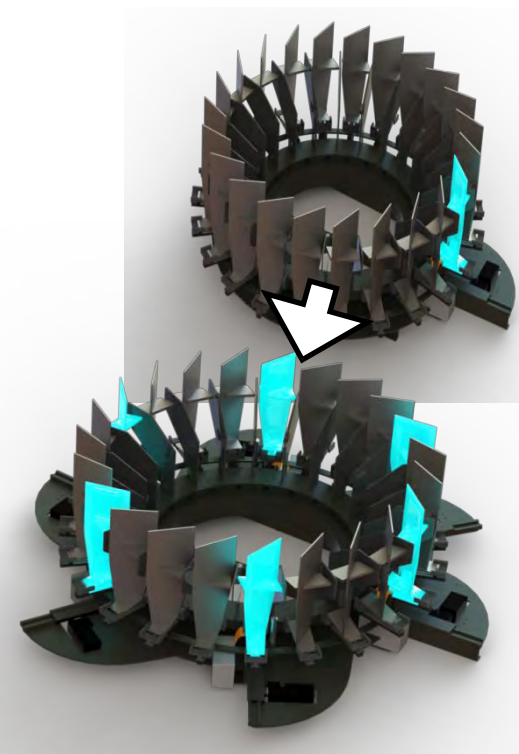


High Throughput Engine Component Inspection Using Massively Parallel Solutions

Neil Goldfine, Scott Denenberg, Yanko Sheiretov, Stuart Chaplan, Don Straney,
Mark Windoloski, and Zachary Thomas

JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013
Tel: 781-642-9666; Email: jentek@jenteksensors.com
web: jenteksensors.com



High Throughput Inspection

Goal:

▪ Reduce inspection time

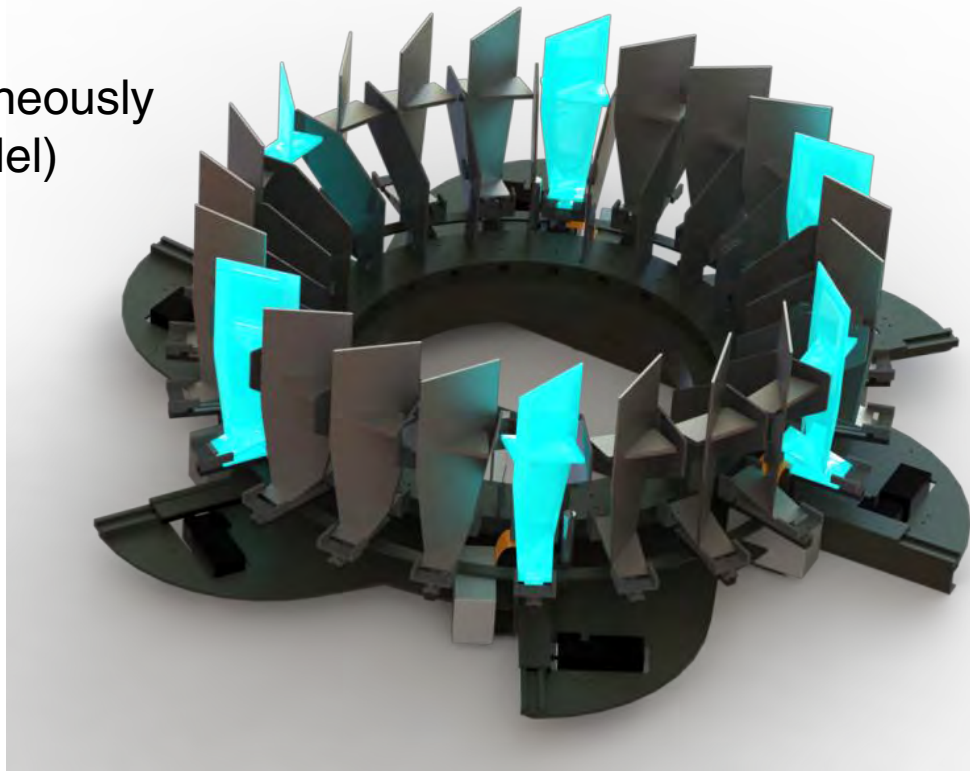
- ✓ Inspect multiple features simultaneously (need many channels, fully parallel)
- ✓ Inspect wide areas fast
- ✓ MWM-Array reduces surface preparation requirements enabling practical high throughput inspection

▪ Reduce costs

- ✓ Lower scanner complexity results from having arrays with many channels
- ✓ MWM-Arrays provide improved performance without requiring rigidity to control lift-off
- ✓ Reduced false indication rates

▪ Minimize burden on inspector

- ✓ Automated analysis
- ✓ Automated reporting



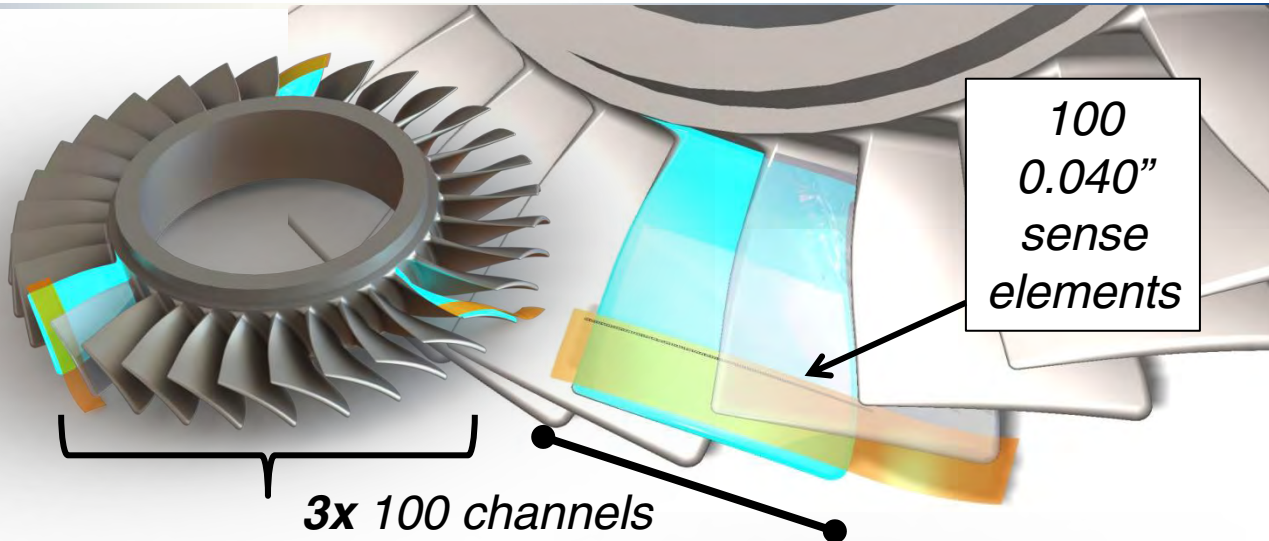
MWM-Array engine inspection is FAA approved on some commercial engines and has been in use by the US Navy for over 5 years with great success

