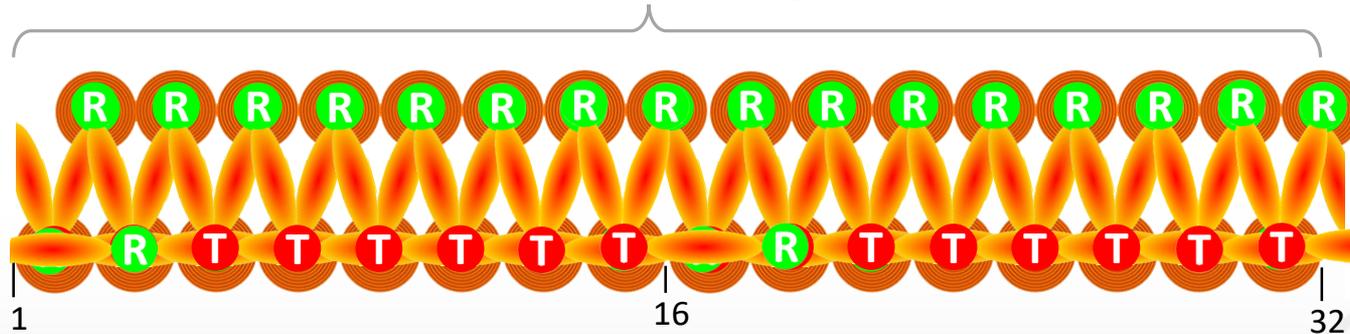


- Multi-coil arrays take EC technology a leap ahead
- ECA probes have multiple coils in the same probe
  - Positioned longitudinally, transversely, or off-axis
  - Fired at coordinated times
- With an array probe, users can
  - Capture more information in a single pass
  - Dramatically increase speed, accuracy, and repeatability
  - Have higher probability of detection (POD)
  - Operate in a wider range of temperature and environmental conditions

# Eddy Current Array Testing (ECA)

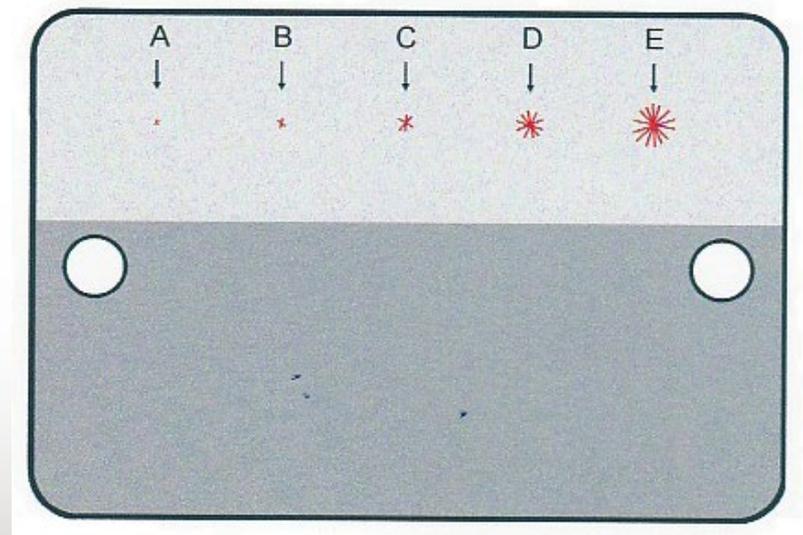


This combination is repeated in sequence across the array of coils in the probe



# TAM Panel PT Details

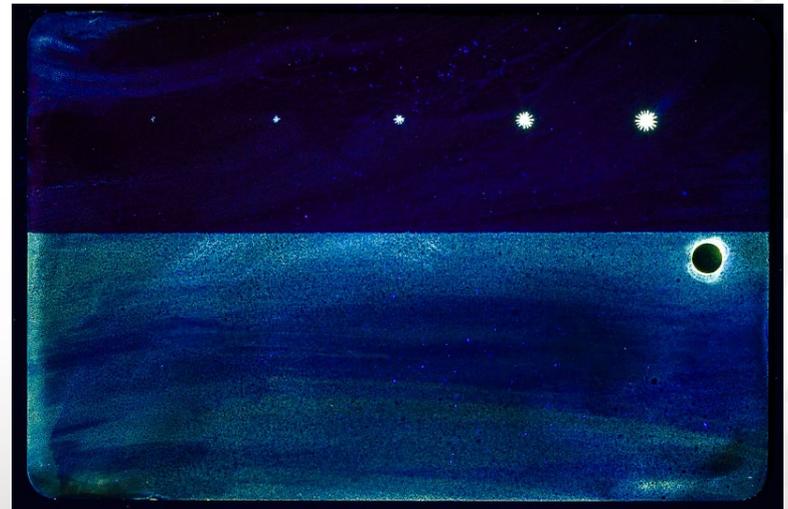
- Test panels are used to test system's overall performance
  - Known as TAM Panels
  - Also known as Sherwin or Magnaflux Test Panels
- Stainless steel 0.25 cm thick, 15 cm wide, 10 cm tall
- Strip of chrome plating has five variable size crack centers
- Other half has an oxide grit blasted surface to monitor background fluorescence



# TAM Panel PT Inspection Challenges



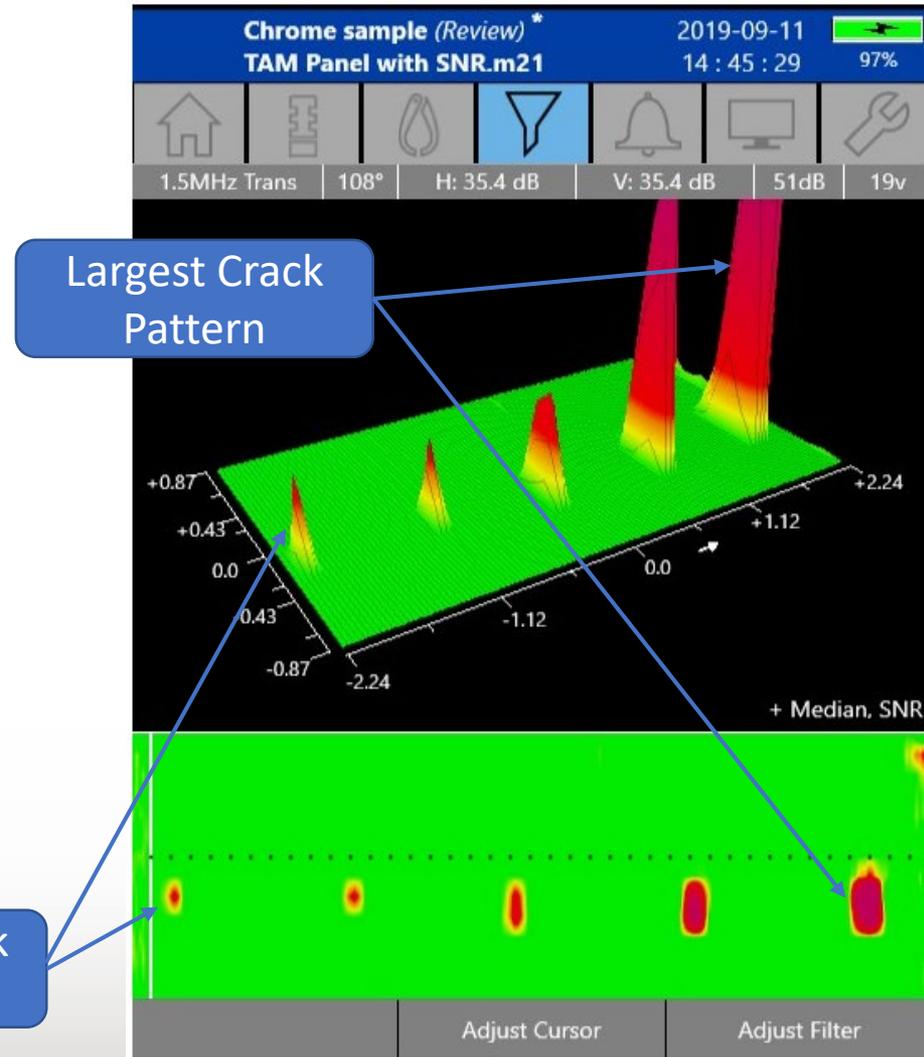
- Largest crack pattern is readily visible with low sensitivity penetrant materials
- Smallest crack pattern is visible with high sensitivity penetrant materials
- Can require more than one penetrant type to cover the full inspection
- This also translates to field testing limitations



