Propulsion – Safety and Affordable Readiness (PSAR) Conference 2015
Baltimore, MD; March 30 - April 2, 2015

Engine Component CBM using Flexible ET Arrays for Crack Depth Measurement

31 March 2015

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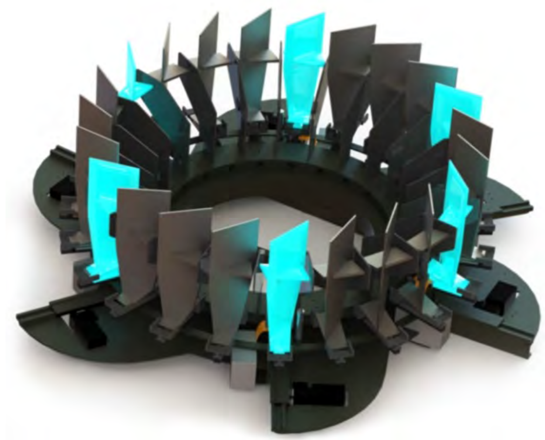
Case Studies

- **Case Study 1:** Commercial aircraft engine knife seal inspection
- **Case Study 2:** US military engine blade dovetail Inspection
  - (a) Crack detection sensitivity in regions with fretting damage
  - (b) Crack depth measurement for CBM
- **Case Study 3:** US military automated engine disk slot inspection
- **High-throughput disk inspection feasibility**

High-Throughput Inspection

Goals:

- **Reduce Inspection Time**
  - Inspect multiple features simultaneously (need many channels, fully parallel)
  - Inspect wide areas fast
  - Reduced surface preparation requirements enabling practical high-throughput inspection



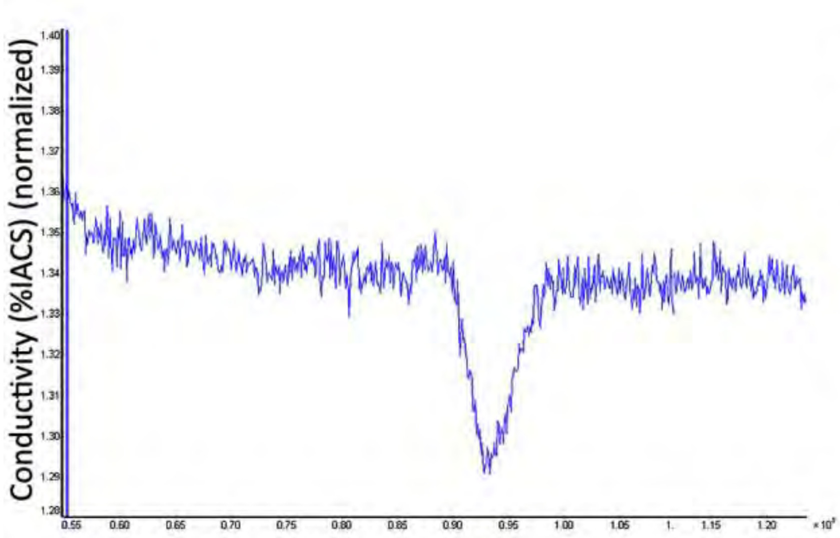
- **Reduce Costs**
  - Lower scanner complexity results from
    - Arrays with **many** channels
    - Flexible/conformable array construct
    - **Accurate lift-off measurement and defect response rescaling**
  - Provide improved performance without requiring rigidity to control lift-off
  - Reduce false indication rates while maintaining a high probability of detection
- **Minimize Burden on Inspector**
  - Automated analysis
  - Automated reporting

MWM-Array engine inspection is FAA approved on some commercial engines (inspecting thousands of components per year) and has been in use for ten years by the US Navy for engine disk slot inspection

>10x Higher Array Transit Velocity with Improved Signal-to-Noise

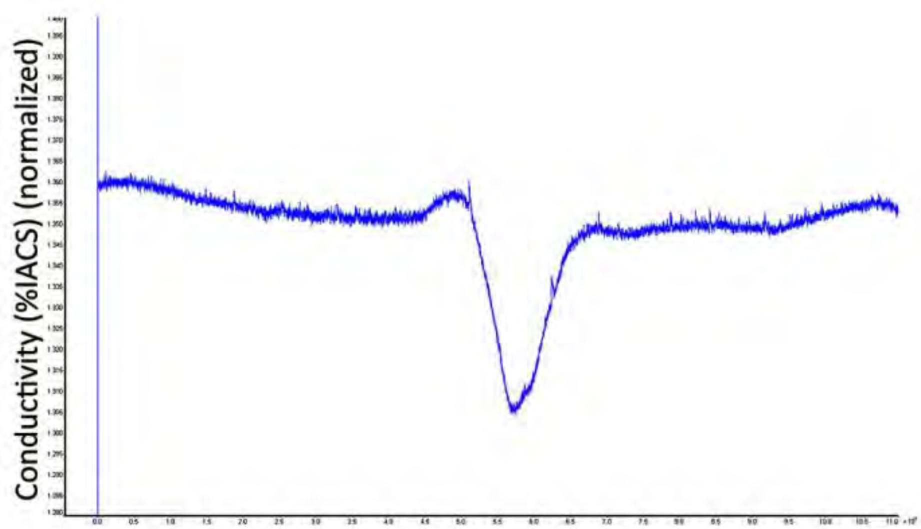
7000 Series Crack response

100 samples per second



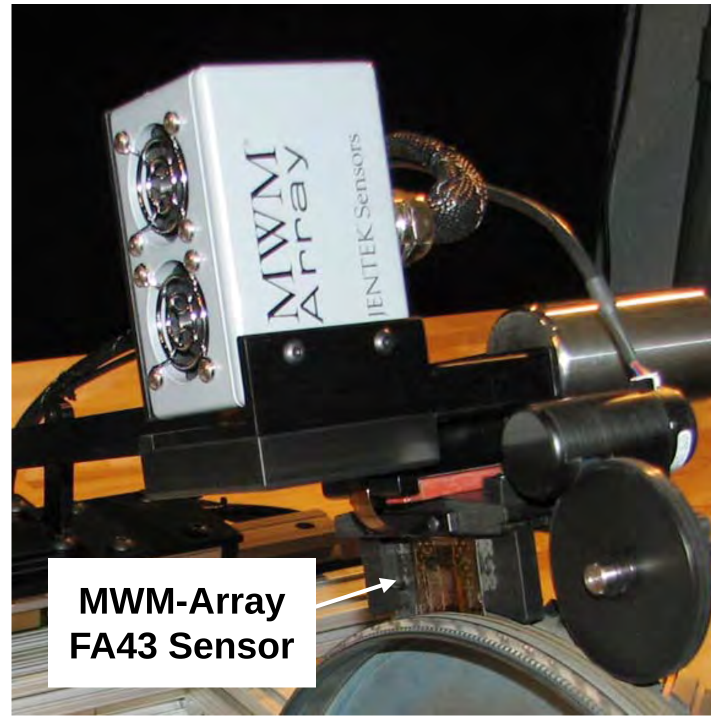
8200 Crack Response

1,300 samples per second



Case Study 1: Knife Seal Inspection

- “Technical aspects of the method are FAA approved” (See Service Bulletin)
- Engine OEM implemented this inspection
- Multiple systems in use world-wide since 2011
- AE family engine knife seal Inspection on several stages for cracks
- Thousands of engine stages inspected per year
- Inspection performed with blades in place (minimal disassembly saves substantial dollars)



MWM-Array FA43 Sensor adapted for knife seal inspection

AE SERIES PROPULSION SYSTEM Rolls-Royce

Service Bulletin Index

LIST OF AE 3007A SERIES SERVICE BULLETINS

SB No.	Rev No.	Title	Compliance Category	Date	Models Affected	Module or ATA Locator
AE 3007A-72-386		See AE 3007A-A-72-386				
AE 3007A-72-388	1	Engine - 6th- thru 13th-Stage Compressor Wheel Knife Edge Seals - Jentek Eddy Current Inspection	8	09-May-11	7A, 7A1/1, 7A1/3, 7A1, 7A1E, 7A1P, 7A2, 7A3	72-37-00

Reference: https://aeromanager.rolls-royce.com/control/publicsite/publicnoticeboard/categorylist?userAction=performDisplayDocument&selectedLevel=2&selectedLevelID=65