High Throughput Inspection Possibilities

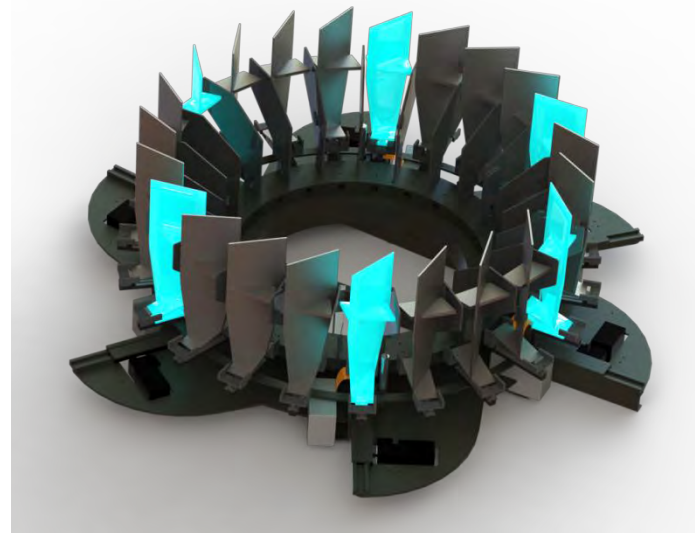


37 channels

OLD



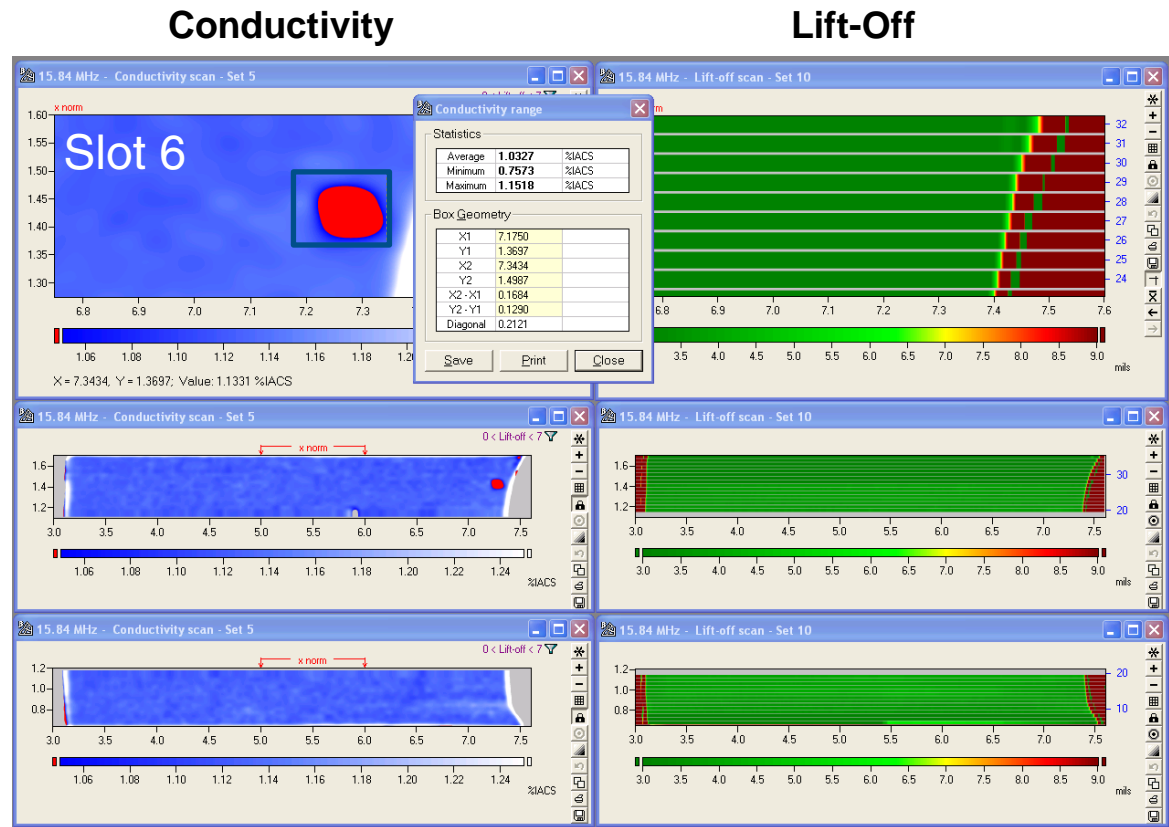
NEW



6x 39 channels

Engine Disk Slot Inspection (at NAVAIR Depot since 2005)

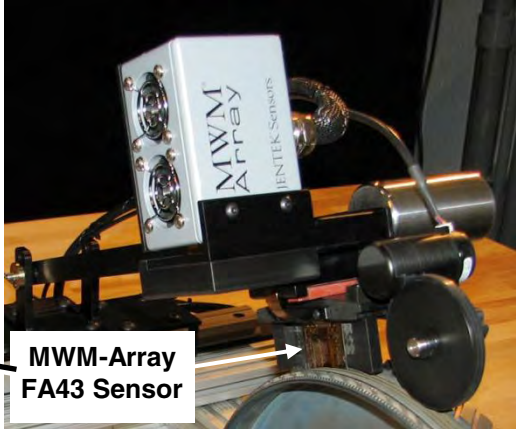
- Model-Based Calibration Verification before, during and after inspections (using MWM-Arrays)
- Disks with verified cracks detected, several of these verified large and small cracks **not detected by conventional ET and LPT**
- No false indications above threshold after over 9000 inspections



Other Inspections for Engine Applications

Knife Edge Seal Inspection

- OEM & FAA approved engine component NDT with MWM-Arrays
- FA43 MWM-Array sensor and conformable cartridges
- “Technical aspects of the method are FAA approved”

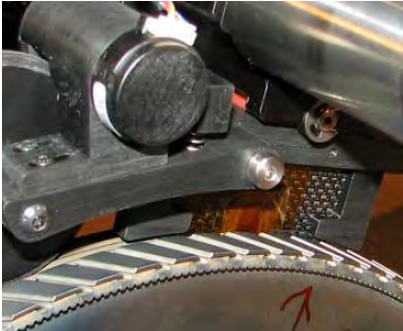


MWM-Array
FA43 Sensor

AE SERIES PROPULSION SYSTEM
Service Bulletin Index

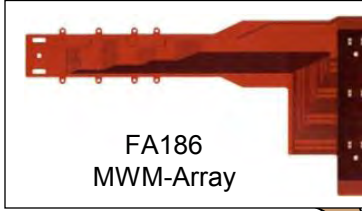
LIST OF AE 3007A SERIES SERVICE BULLETINS

SB No.	Rev No.	Title	Compliance Category	Date	Models Affected	Module or ATA Locator
AE 3007A-72-386		See AE 3007A-A-72-395				
AE 3007A-72-388	I	Engine - 6th thru 13th Stage Compressor Wheel Knife Edge Seals - Jentek Eddy Current Inspection	II	09-May-11	7A, 7A1/L, 7A1/3, 7A1, 7A1E, 7A1P, 7A2, 7A3	



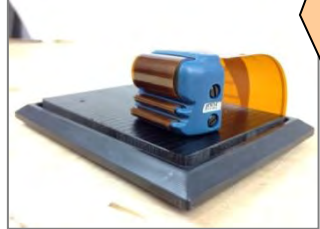
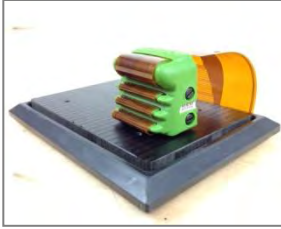
Fir Tree Inspection

- Fully integrated, automated and transportable

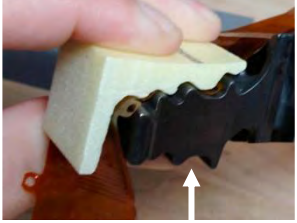
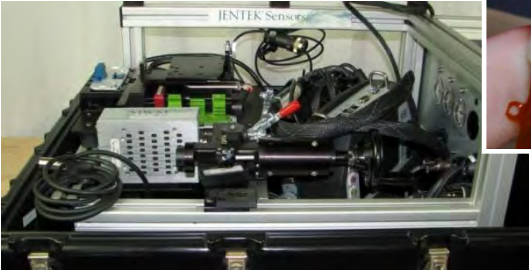


FA186
MWM-Array

MWM-Array FA186 Sensor Cartridges



Packaged System

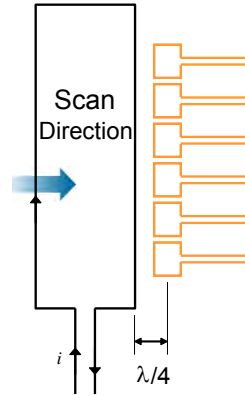
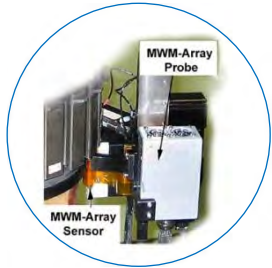


Non-application blade shown for prototyping reference

Technology Summary / Overview

1. Sensors: MWM®-Arrays & MWM®-Rosettes

- **Paradigm shift** in sensor design (first priority is predictable response based on physics-based modeling)