# TAM Panel Using ECA



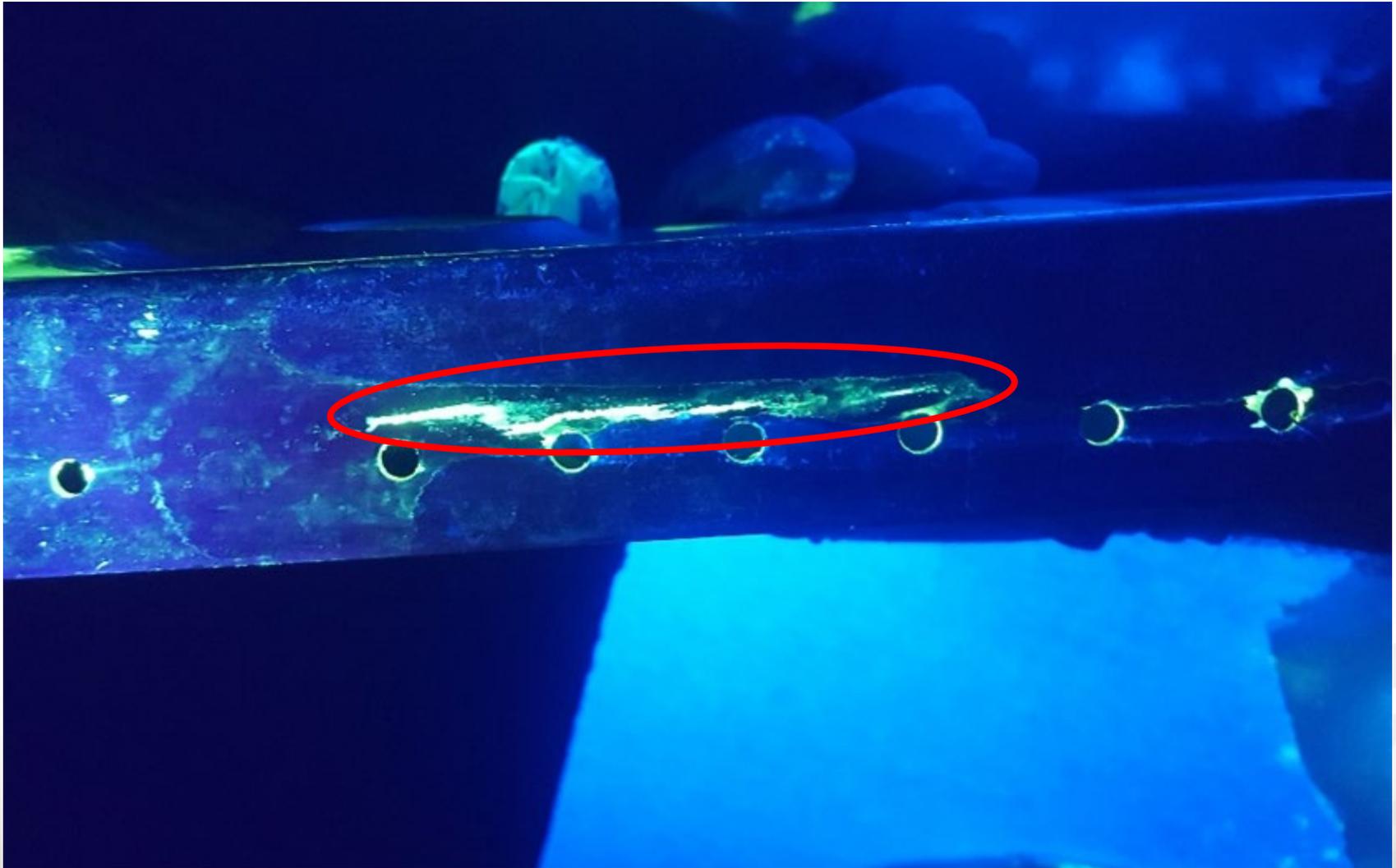
- Largest crack pattern is clearly visible
- Smallest crack pattern is also visible with a high POD
- Only one scan is needed to cover the full inspection
- This translates to field testing capability of detection



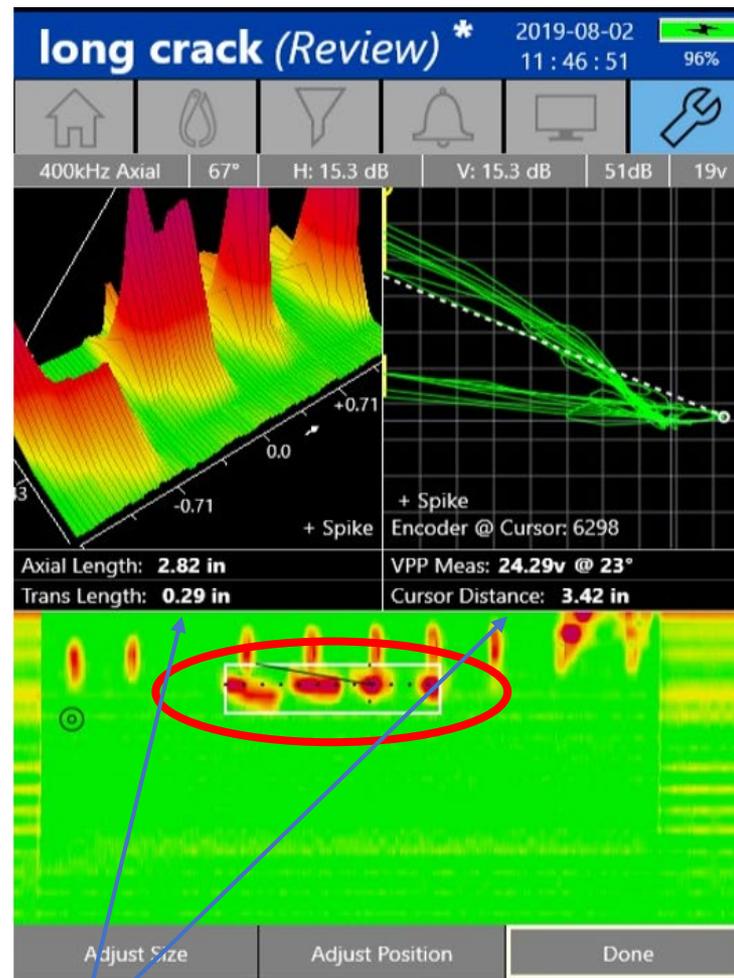
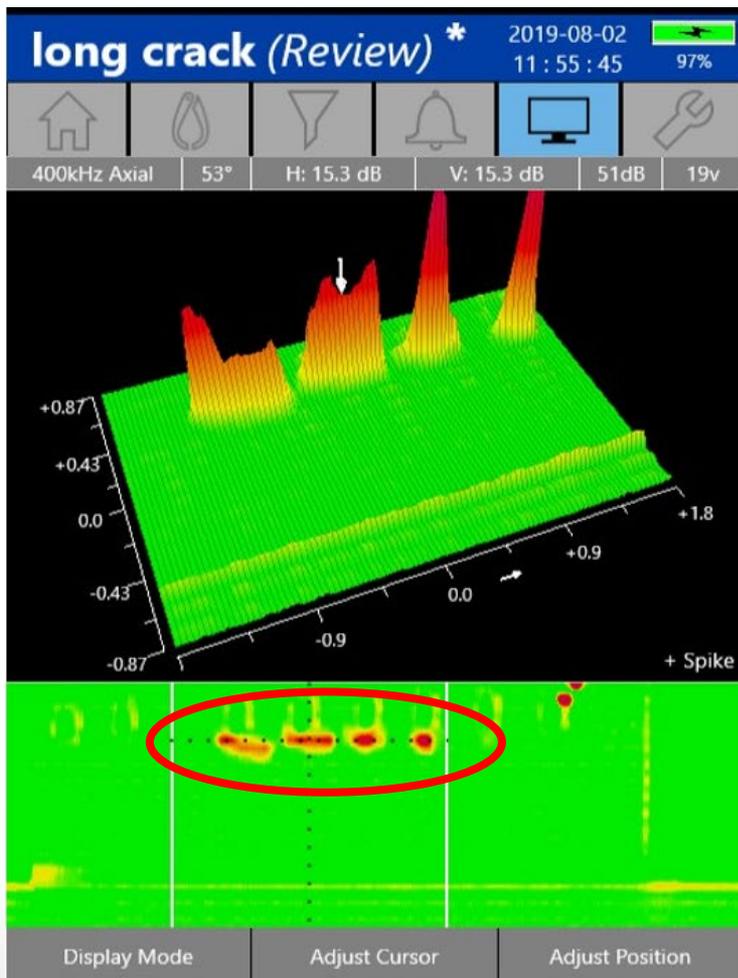
# PT on Aerospace Part