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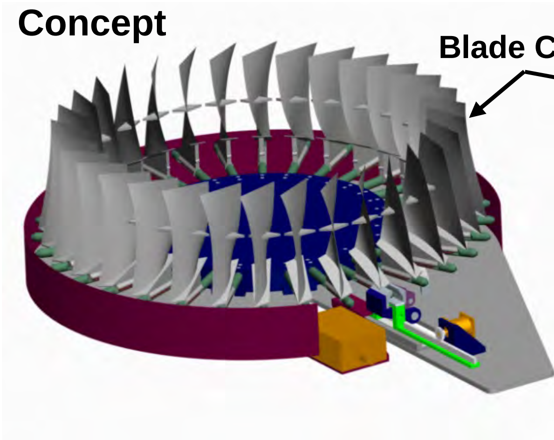
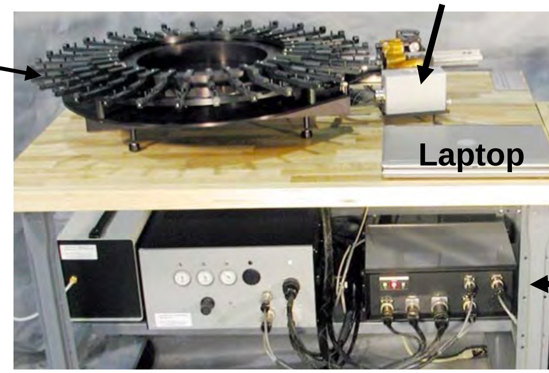
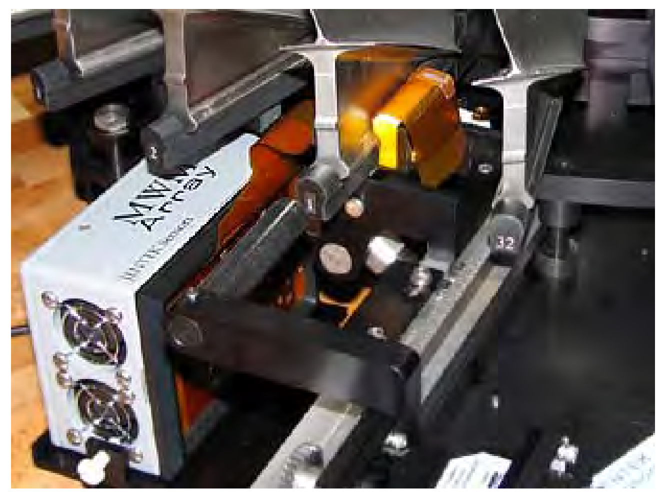
Case Study 2: Military Blade Dovetail Inspection



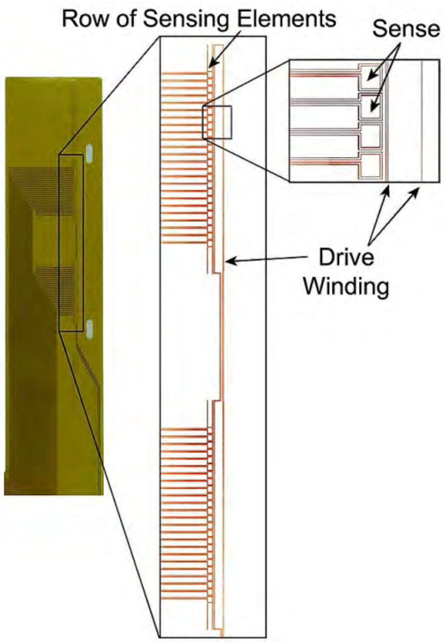


Completed U.S. Military Dovetail Inspection System - Delivered Fall 2006

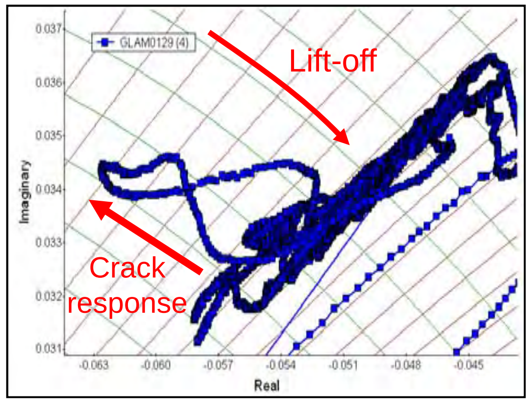


Case Study 2: Military Blade Dovetail Inspection

MMW-Array Sensors

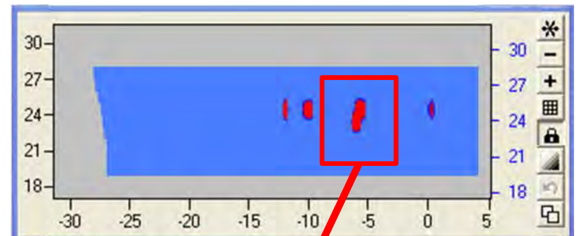


Precomputed Database (Grid)



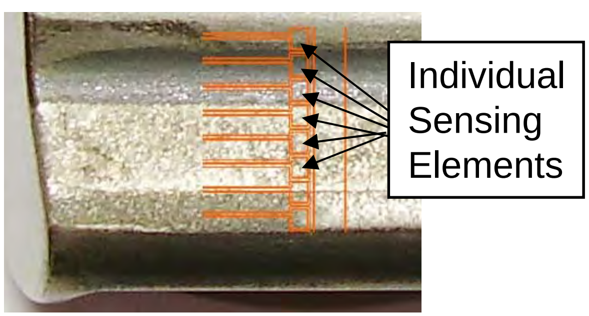
Crack response rescaled based on lift-off

C-Scan Image

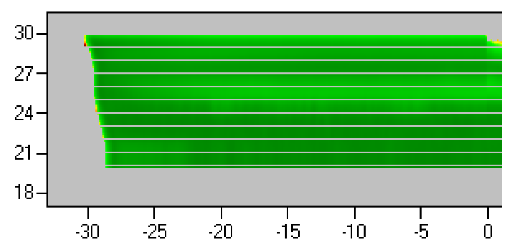


42-mil Crack

Sensor Coverage

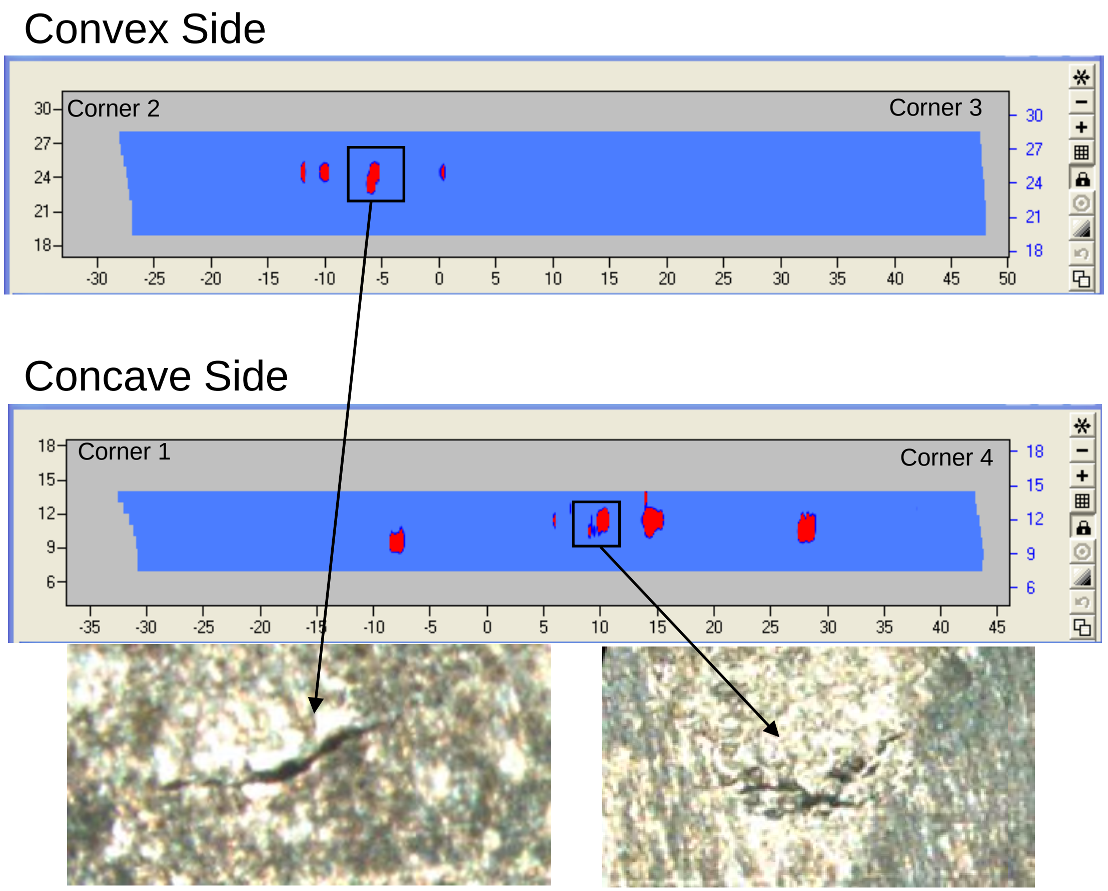


Lift-Off Imaging



Sensor Position at Edge of Dovetail

Case Study 2a: Blade Dovetail Crack Detection Performance



42-mil Crack

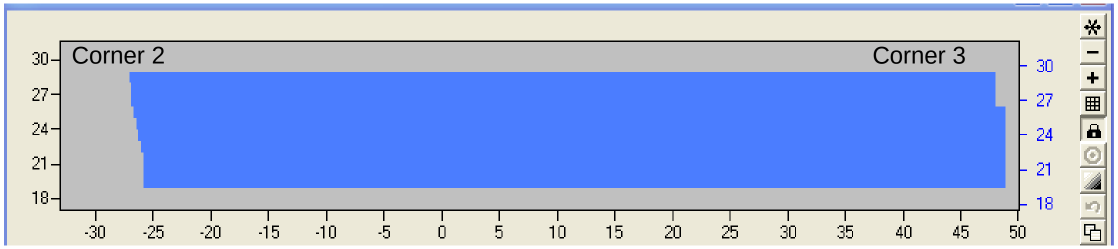
75-mil Crack Cluster (Maximum Crack Length 50 mils)