2. Next Generation 8200 α GridStation® Electronics

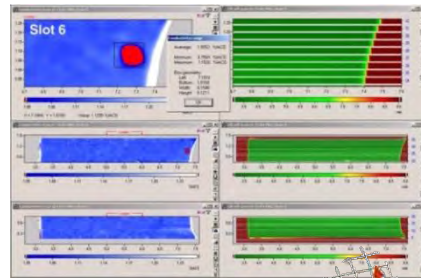
- 10x signal-to-noise improvement
- Very low frequencies (deep penetration)
- Crack detection through up to 0.5 inches of material
- Reduced drift



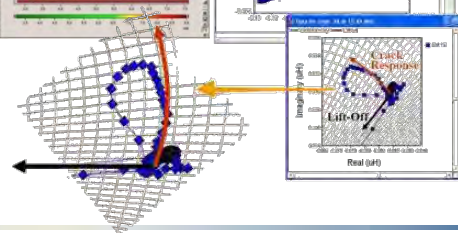
3. GridStation® Software using Hyperlattices™

- **Rapid, autonomous data analysis**
Performs multivariate inverse method (MIM) using precomputed databases
- Defect Images
- Performance Diagnostics
- Noise Suppression

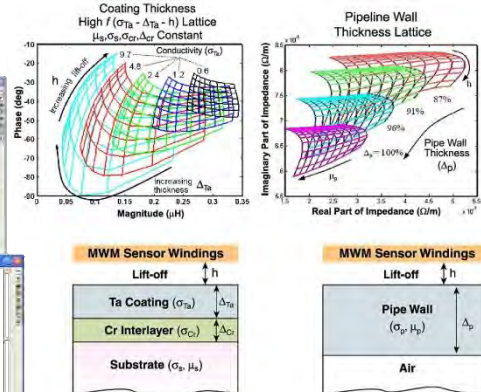
Images



Analysis

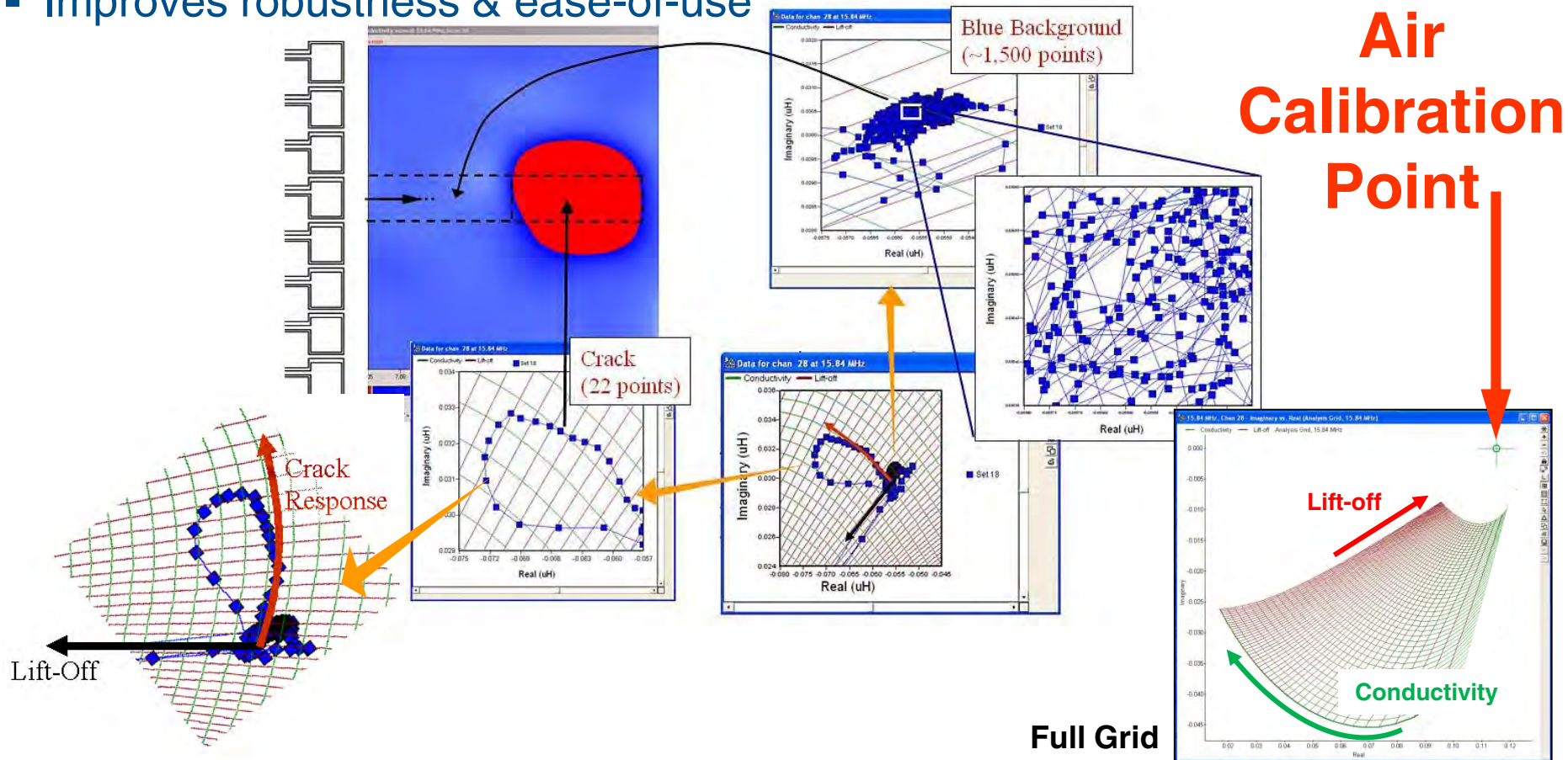


Solve Multiple Unknown Problems
MIM



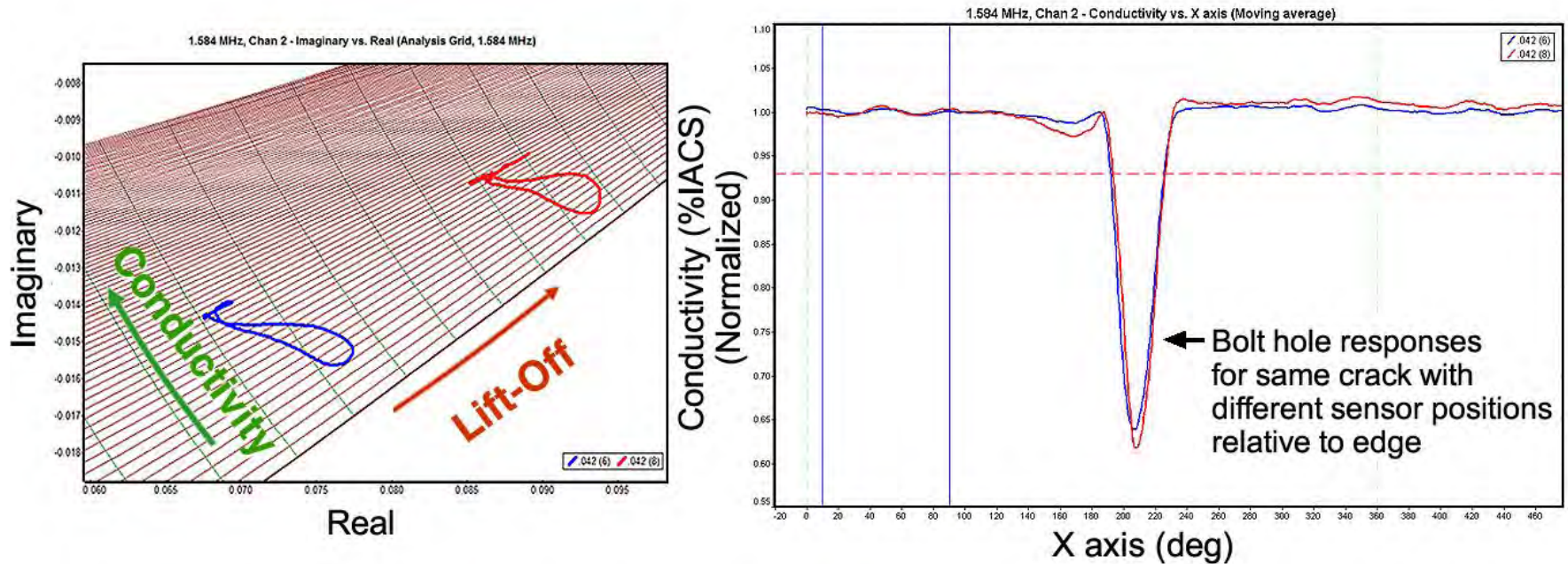
“Air” Calibration and Rapid Data Analysis