# PT on Aerospace Part



# ECA on Aerospace Part



Long axial crack with measurements noted

# Surface Crack at Rivet Hole PT Details

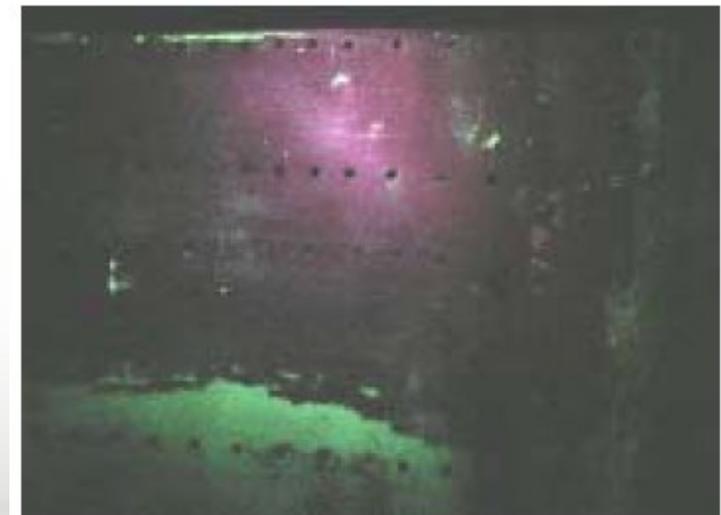
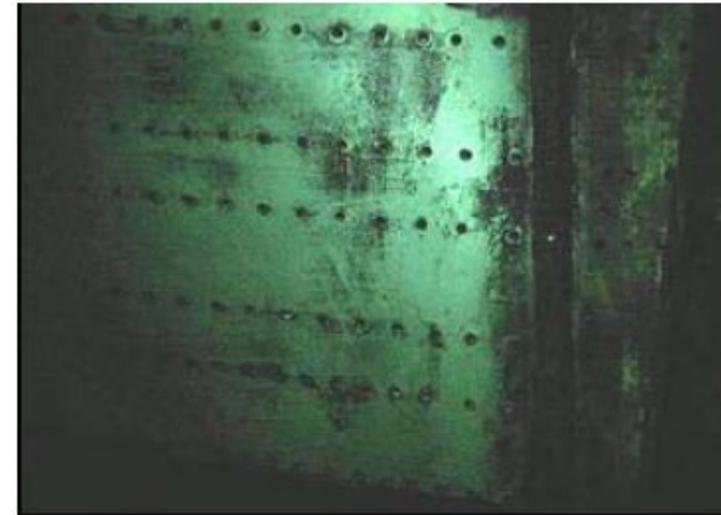


- PT is often used to find surface indications around aerospace rivets in skins, stringers, and other structural parts
- In parts that have paint or other coatings they must be stripped to get to the surface of the base material
- The chemical stripping process can be ineffective in removing all organic and inorganic surface coatings

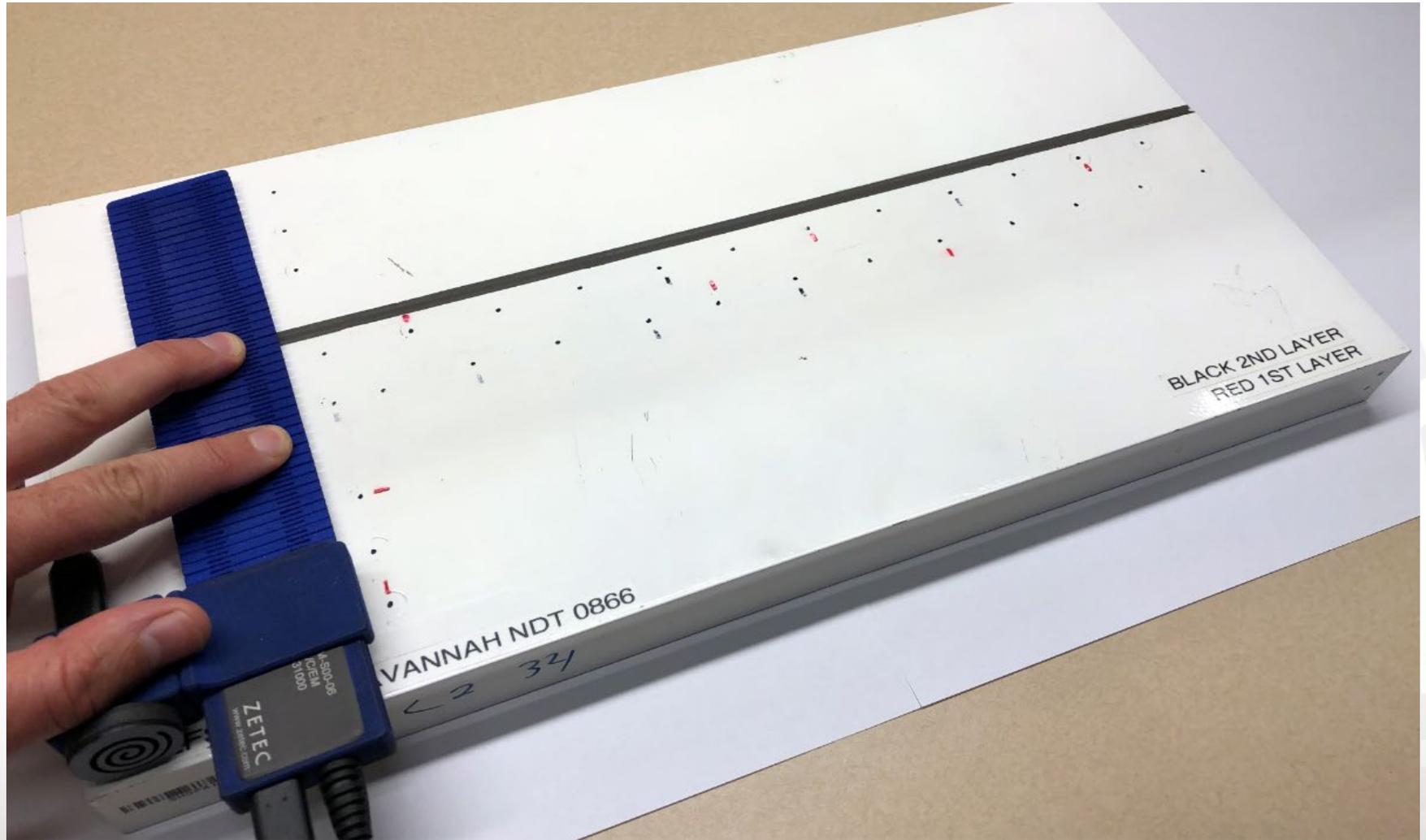
# Surface Crack at Rivet Hole Challenges



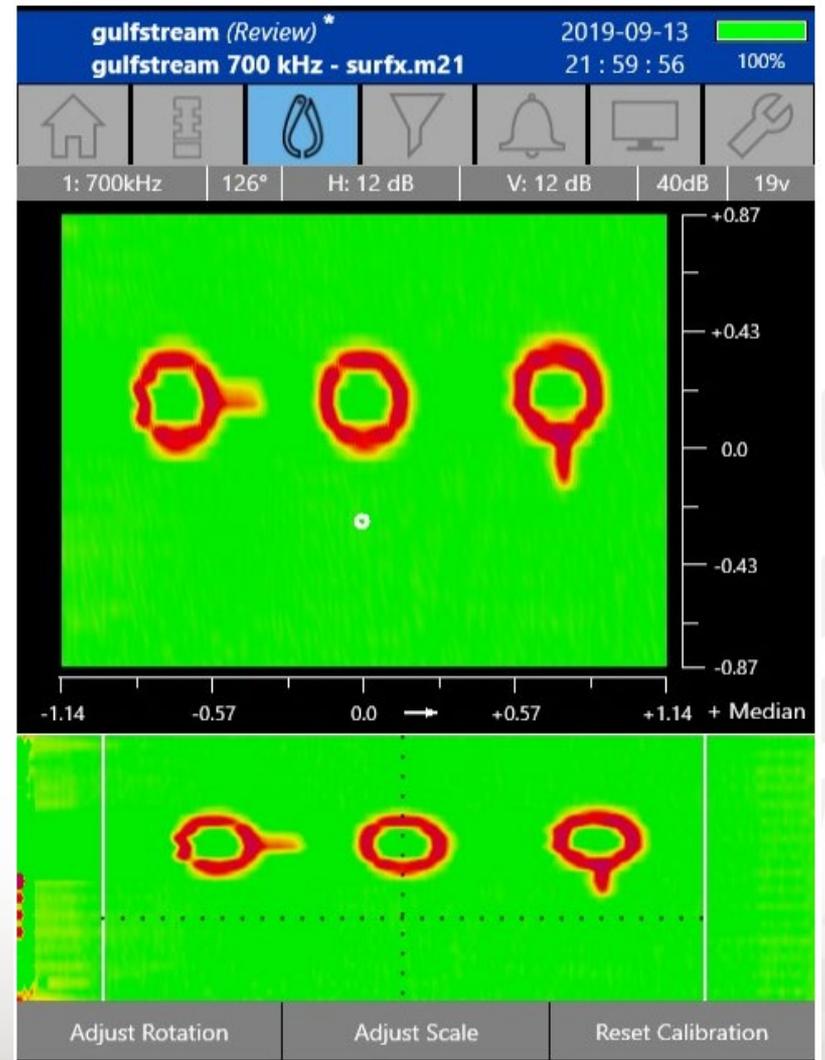
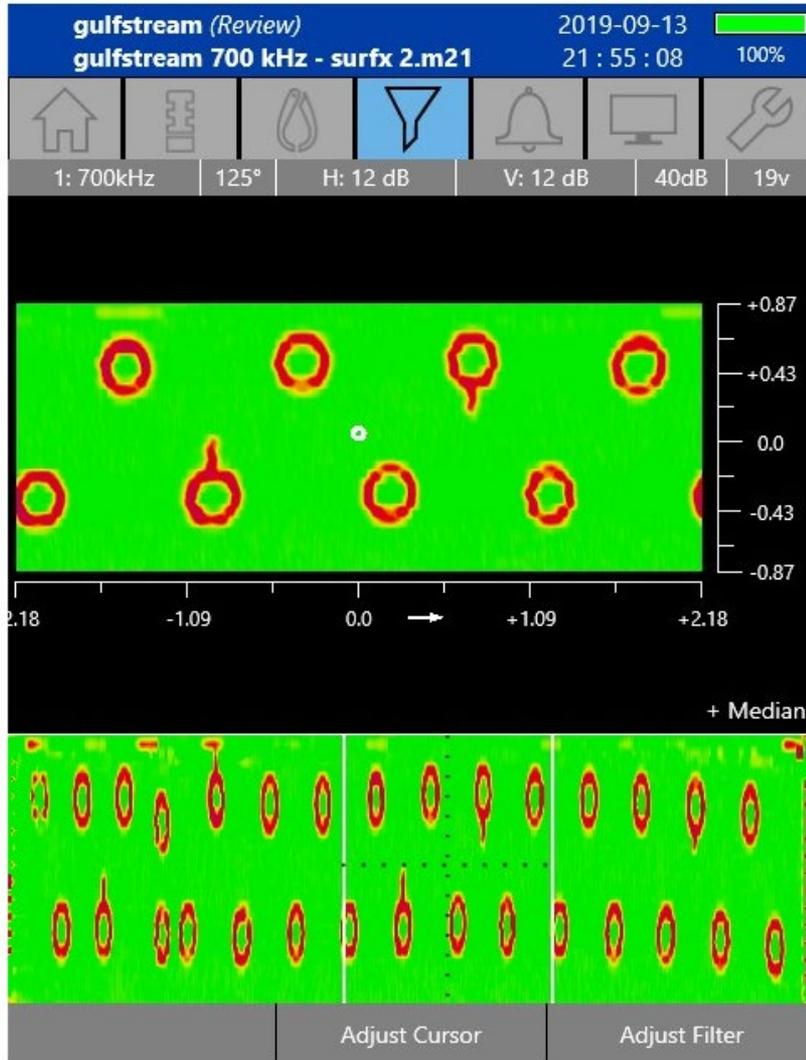
- In this example an anodize coating remained that fluoresced, reduced contrast, and could mask potential discontinuity indications
- As a result 17,600 fastener hole inspections were required to be performed using Bolt Hole Eddy Current