- Training Set Blade with "Known Cracks"
- Cracks verified using acetate replicas
- On similar blades, MWM-Arrays detected cracks that were **not found by the OEM optical method**
- **These are tight cracks in regions with fretting damage**

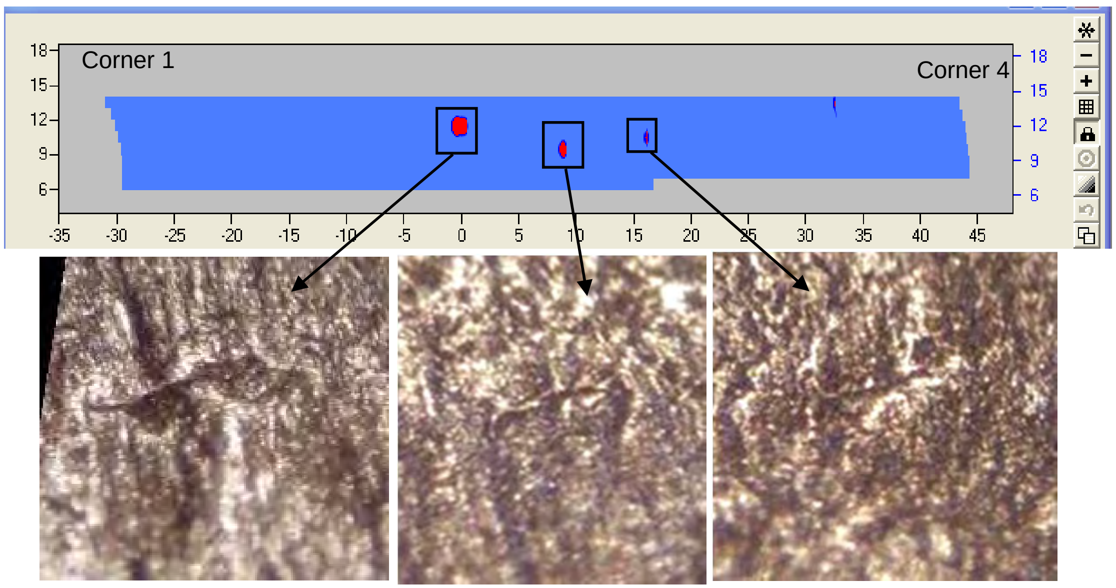
NOTE: Missing using optical methods is not surprising given length.

Case Study 2a: Blade Dovetail Crack Detection Performance

Convex Side



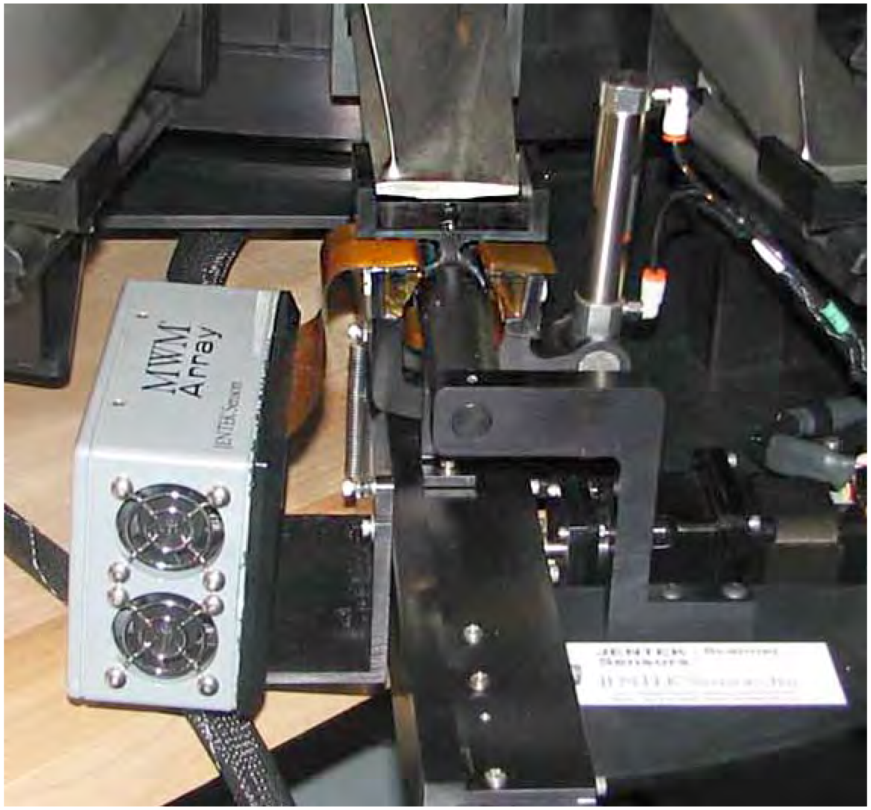
Concave Side



20-mil Crack *15-mil Crack* *15-mil Crack*

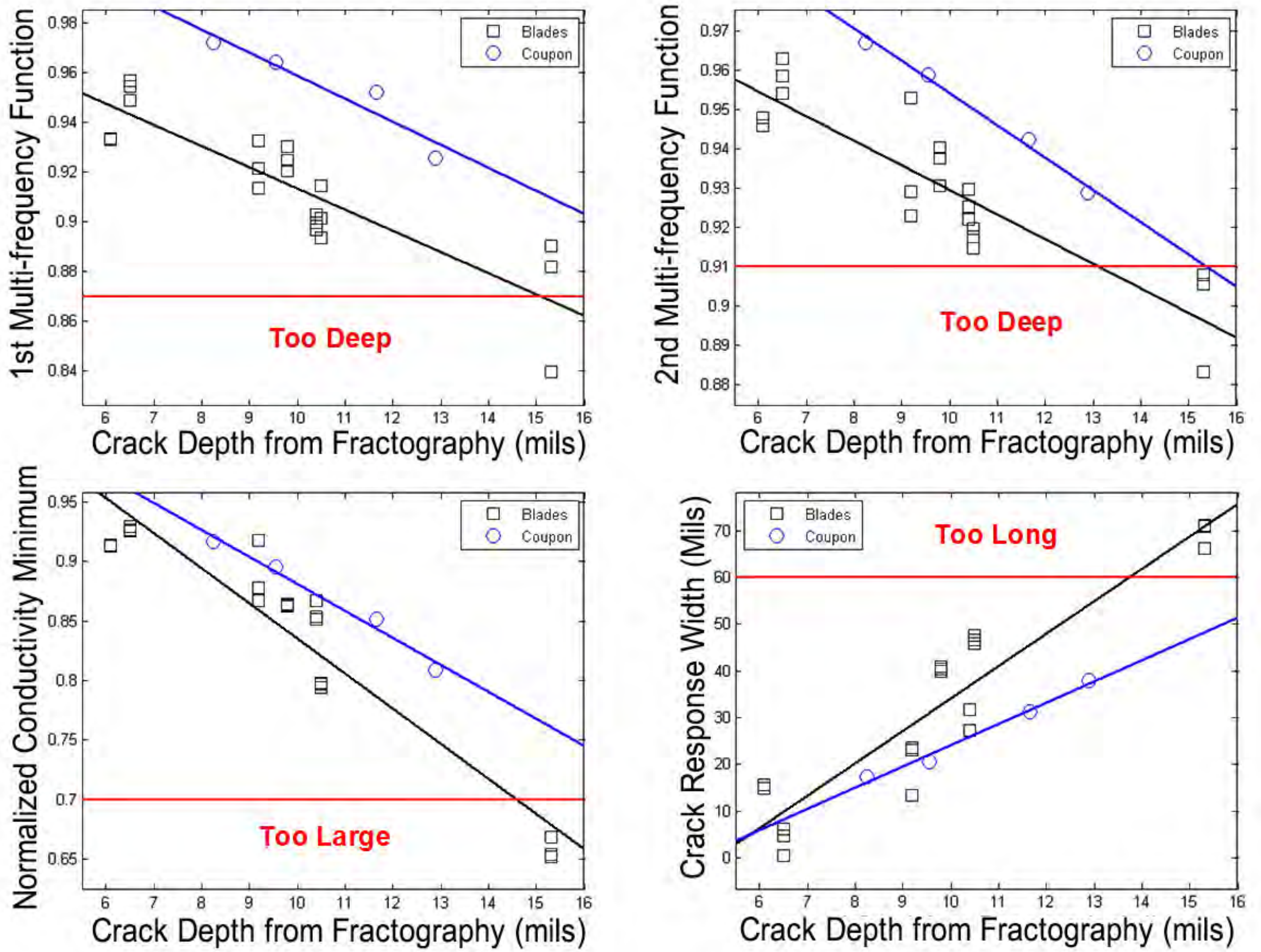
- Training Set Blade identified as having "No Cracks"
- Cracks found and verified
- These three verified cracks were not found by the OEM optical method