- Calibration in air eliminated opportunity for human error and avoids masking of degraded instrument performance.
- Grid methods convert impedance into conductivity and lift-off at each point in the image
- Improves robustness & ease-of-use



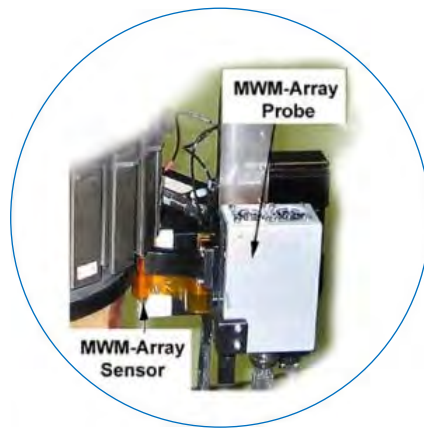
Grid Method Advantage

Automatically Rescales Crack Response for Lift-Off Variation



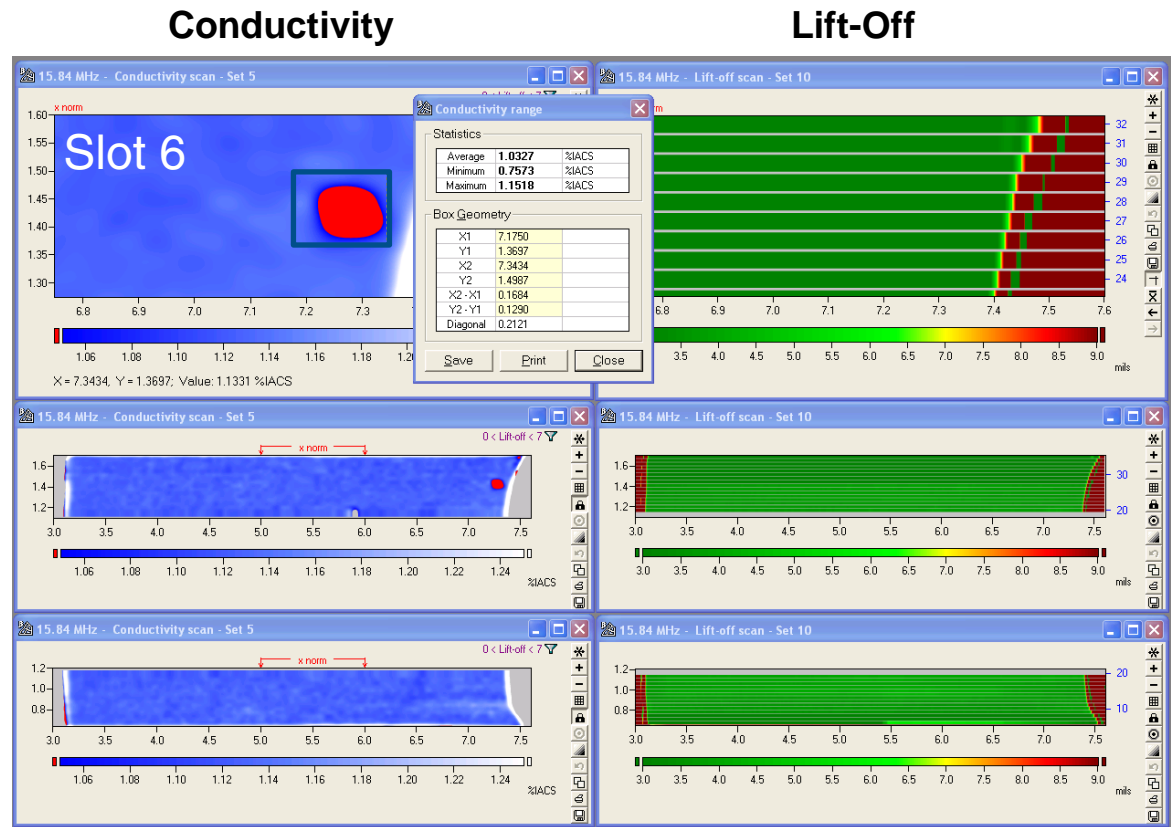
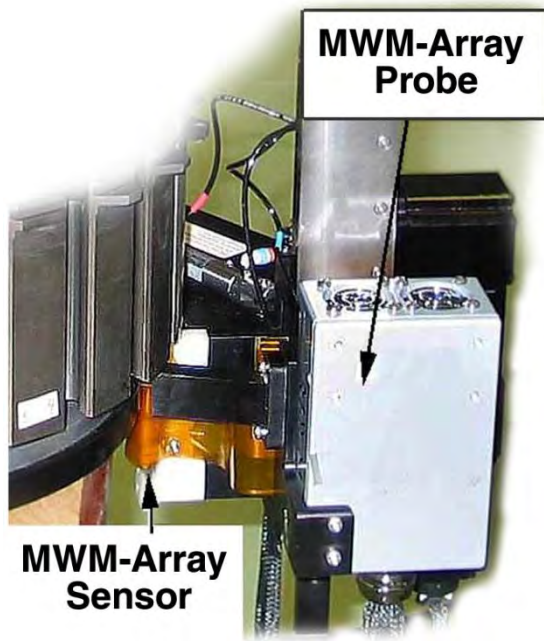
Therefore C-Scan Image **Threshold**
is Independent of Lift-off

Engine Disk Slots & Engine Blade Dovetails



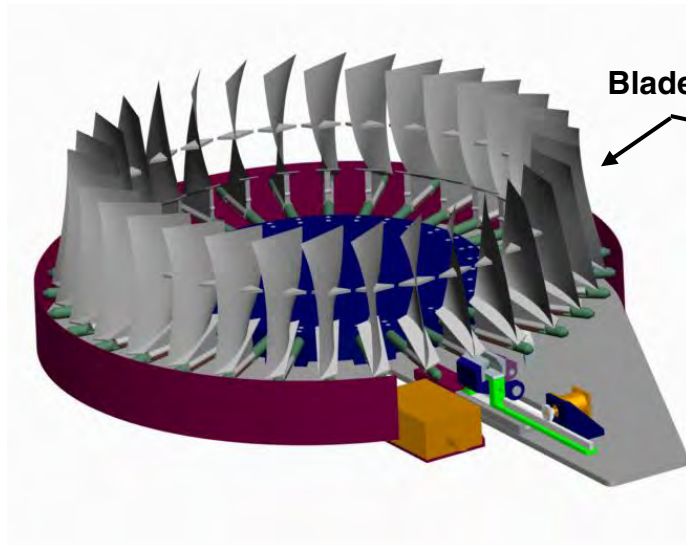
Engine Disk Slot Inspection

- Model-Based Calibration Verification before, during and after inspections (using MWM-Arrays)
- Disks with verified cracks detected, several of these verified large and small cracks **not detected by conventional ET and LPT**
- No false indications above threshold after over 9000 inspections