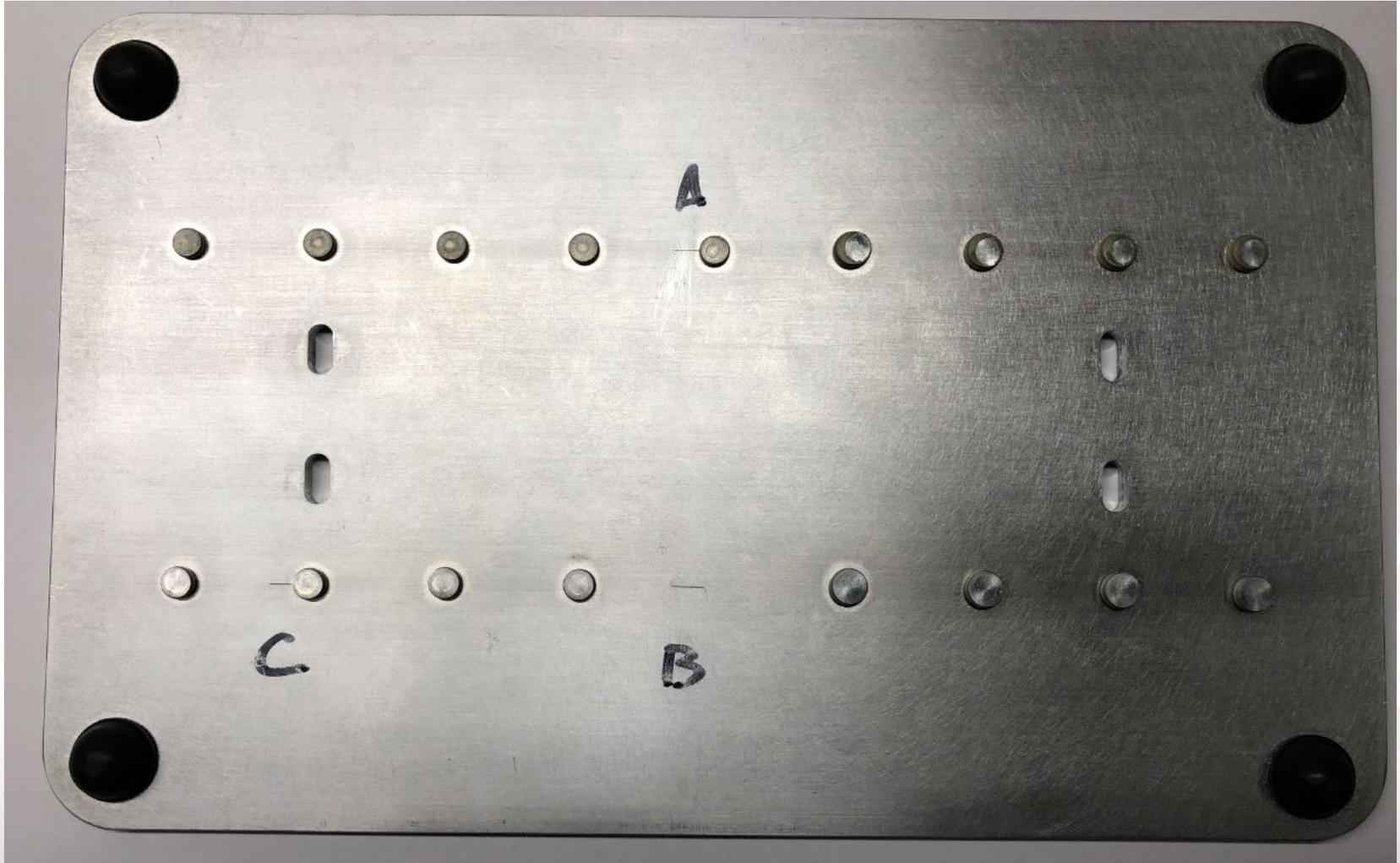
# Surface Crack at Rivet Hole Using ECA



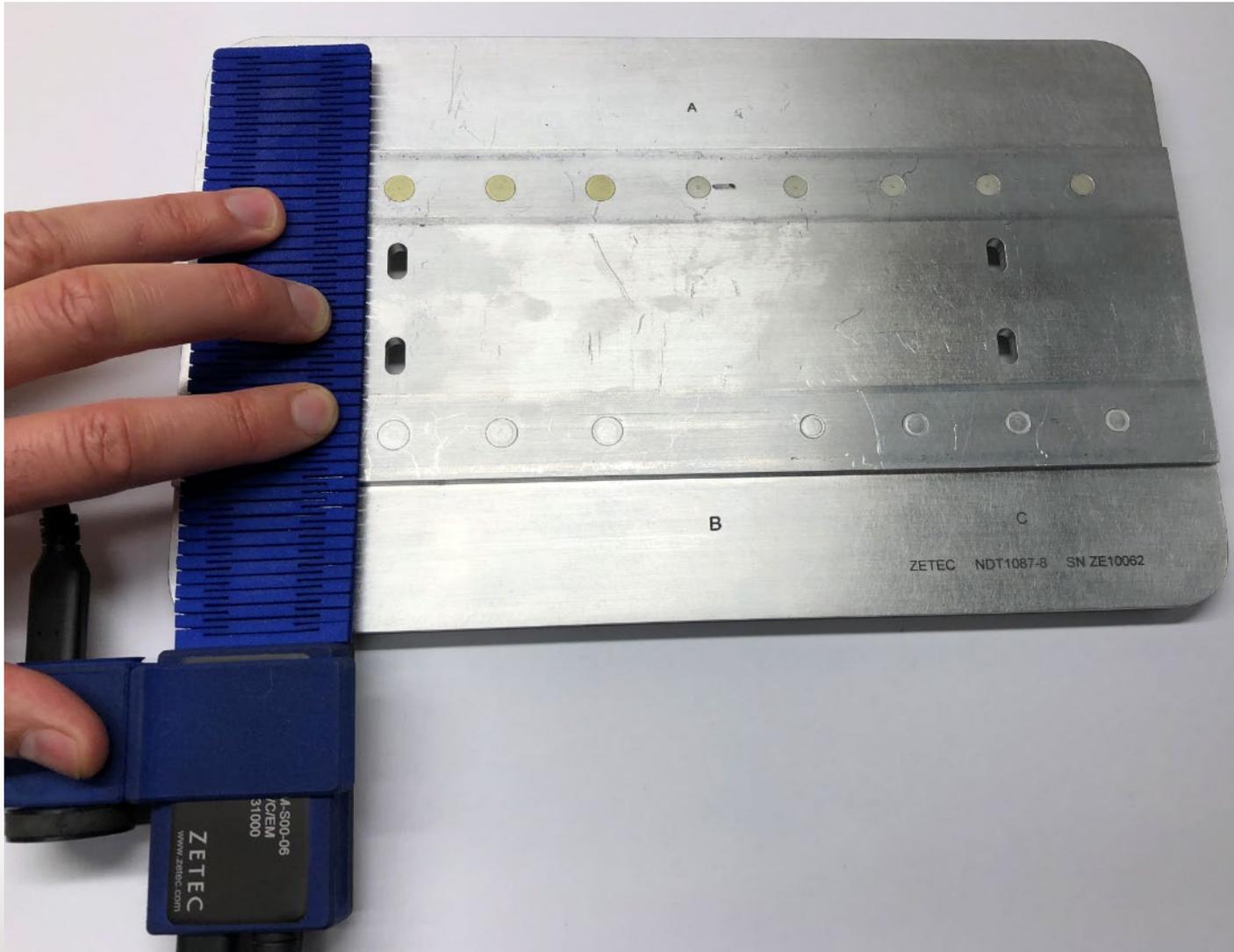
# Surface Crack at Rivet Hole Using ECA



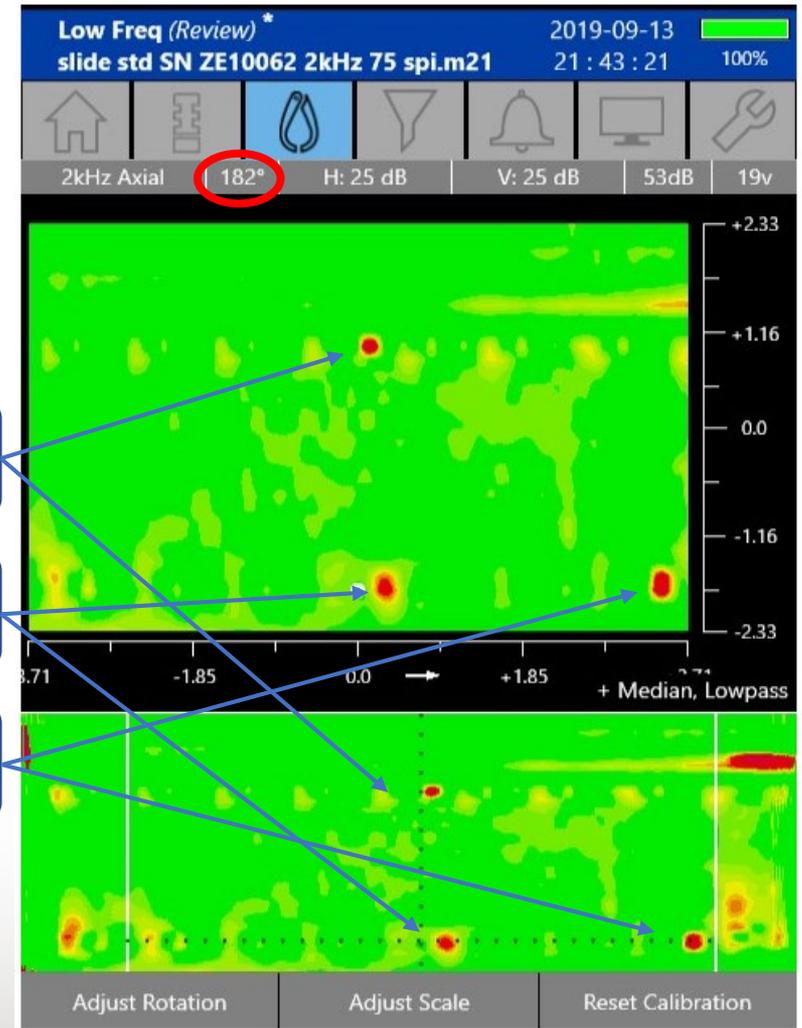
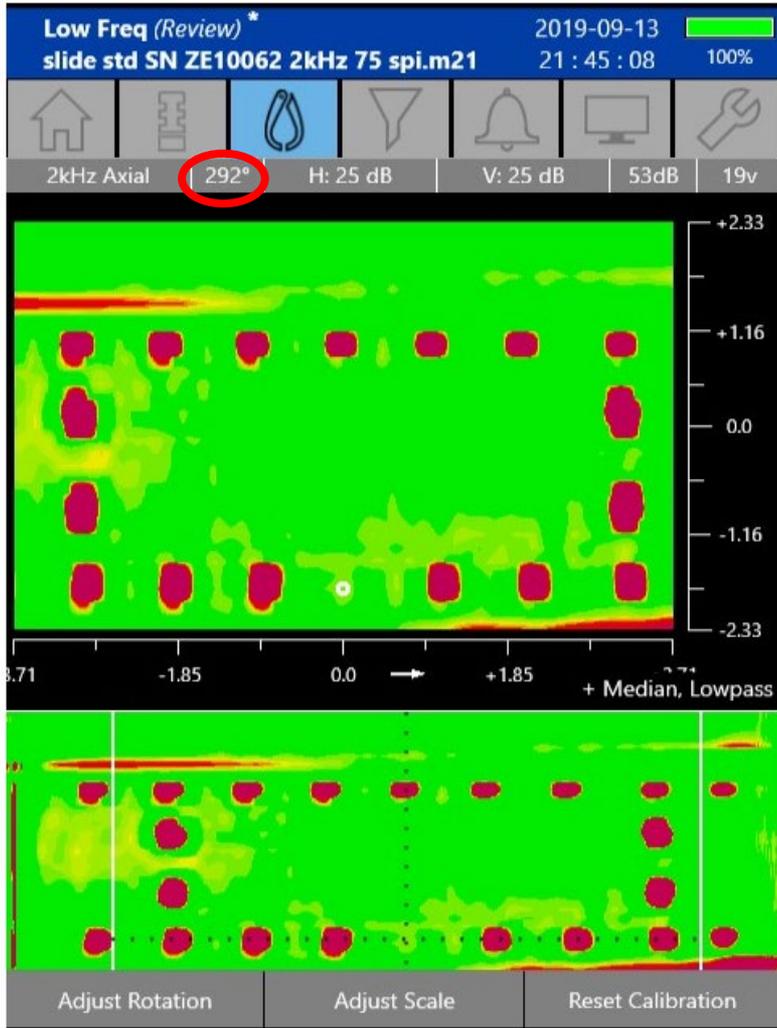
# Subsurface Crack at Rivet Hole LF ECA