Case Study 2b: Military Engine Crack Depth Measurement



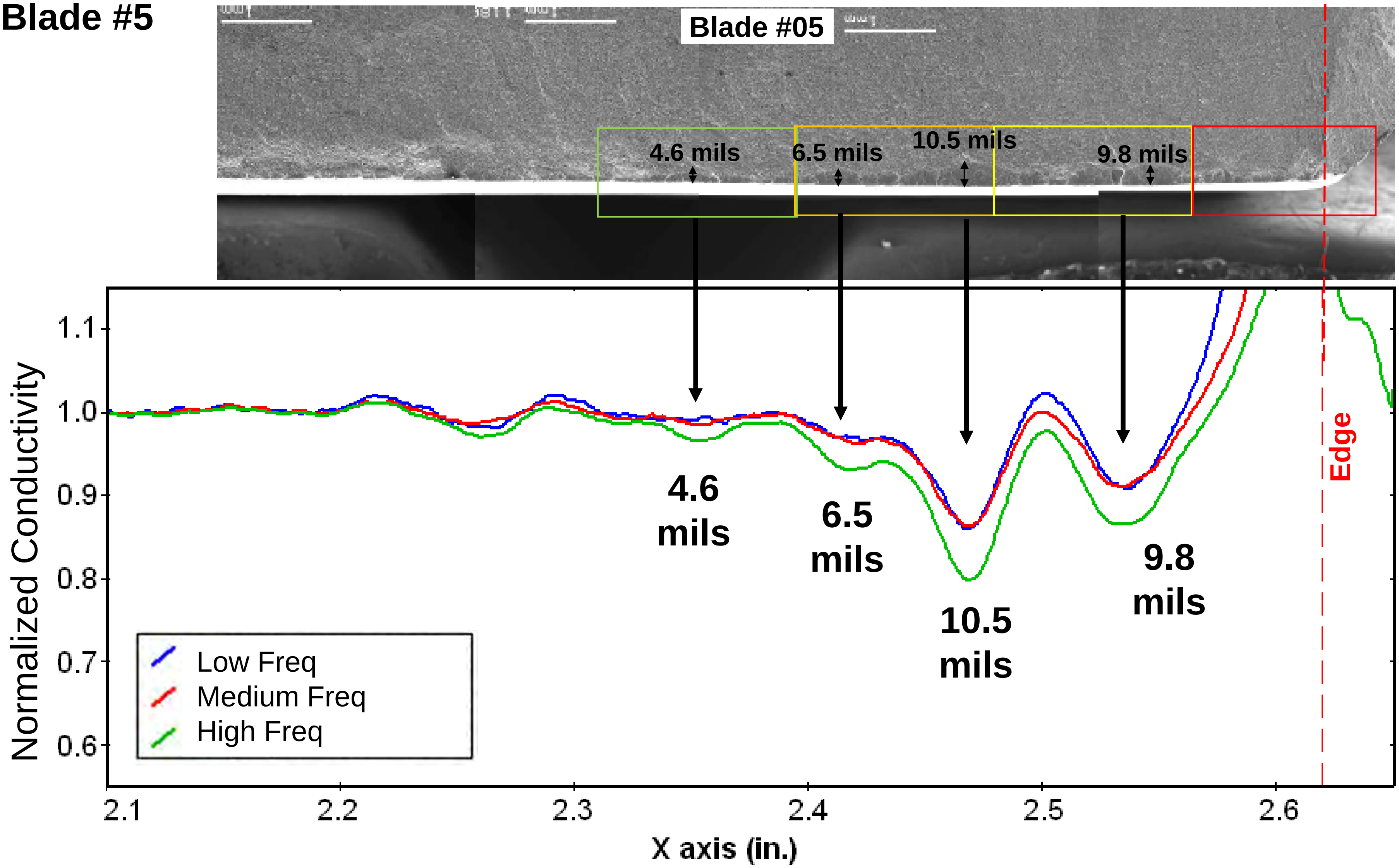
- Engine Blade Dovetail
- Provide crack depth measurement to enable CBM /repair of blade dovetail for life extension
- Technical approach: multiple frequency MWM-Array detection, location and depth sizing for cracks in regions with fretting damage
- Validation method – Detection performance validation included POD study
- Status: Solution validated and system delivered

Case Study 2b: Crack Depth Measurement Results



Case Study 2b: MWM-Array Conductivity Response

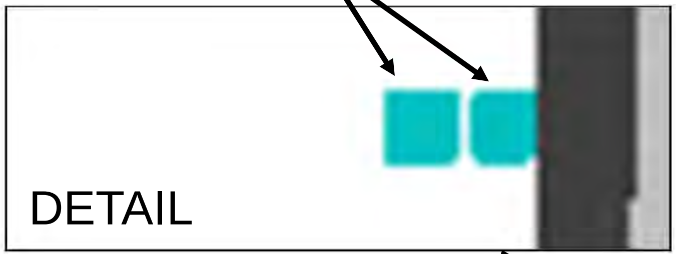
Blade #5

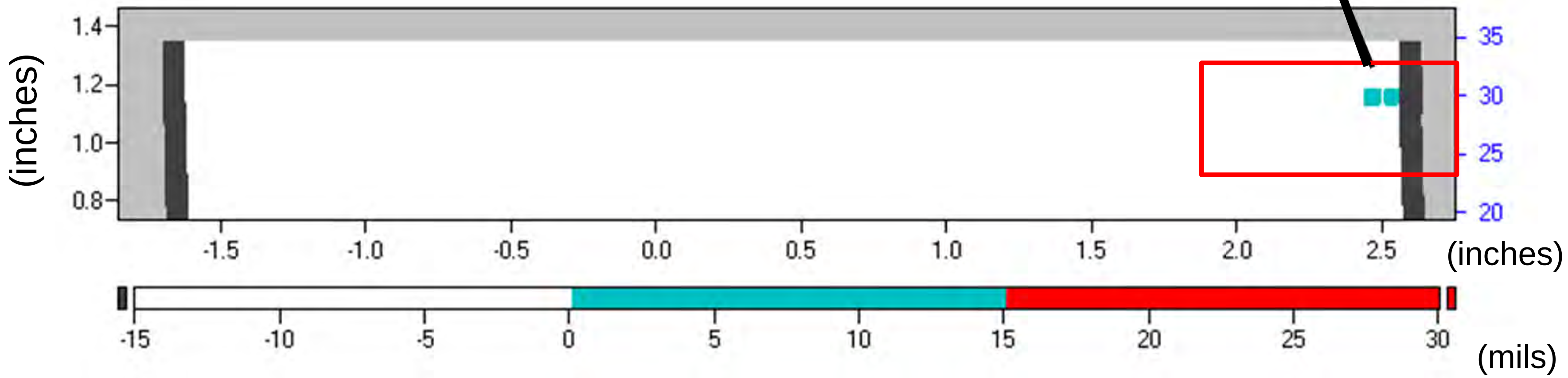


Case Study 2b: User Interface Output

Blade #5

Shallow cracks (Light blue)