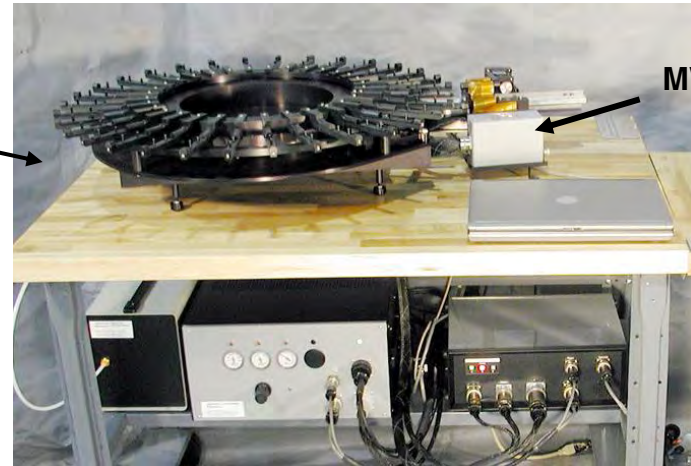


Automated Blade Dovetail Inspection

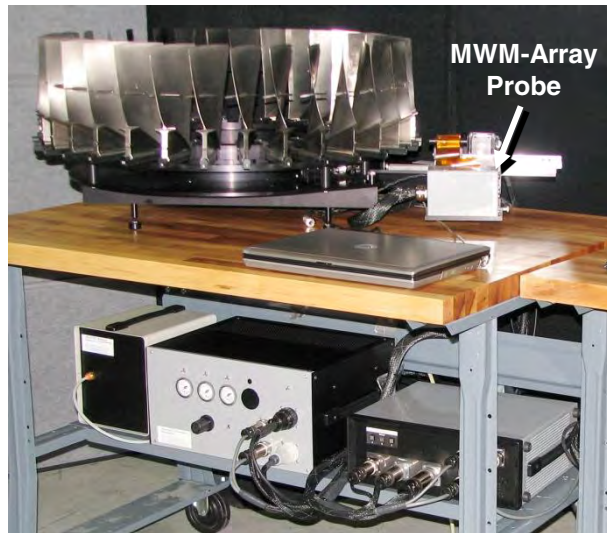
Engine Components at FRC-SE Jacksonville, FL



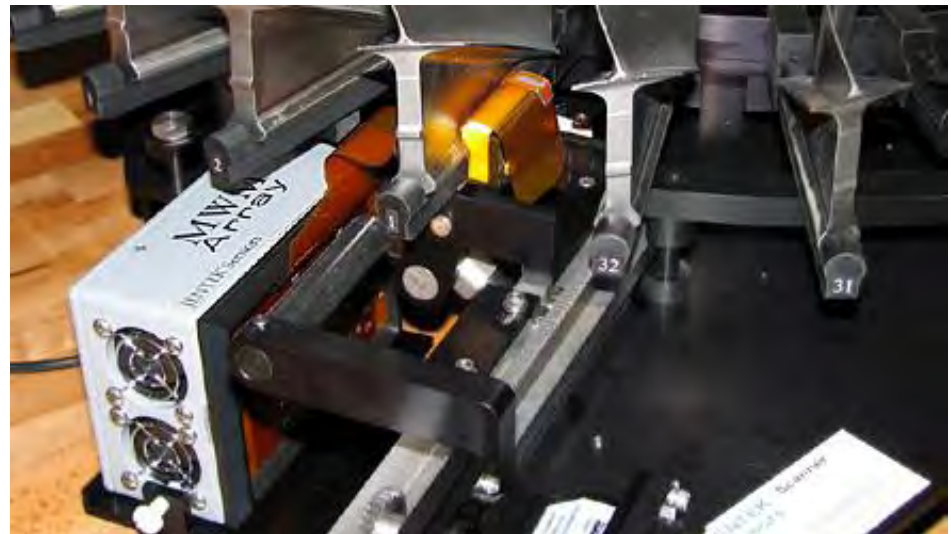
Blade Carousel



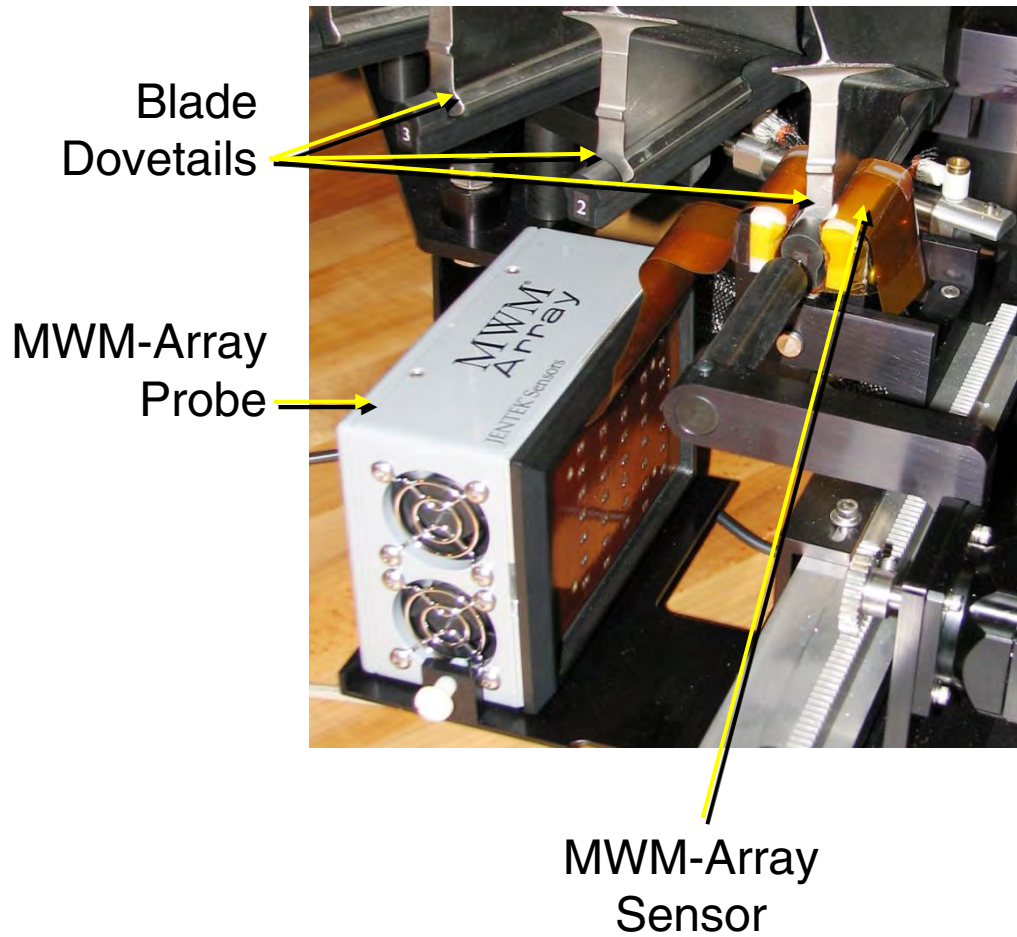
MWM-Array Probe



MWM-Array Probe



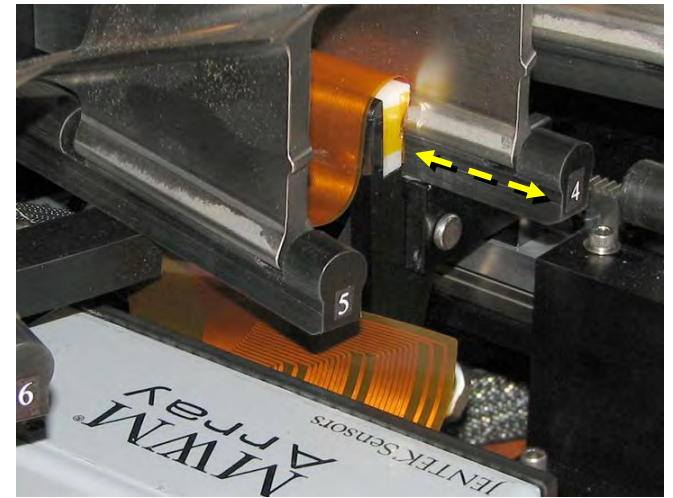
Automated MWM-Array Blade Dovetail Inspection