# Subsurface Crack at Rivet Hole LF ECA



# Subsurface Crack at Rivet Hole Using ECA



A

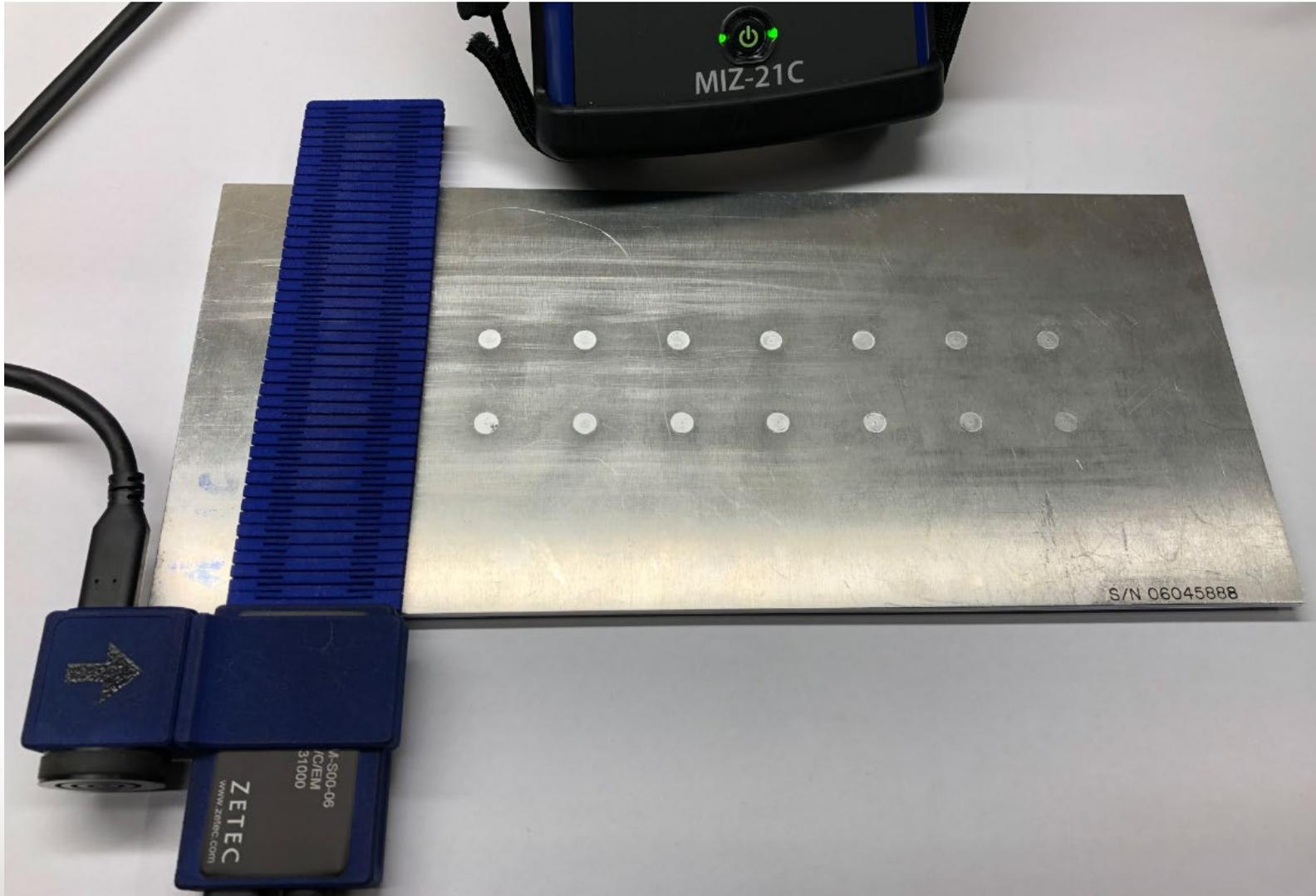
B

C

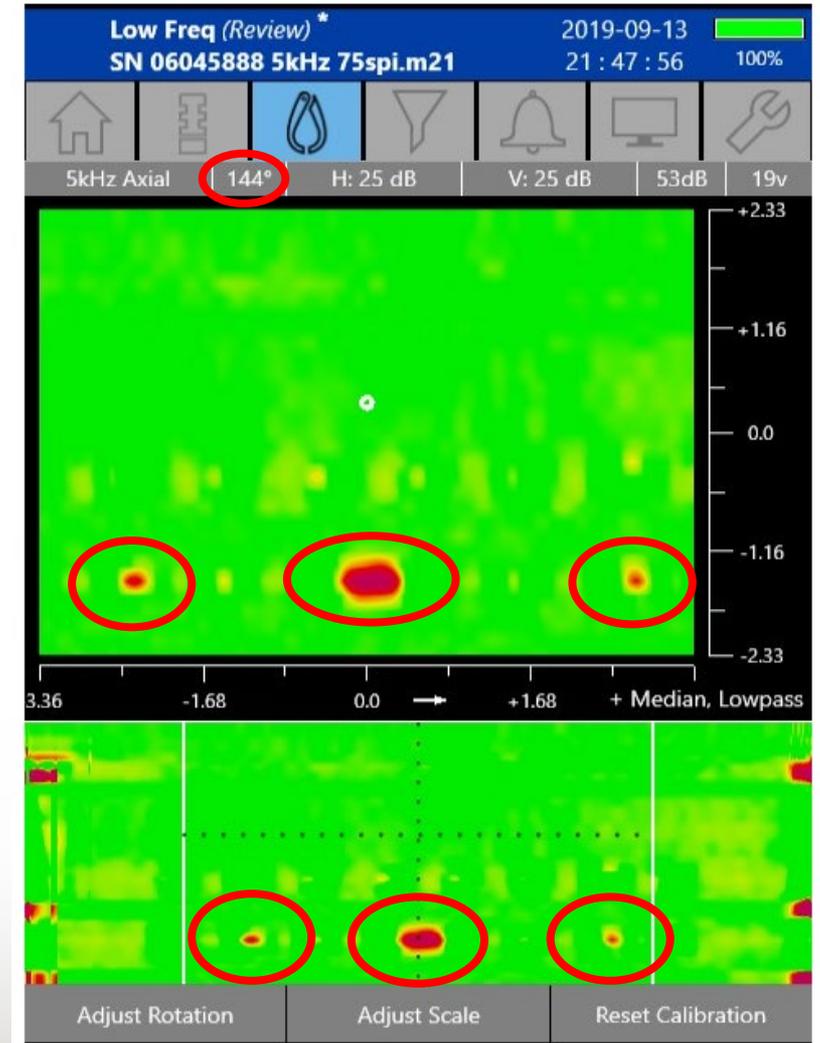