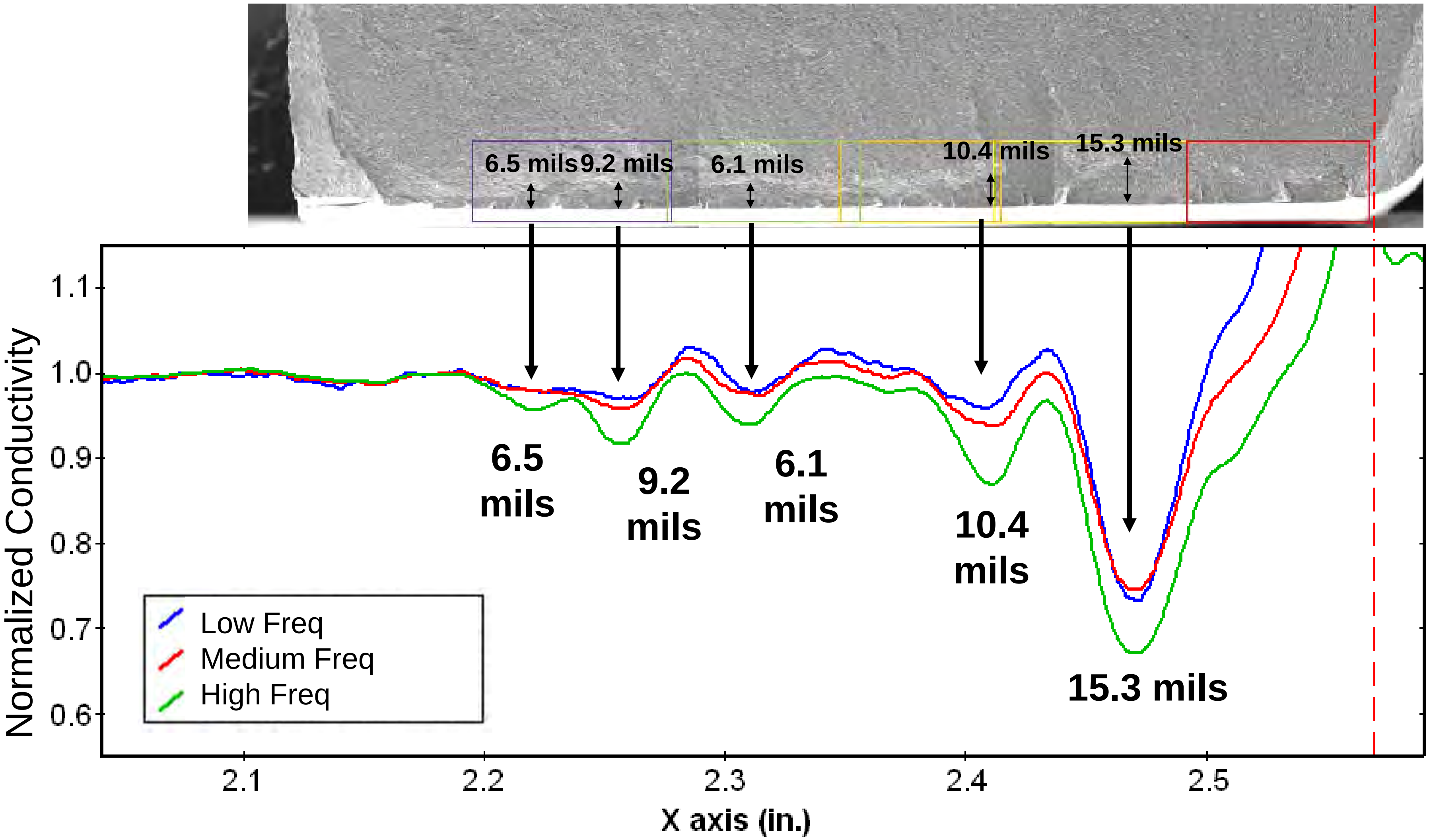




Entire image encompasses one complete side of dovetail

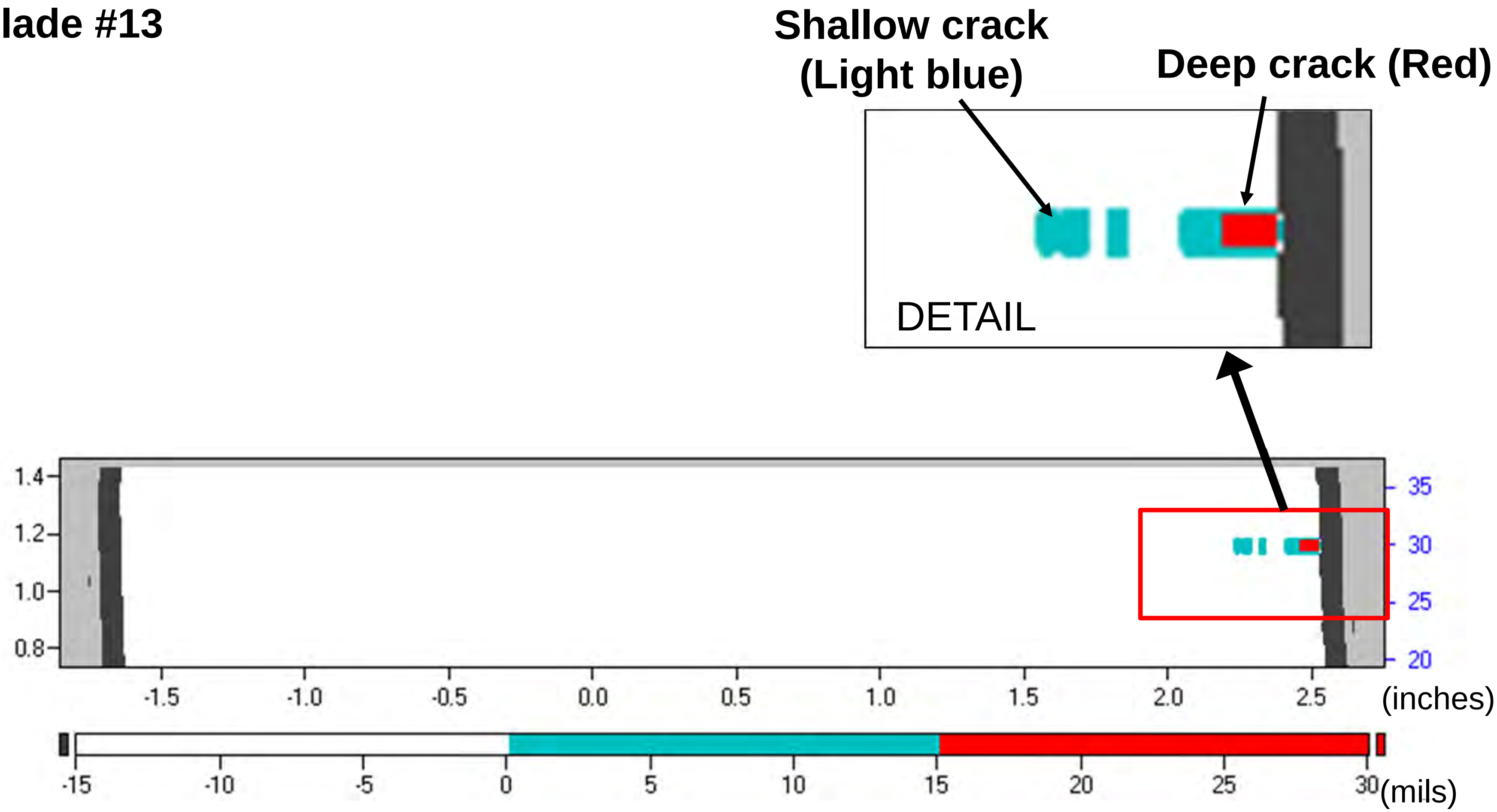
Case Study 2b: MWM-Array Conductivity Response

Blade #13



Case Study 2b: User Interface Output

Blade #13



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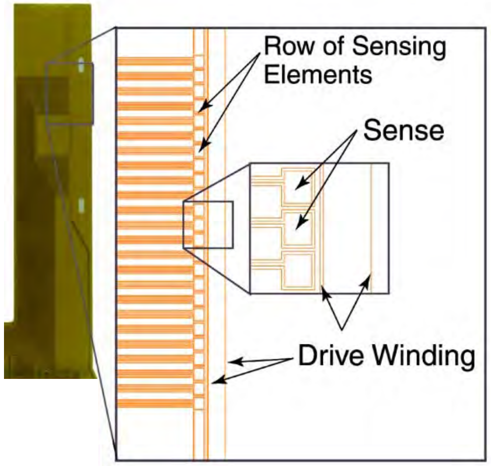
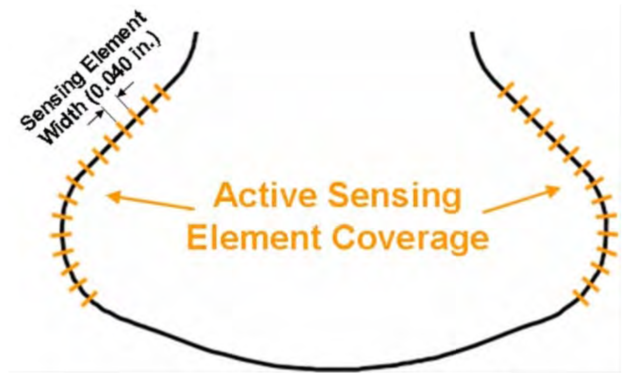
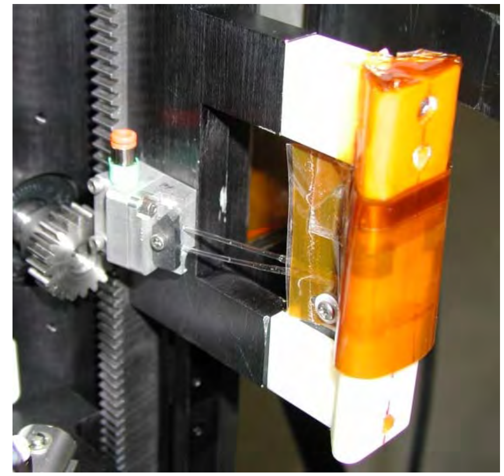
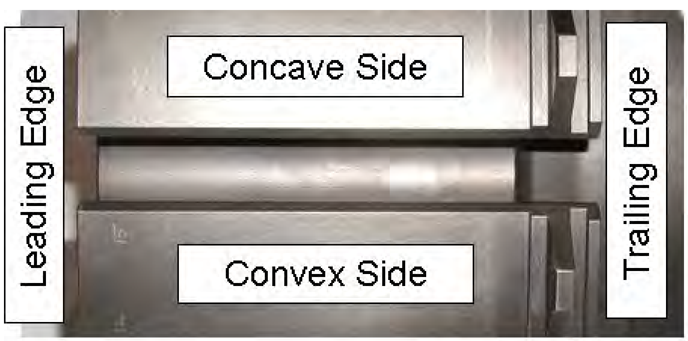
- **High-throughput disk inspection feasibility**