Sensor position at edge of dovetail



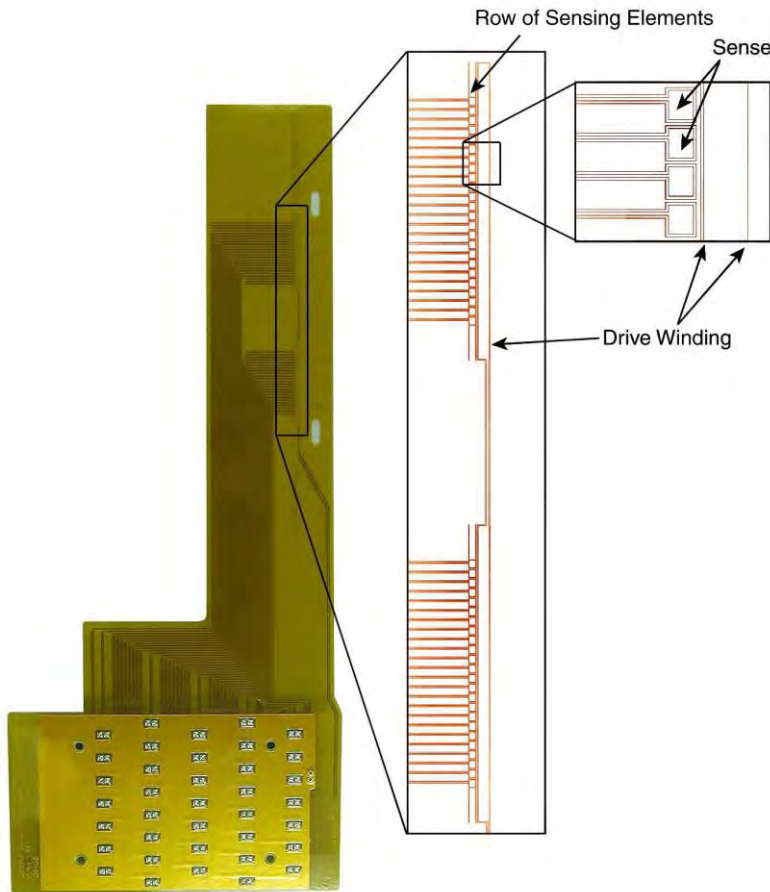
Sensor position halfway down dovetail



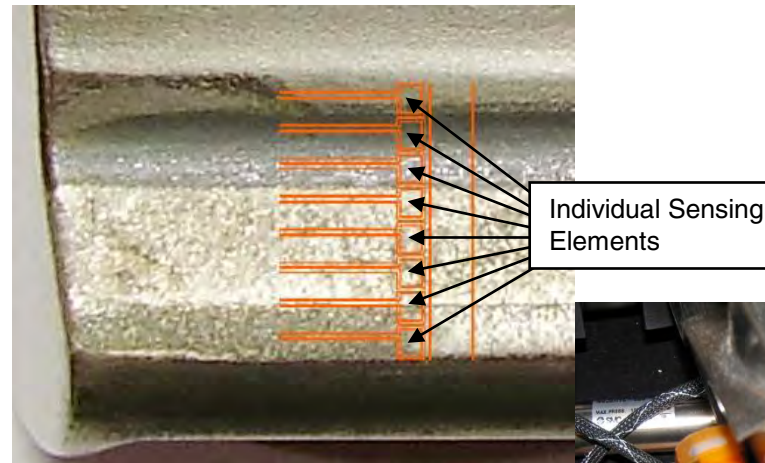
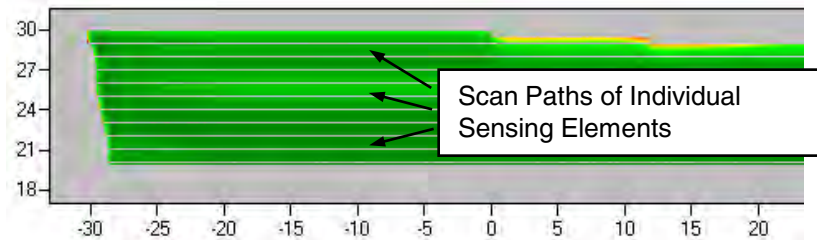
Automated Blade Dovetail Inspection

- Inspect for cracks (goal: 0.015 in. x 0.008 in.)

MWM-Array FA57



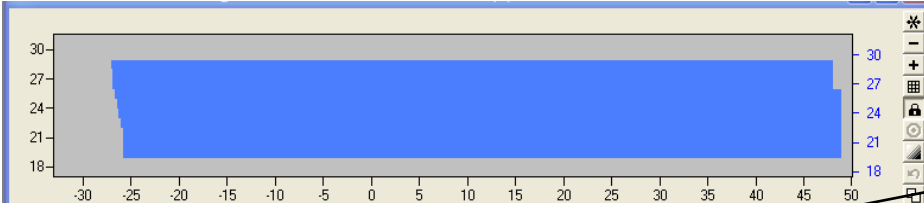
Sensor Coverage



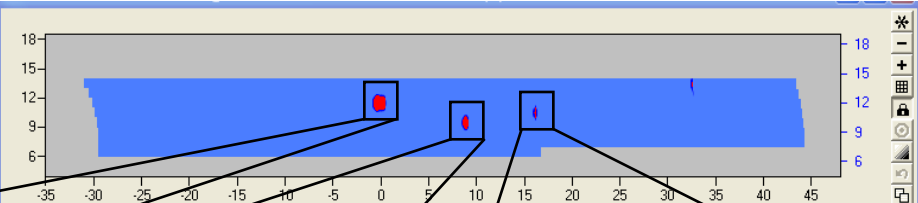
Filtered MWM-Array Results

Note:
Training Set Blade Identified Prior to MWM-Array Inspection as Having “No Cracks”