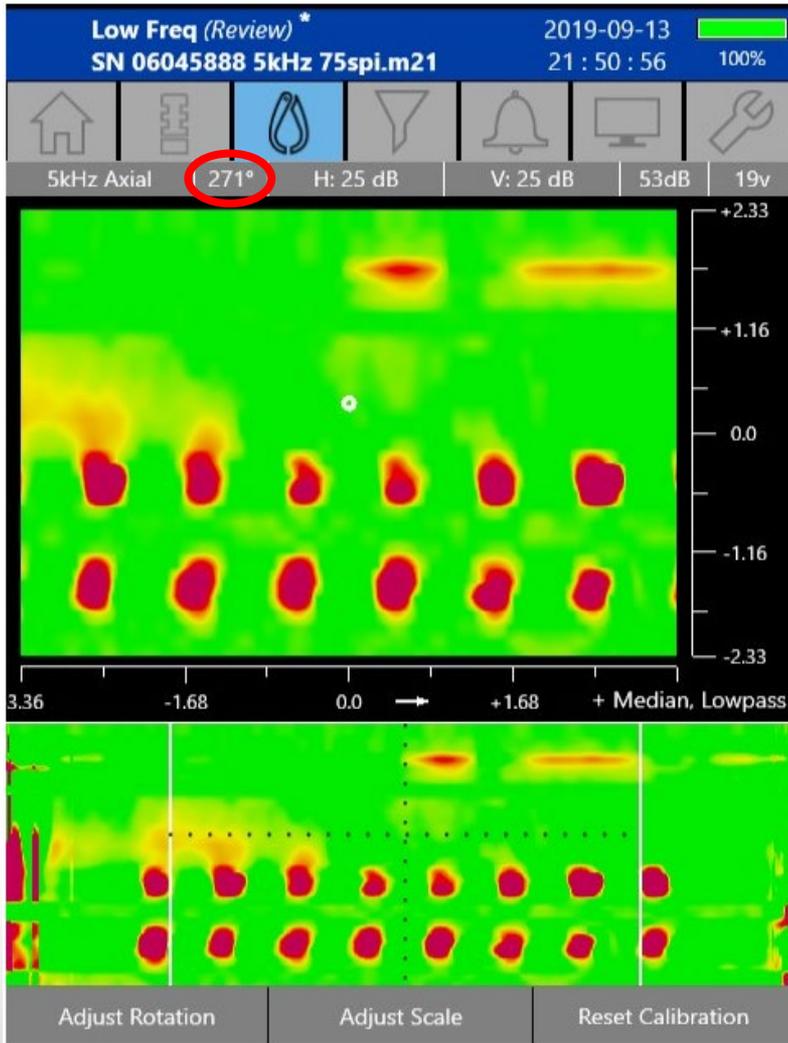
# Subsurface Crack at Rivet Hole LF ECA



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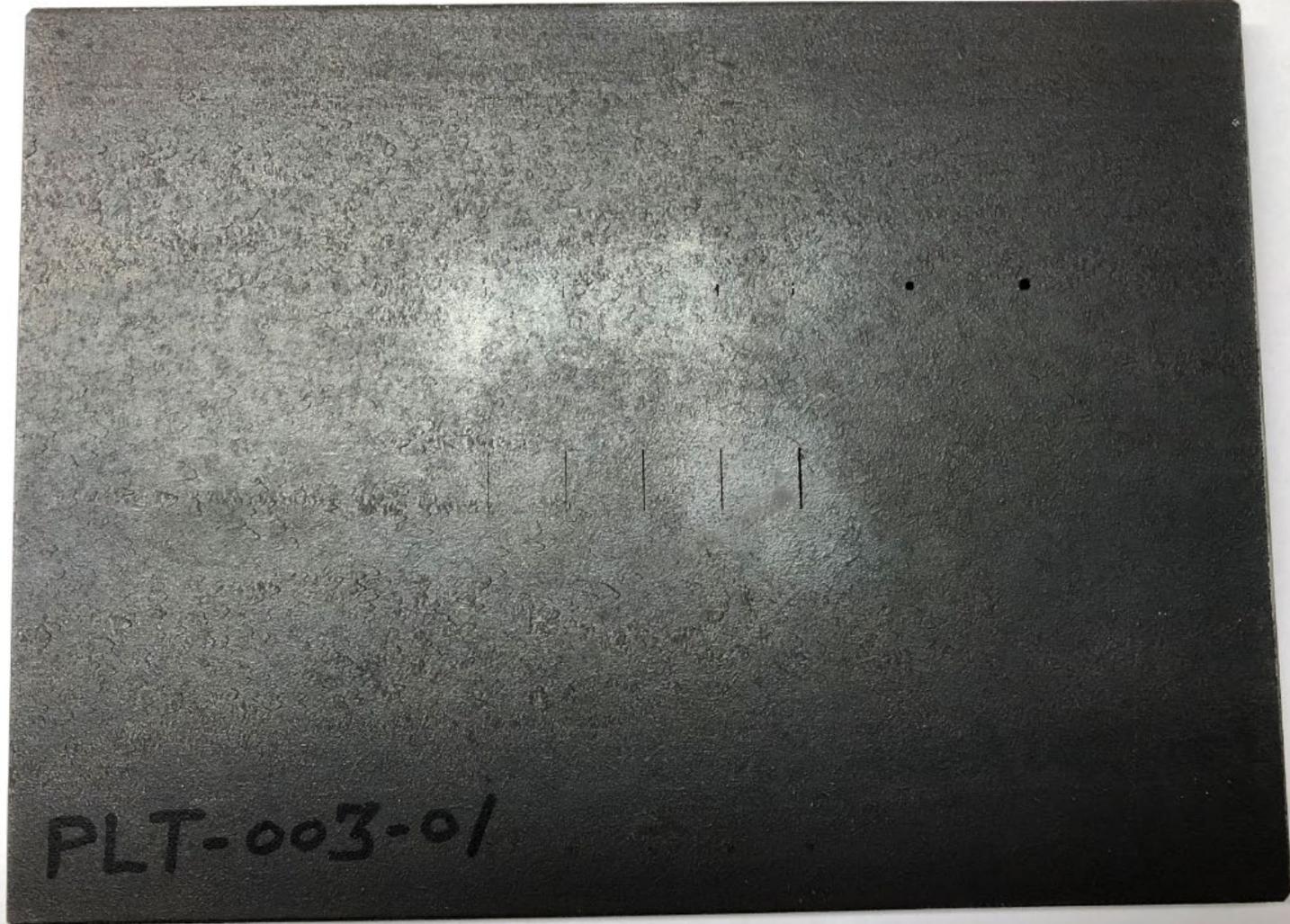