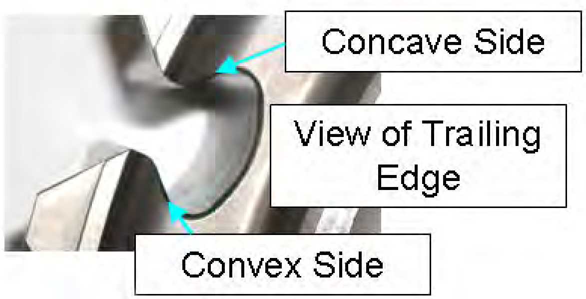
Case Study 3: Automated Engine Disk Inspection System

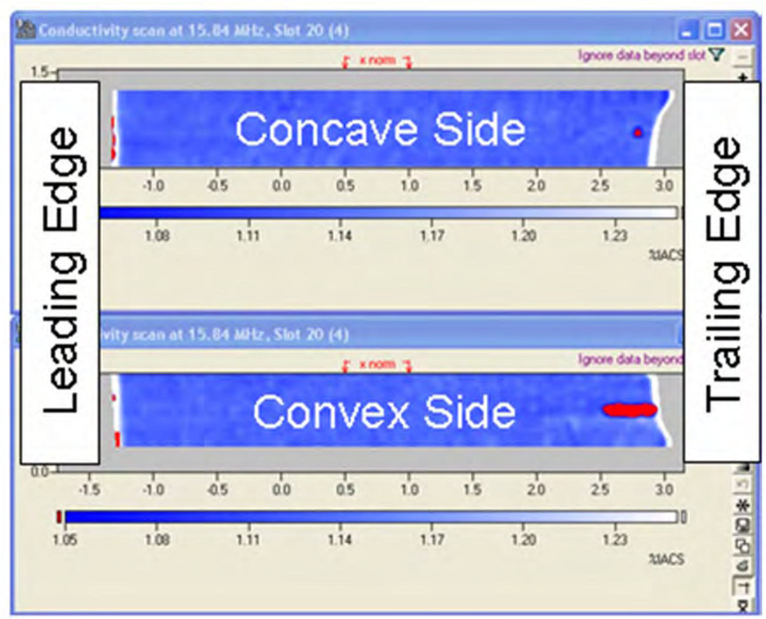








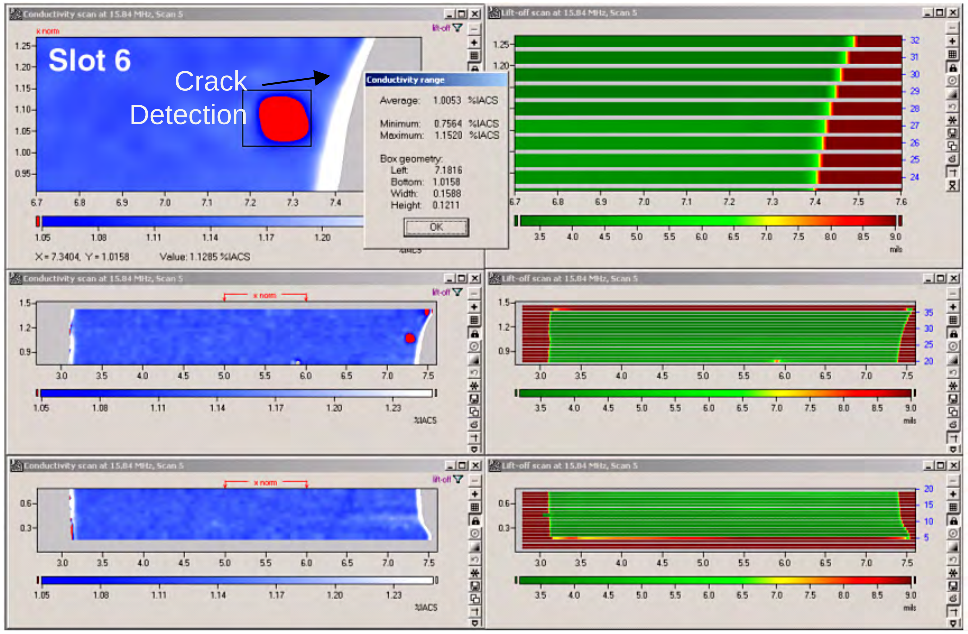




Case Study 3: Automated Engine Disk Inspection System

- In use at NAVAIR Depot since April 2005, **with "no noticeable change in sensitivity", for a decade**
- Nine disks with **verified cracks detected**, several of these large and small cracks **not detected by conventional ET and LPI**
- No false indications (over >15000 slots inspected: false indication rate <0.01%)

Conductivity **Lift-Off**



Winner, FAA-Air Transport Association 2007 "Better Way" Award for "MWM and MWM-Array Engine Component Inspection Technology"