Convex Side



Concave Side



20-mil Crack

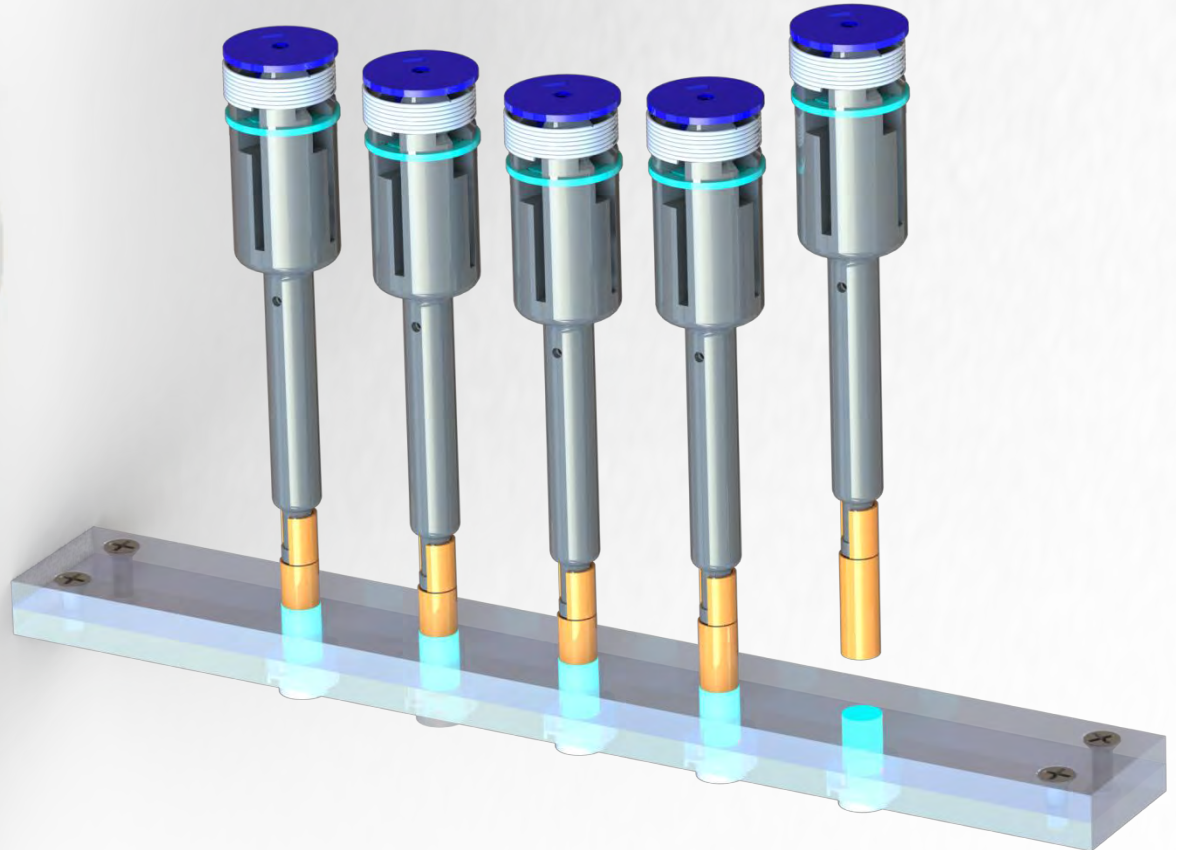


15-mil Crack



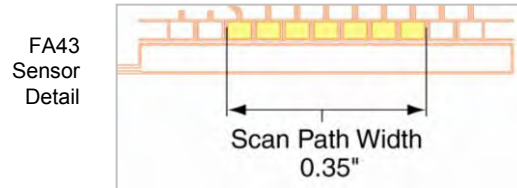
15-mil Crack

Bolt-Hole Inspection and Other Applications

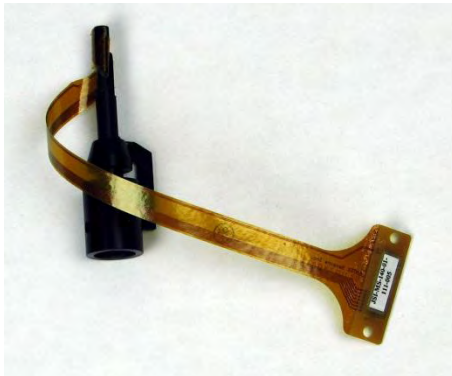


Previous Bolt-Hole Scanner Design

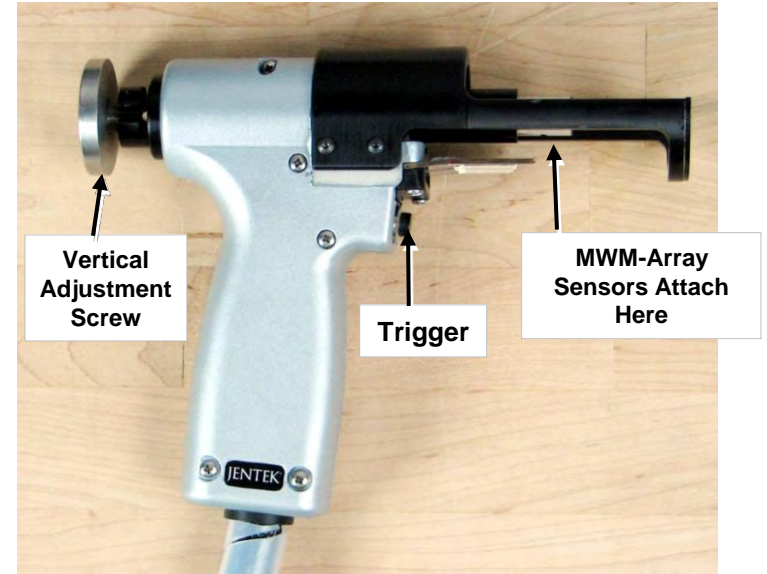
- C-Scan Imaging using MWM-Arrays
- Detection of Cracks at Edges with edge location correction
- Spatial Filtering for Cracks at Edges



Mandrel Assembly with interchangeable MWM-Arrays



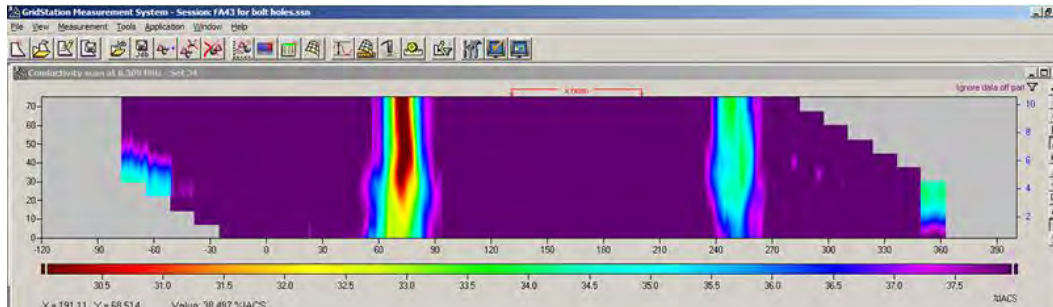
FA166 FA182 FA43



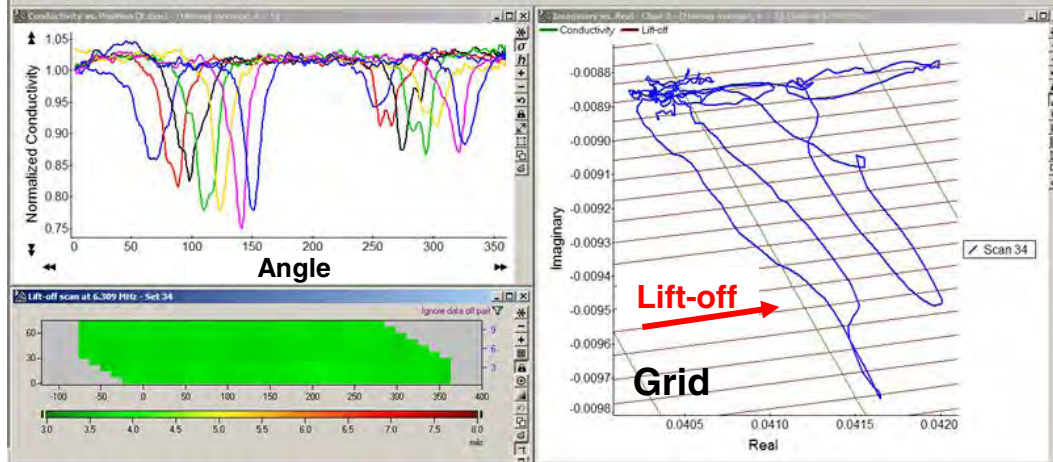
Crack Detection / C-Scan Imaging for Bolt-Holes Without bushings



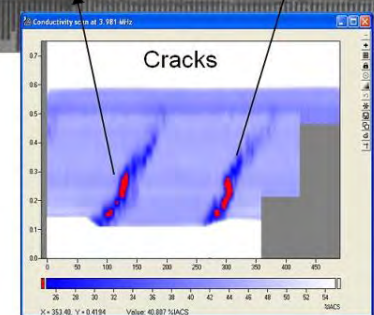
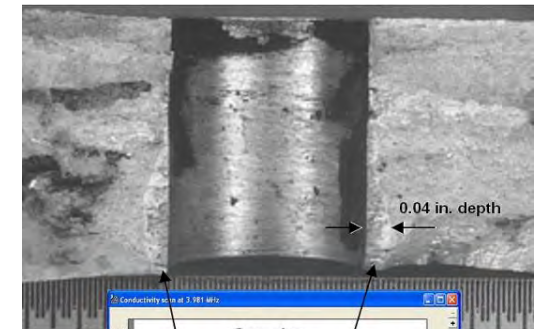
C-Scan