# Ferrous Parts MT Details



- Carbon Steel material
- Aerospace parts include:
  - Engine parts – Crankshafts, Connecting Rods, Engine Mounts, Low Pressure Turbine Shafts, Gear Box Assemblies, Gear Reduction Components, Compressor Discs
  - Structural parts – Under Carriage, Landing Gear

# Ferrous Parts MT Details



# Ferrous Parts MT Challenges



- Often MT can be required by manufacturer procedures
- MT can require the removal of paint and other non-conductive coatings to perform the inspection
- It's a time consuming process that is highly dependent on the skill of the inspector and includes the handling and disposal of chemicals
- MT has limited ability to record data files and provide that traceability
- Inspection traceability is becoming more critical with the liabilities associated with aerospace component failure

# Ferrous Parts Using ECA



- Can quickly inspect large ferrous surface areas through paint and other non-conductive coatings without removal
- Has limited influence by the inspector's skill
- Can conform to complex geometries using highly flexible thin film printed coils
- Can provide recorded data traceability

# Propeller Bolts MT Details

- Propeller Bolts are frequently inspected with MT
  - Highly stressed component
  - Small defects can develop to complete failure
  - Entire propeller disassembled and inspected annually or per manufacturer's specifications



*Flanged propeller shaft*



*Propeller mounting bolts*

# Propeller Bolts MT Challenges

- Large setup and must handle magnetic particle chemicals

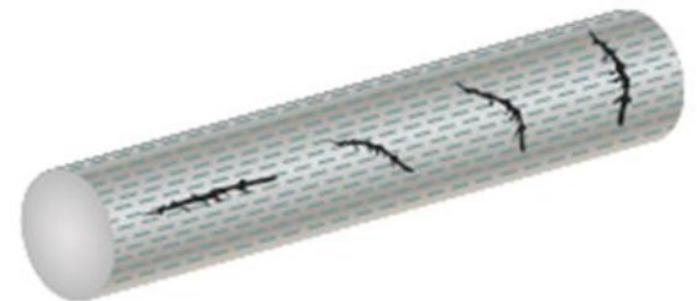
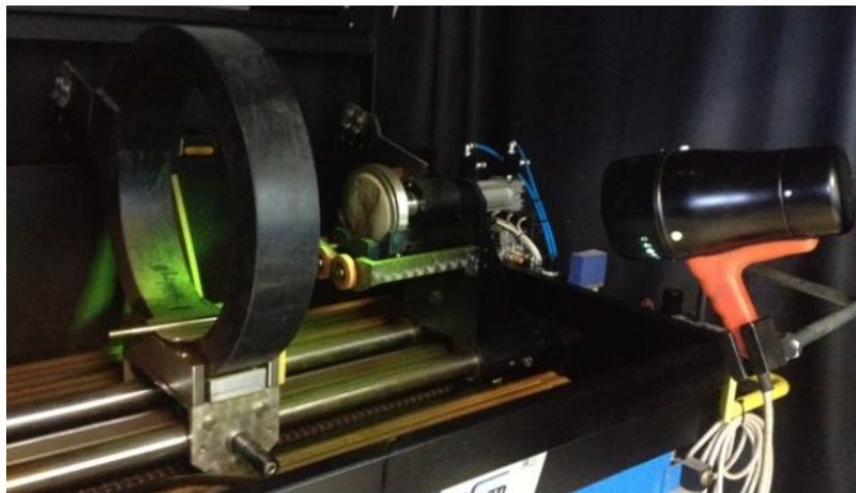


*Magnetic particle inspection test bench*



# Propeller Bolts MT Challenges

- Longitudinal magnetization
- Indications 45° to 90° with respect to axis give best response

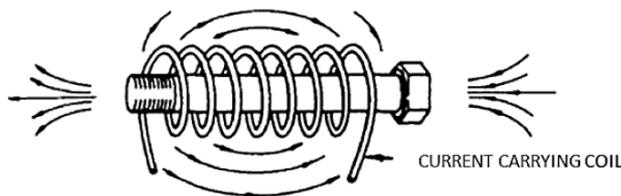


Poor

Fair

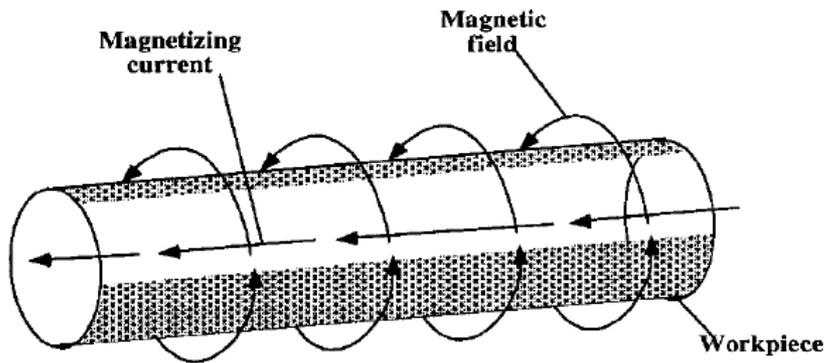
Good

Best



# Propeller Bolts MT Challenges

- Circular magnetization
- Indications 0° to 45° with respect to axis give best response