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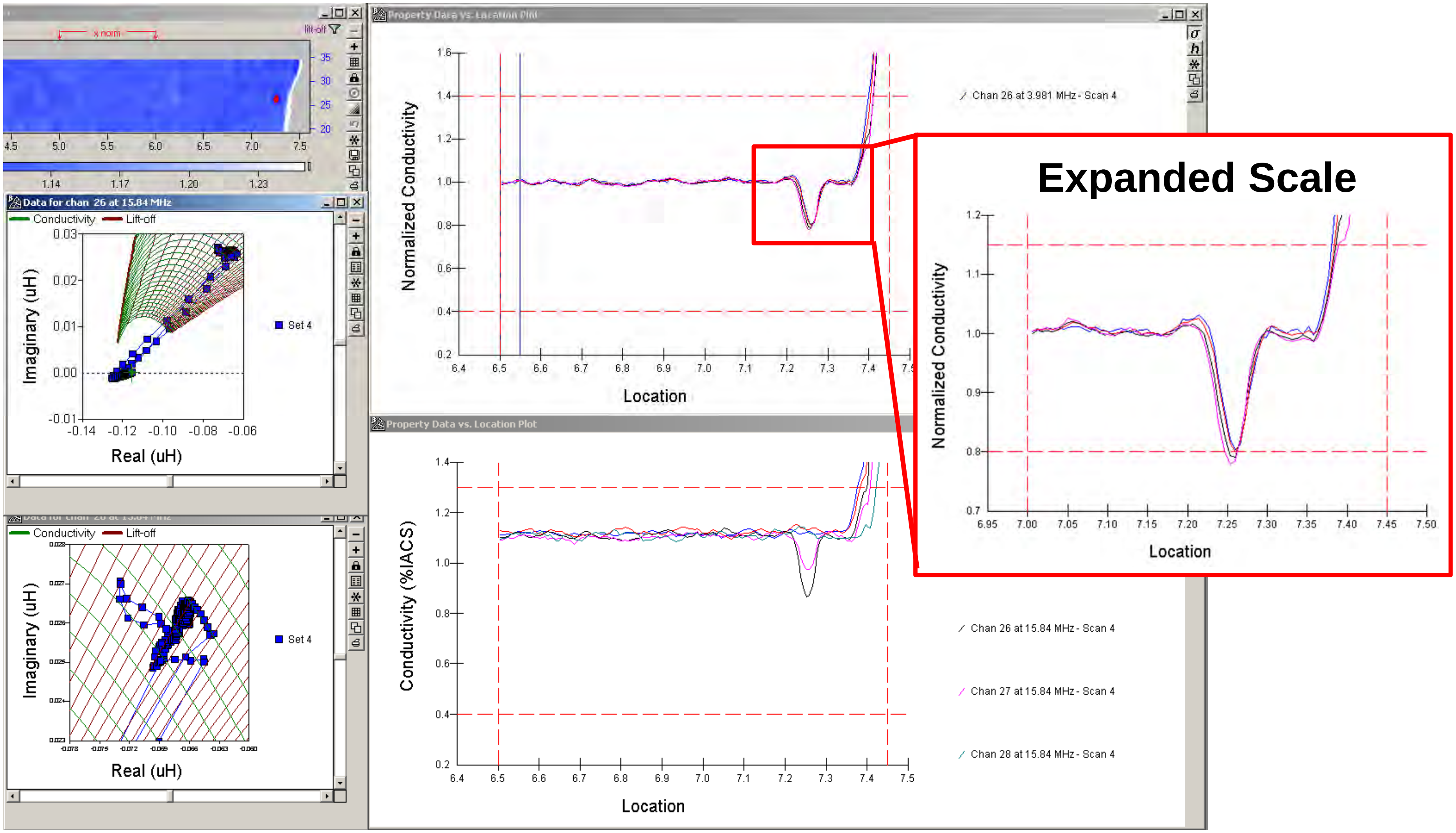
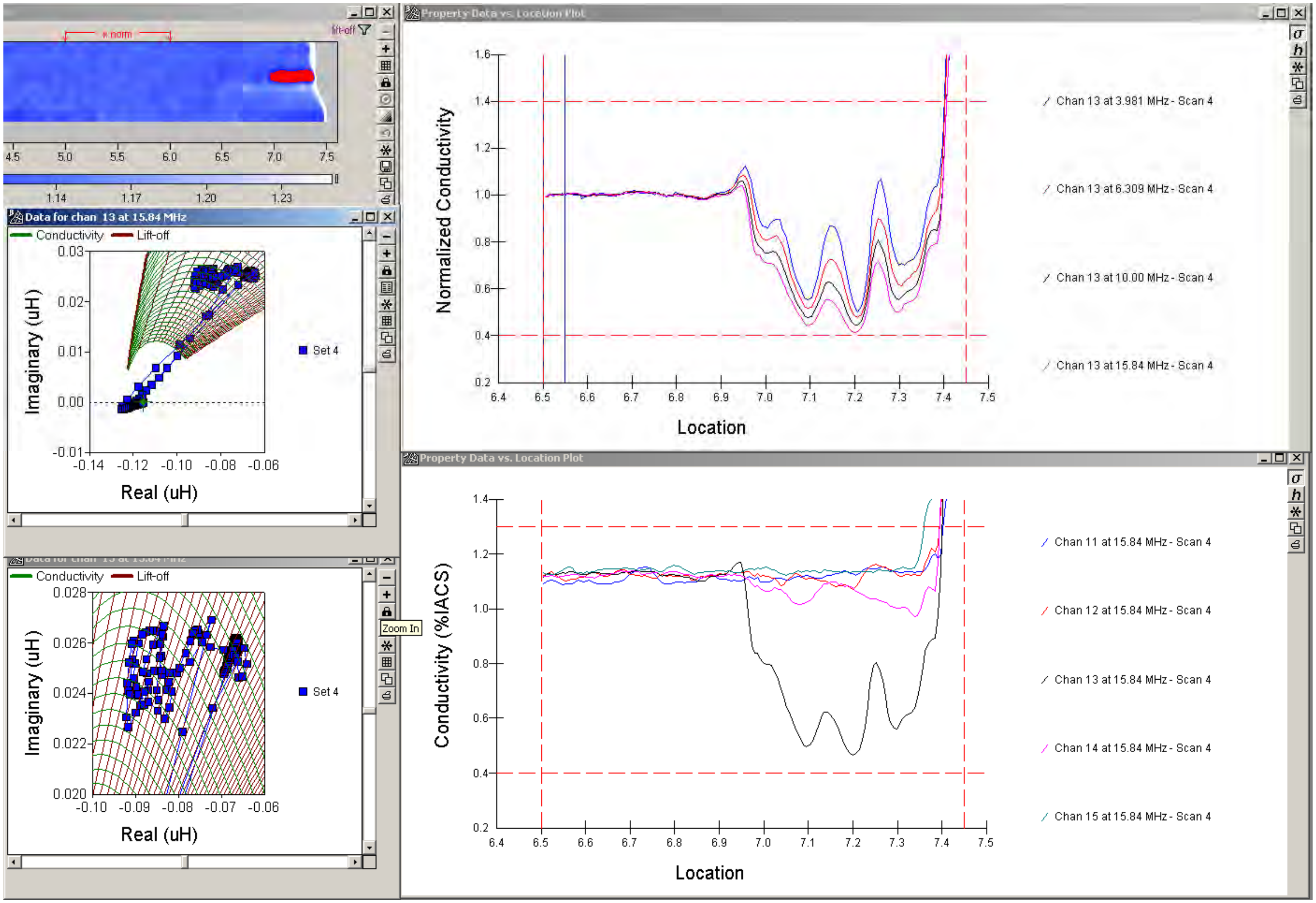
Case Study 3: Engine Disk Slot Data

Disk #04, Slot #20, Concave Side

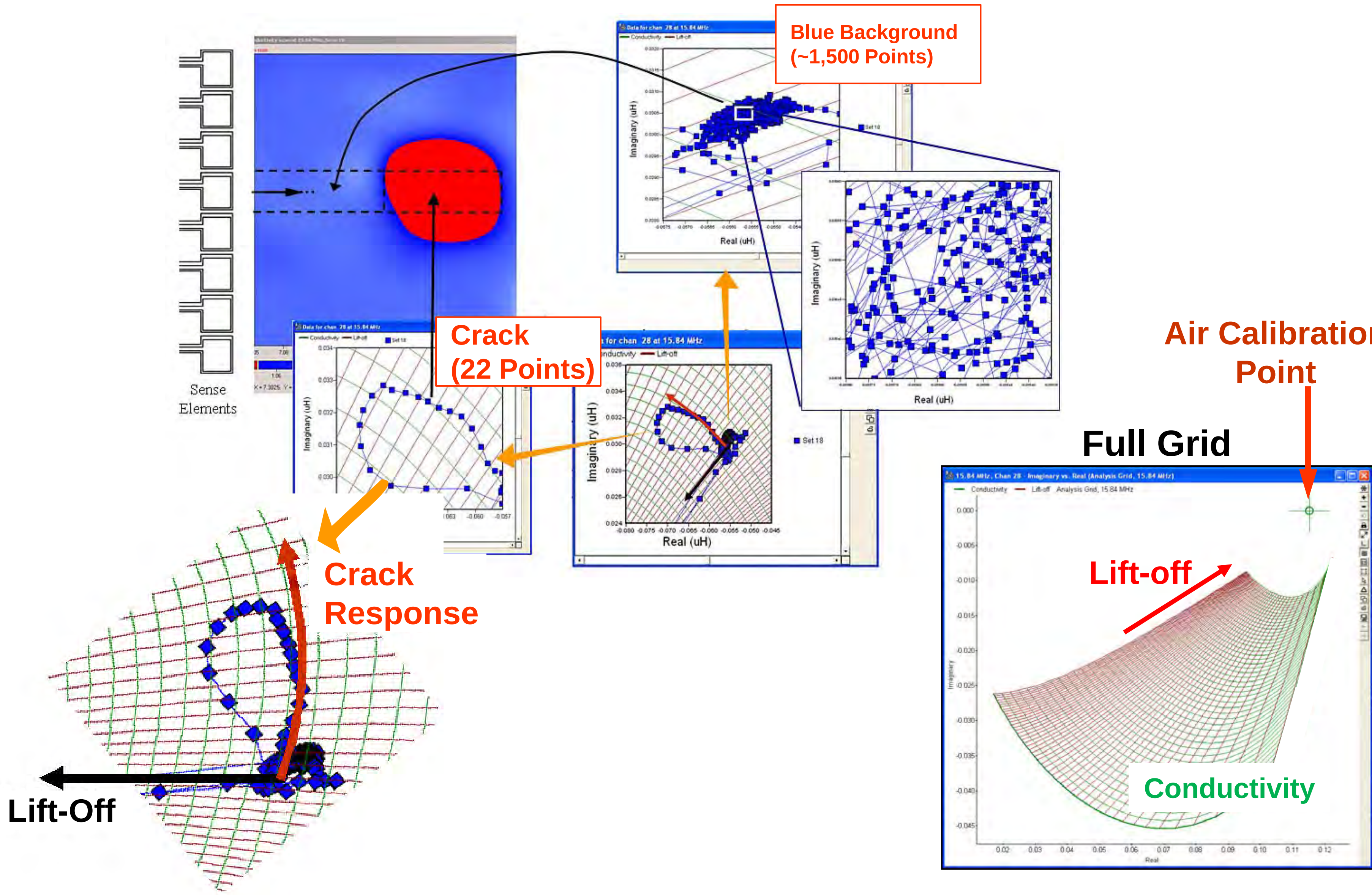


Case Study 3: Engine Disk Slot Data

Disk #04, Slot #20, Convex Side



Air Calibration and Conductivity/Lift-Off Grids



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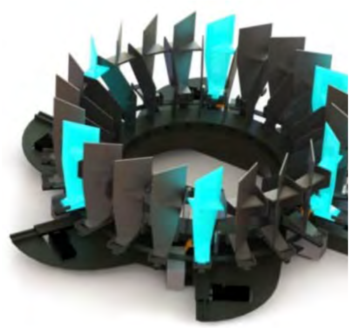
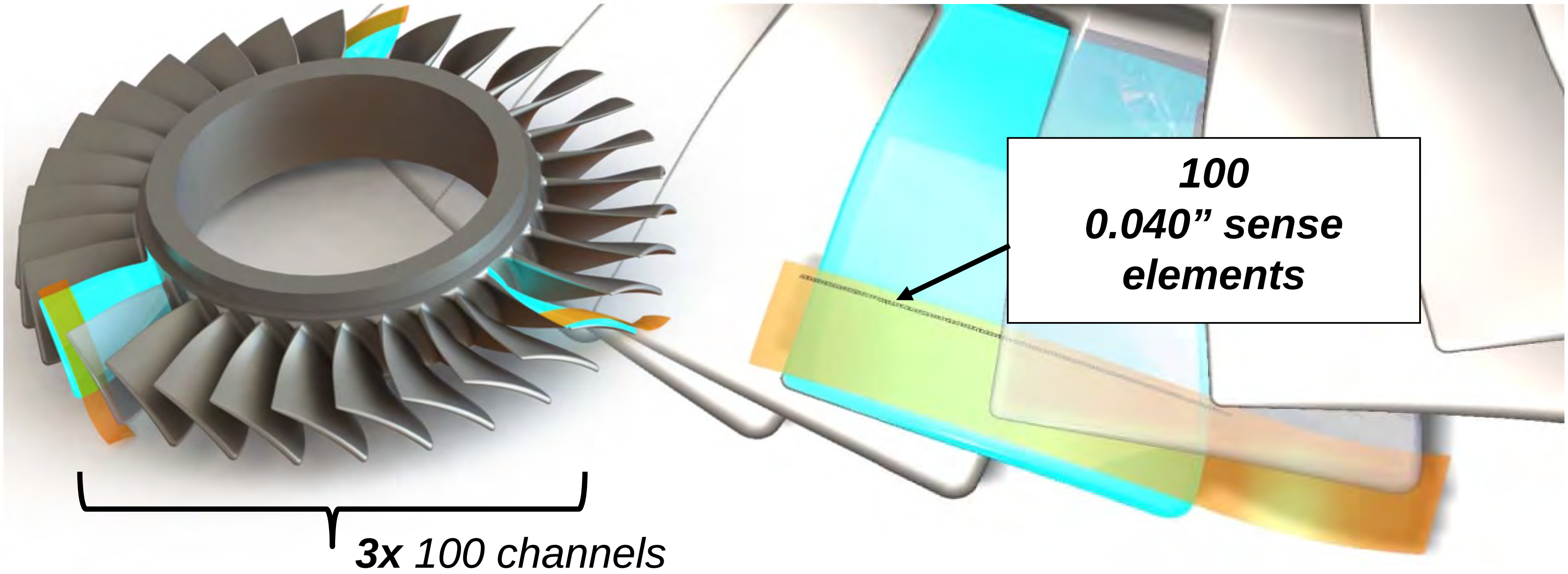


Higher Throughput Inspection Options

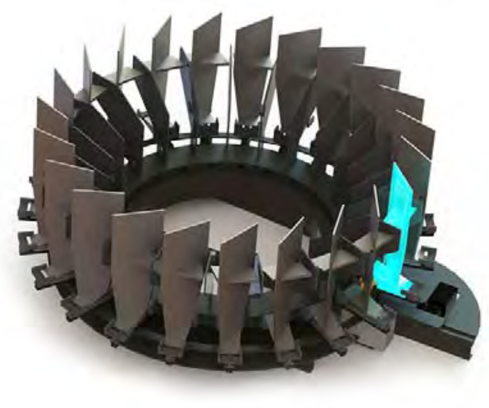
- **Scan broad surface areas**
- **Scan multiple features at same time**



Higher Throughput Inspection Options

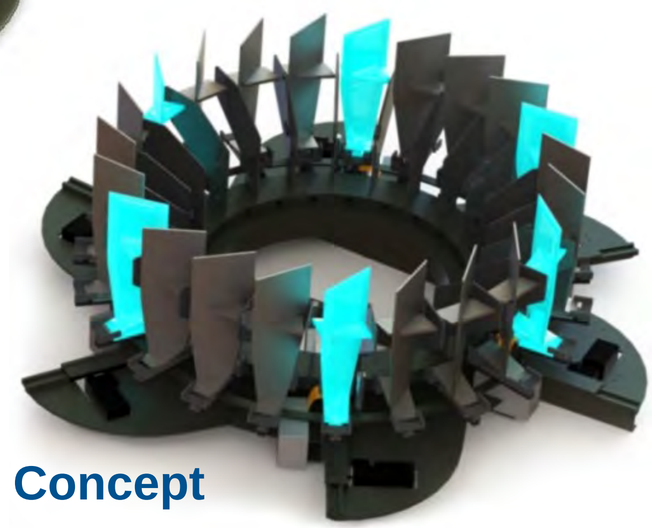
Current Approach:

Scan 1 blade at a time,
37 channels



Scan up to 6 blades at once

3 Blade Concept

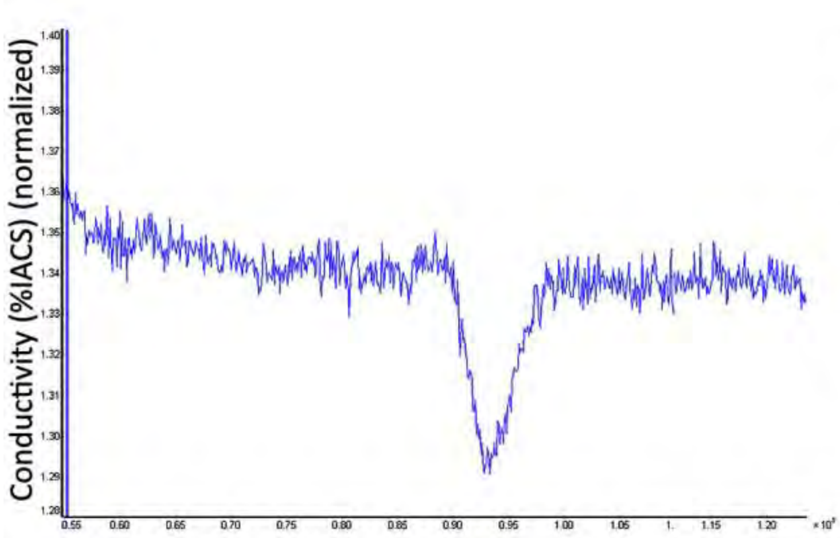


6 Blade Concept

>10x Higher Array Transit Velocity with Improved Signal-to-Noise

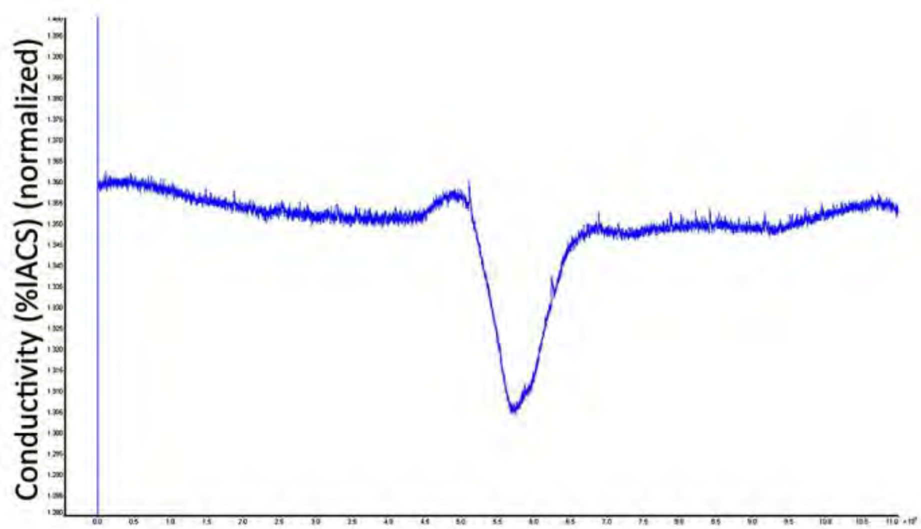
7000 Series Crack response

100 samples per second



8200 Crack Response

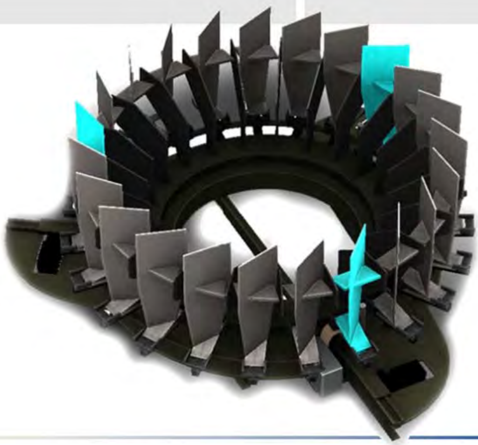
1,300 samples per second



High Throughput Case Study: Disk Slot Inspection

Current Navy System Performance

	7000 System, 37 channels	8200 System, 119 channels
Scan time	90 seconds per blade	9 seconds
Rotation time	30 seconds per blade	30 seconds
Total Time 1 array	1 hour	20 minutes
Total Time 2 arrays	N/A	10 minutes
Total Time 3 arrays	N/A	7 minutes



Questions?

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