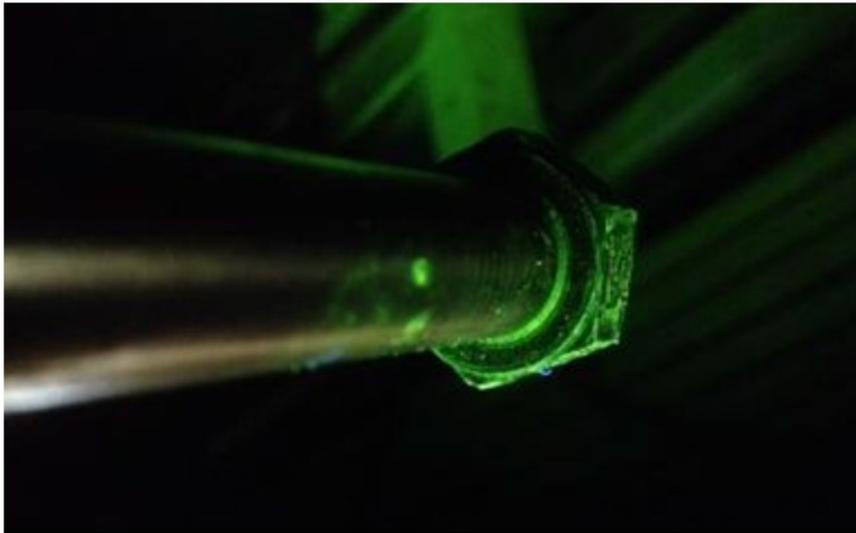
Best

Good

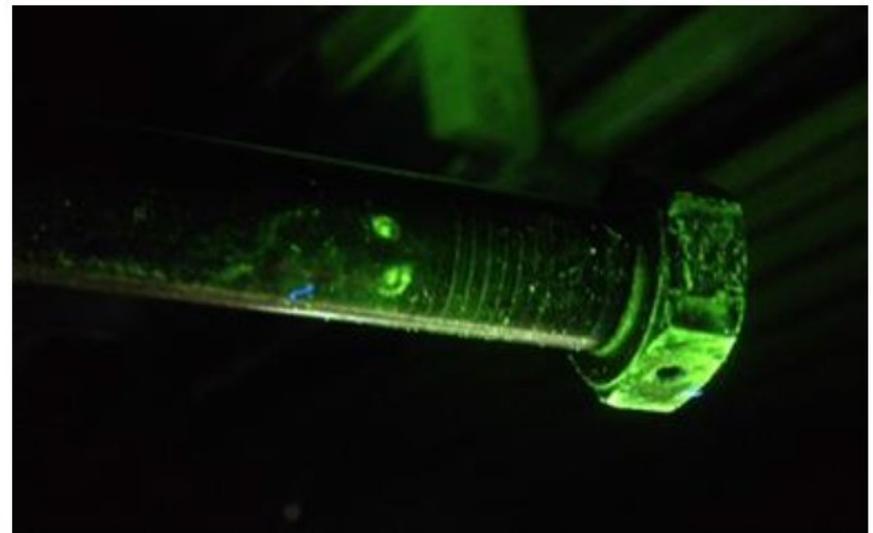
Fair

Poor

# Propeller Bolts MT Results



*Indication of cracks on a bolt*

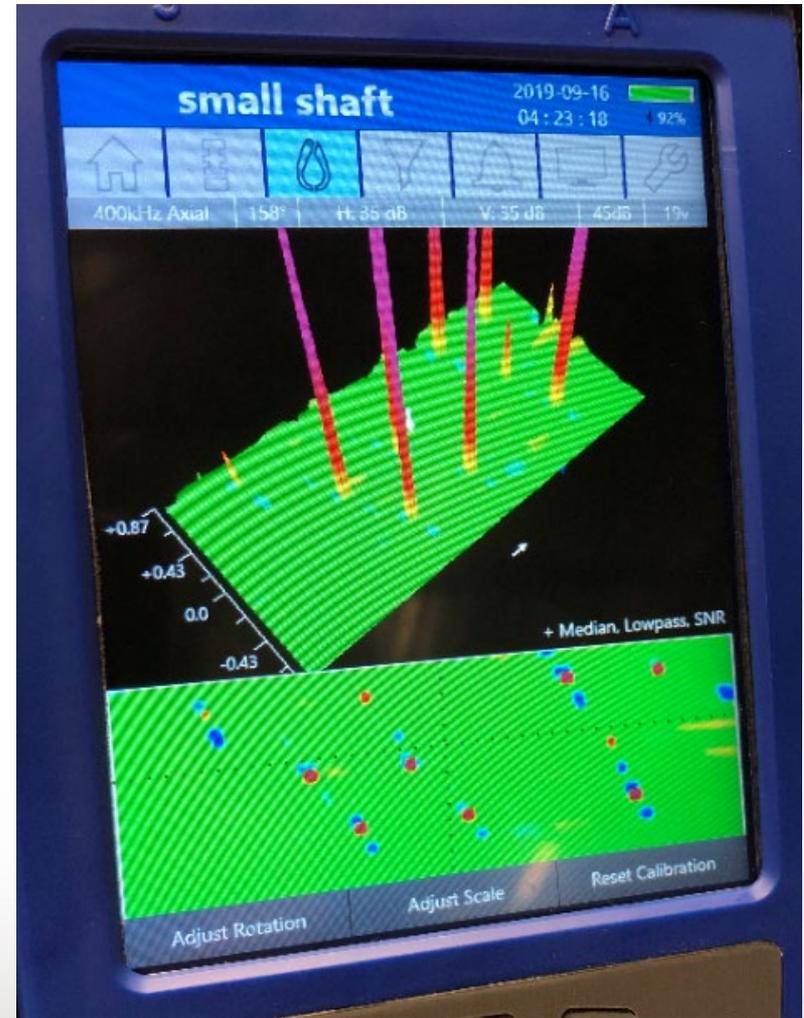
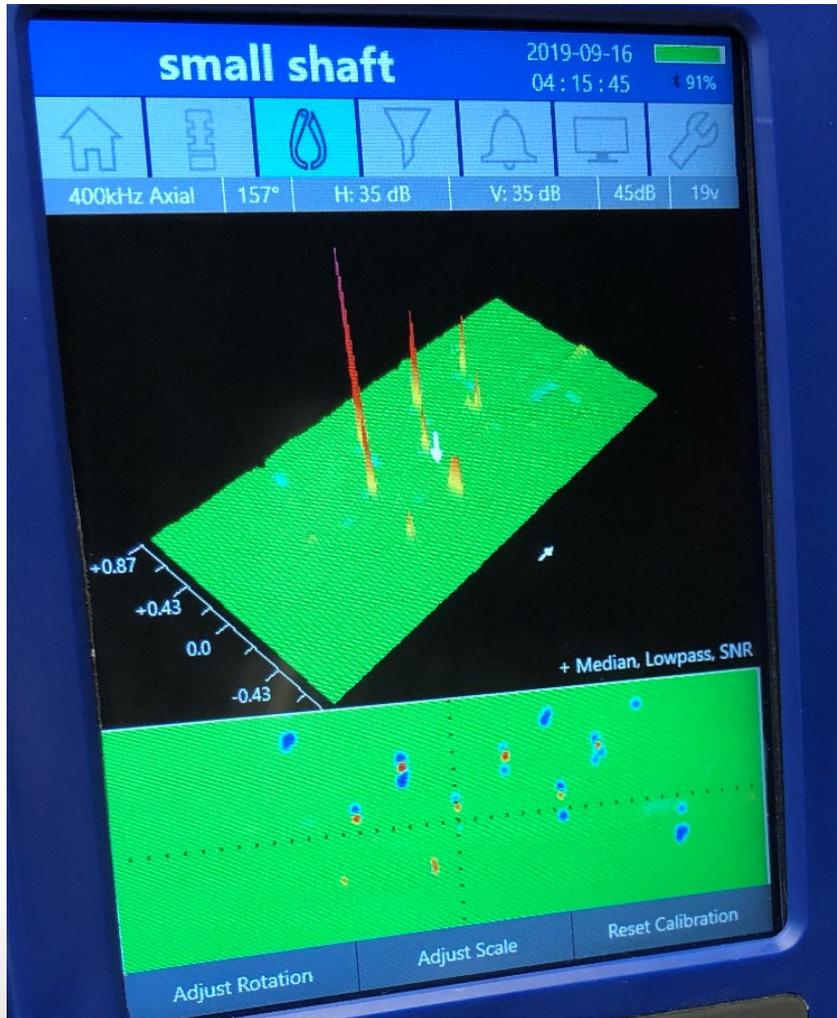


*Schematic Indication of cracks on a bolt*

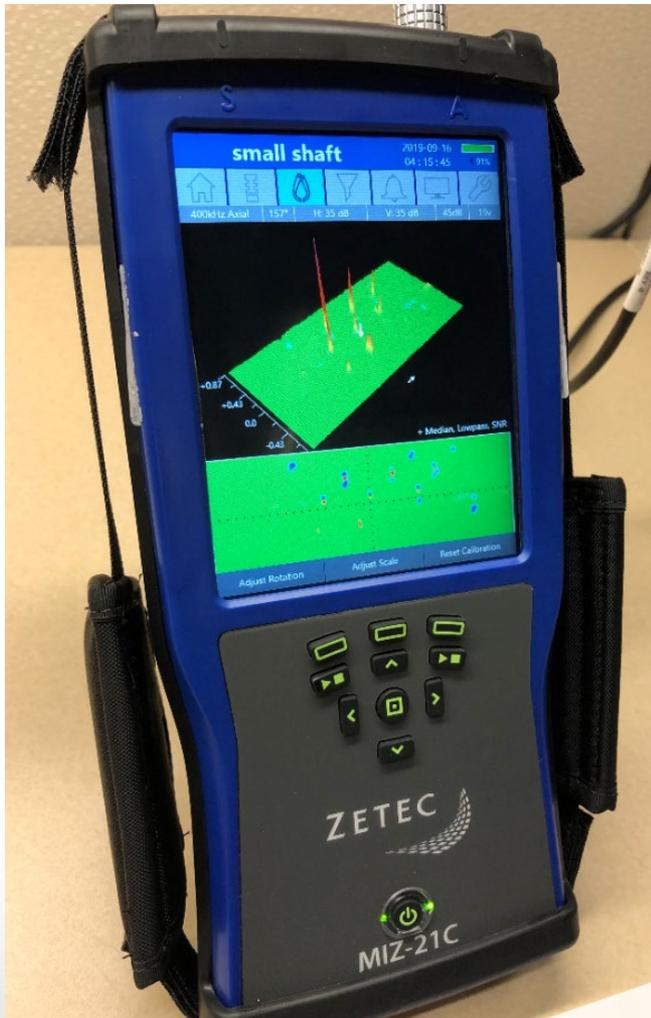
# Propeller Bolts Using Tape ECA



# Propeller Bolts Using Tape ECA Results



# Propeller Bolts Using Tape ECA



- Only one scan is needed to collect all data using a thin film printed coil ECA that is wrapped around the tube
- Indications can be any angle and Tape ECA will detect them
- Scan takes less than a minute per Propeller Bolt
- No need to handle chemicals or prepare surface

# Conclusions

- PT and MT have their advantages, but there are number of disadvantages that makes them suitable candidates for replacement with ECA
- ECA can find large and small indications in one scan and avoids having to use separate exams for low and high sensitivity penetrant materials
- During surface crack inspections around rivet holes paint does not need to be removed when using ECA, and if a Low Frequency ECA is used the subsurface indications can also be found
- ECA is capable of replacing many ferrous material MT surface inspections
- Propeller Bolts can quickly be inspected in one pass with ECA Tape Probes that have thin film printed coils that allow for small bend radius
- ECA can operate in a wider range of temperature and environmental conditions than PT and MT, in most cases has a higher POD, and can greatly improve productivity

# References



- P. Vijayaraghavan, “Magnetic Particle & Penetrant Inspection of Aerospace Components During Manufacture & Service”, The e-Journal of Nondestructive Testing 20, 1-6, (June 2015).
- NASA Preferred Reliability Practices, “Penetrant Testing of Aerospace Materials”, Practice No. PT-TE-1426, 1-6.
- NASA Preferred Reliability Practices, “Magnetic Particle Testing of Aerospace Materials”, Practice No. PT-TE-1425, 1-5.
- A Uludag, “The Magnetic Particle Inspection Examination of Aircraft Propeller Mounting Bolts”, Journal of Multidisciplinary Engineering Science and Technology 3, 1-5, (December 2016).
- L. Culbertson, “Eddy Current Inspection Conventional to Array”, 2017 A4A NDT Forum, 1-50, (September 2017).

***Thank You***  
***Questions?***