B-Scan

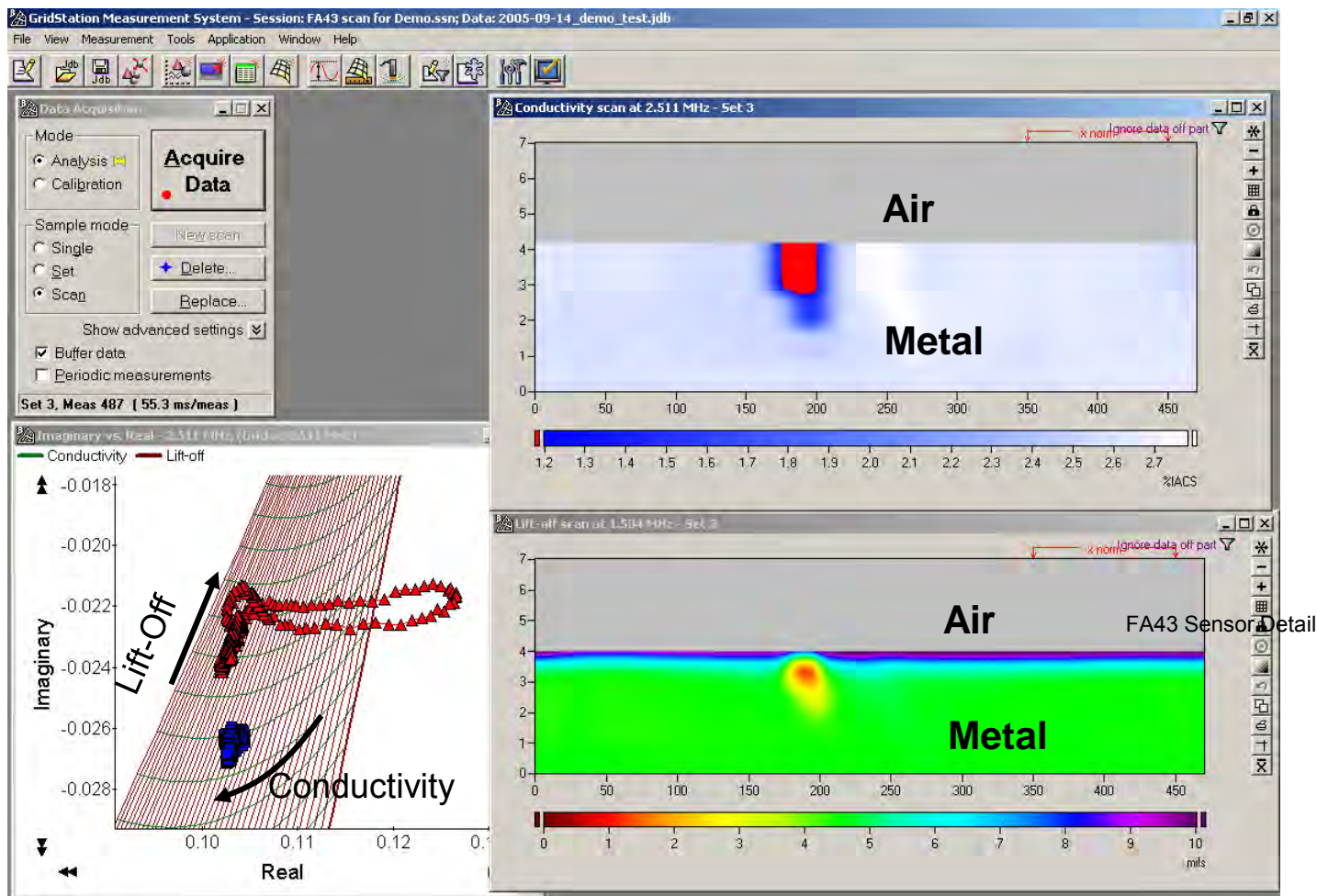


Lift-Off

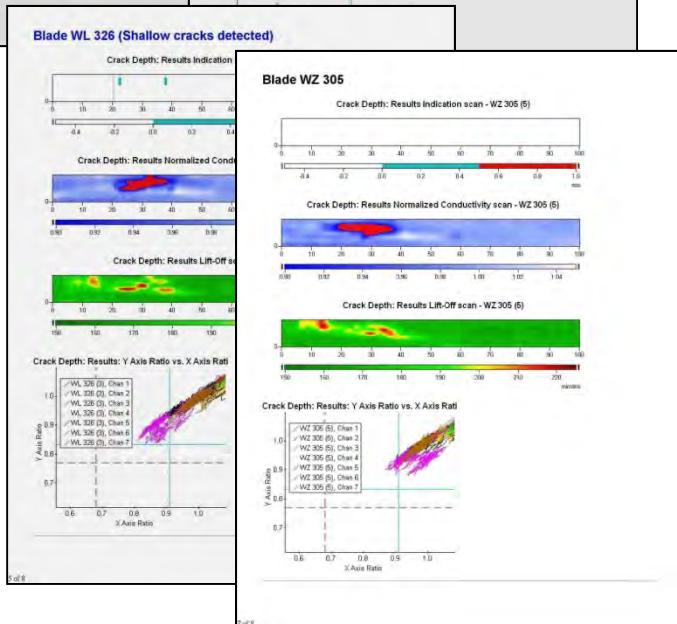
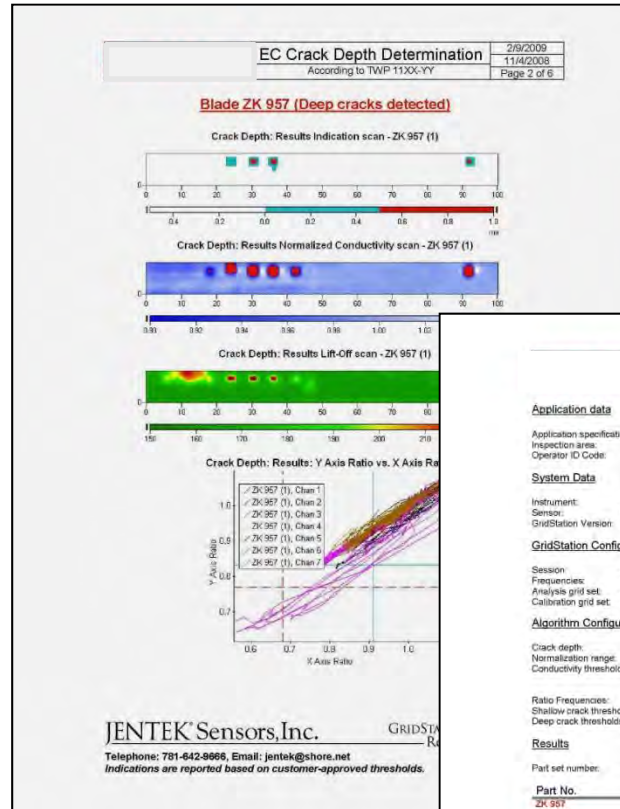
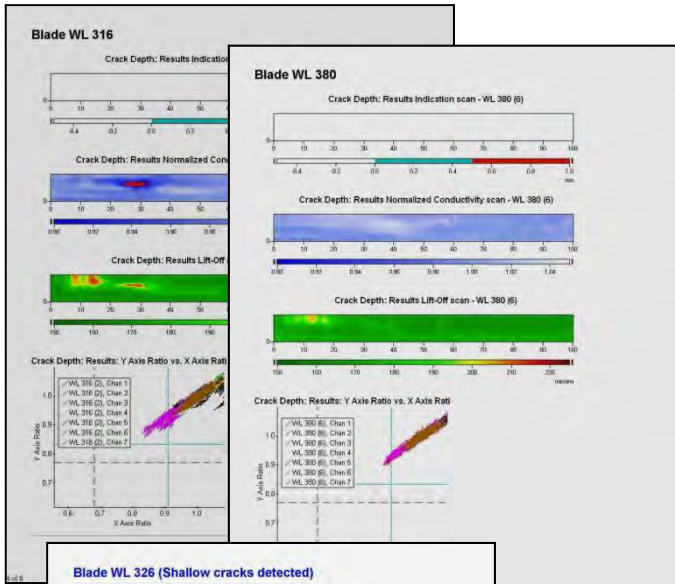


Detection of Cracks at Edges with GridStation Edge Location Correction

GridStation Conductivity/Lift-Off Images (Unfiltered)



Automated Crack Depth Reporting Example



EC Crack Depth Determination
According to TWP 11XX-YY

2/9/2009
11/4/2008
Page 1 of 6

Application data

Application specification: TWP 11XX-YY
Inspection area: fillet airfoil-platform ps
Operator ID Code: JENTEK

Base Metal: IN738
Surface: stripped

System Data

Instrument: JISI-IN-7007
Sensor: FA130
GridStation Version: 4.11 - Beta

Probe: JISI-SH-19-D1RB-200
Scanning fixture: BladeFillet-V
Algorithm Version: 1, 0, 0, 0 (Dec-18-2008)

GridStation Configuration Data

Session: C:\Jentek\Grids\GridTest\session1
Frequencies: 305.107 kHz, 620.957 kHz, 1.00000 MHz, 1.55489 MHz, 2.51188 MHz, 3.98107 MHz
Analysis grid set: C:\JENTEK\Grids\CrackDepthGrids
Calibration grid set: C:\JENTEK\Grids\CrackDepthGrids

Algorithm Configuration Data

Crack depth:	Shallow:	0.5 mm	Deep:	1.0 mm
Normalization range:	From:	70 mm	To:	80 mm
Conductivity threshold:	Frequency:	3.981 MHz	Threshold:	0.8

Ratio Frequencies:
Shallow crack thresholds: X-Axis (305.1 kHz)/(3.981 MHz) = 0.51, Y-Axis (208.1 kHz)/(1.000 MHz) = 0.833
Deep crack thresholds: 0.85

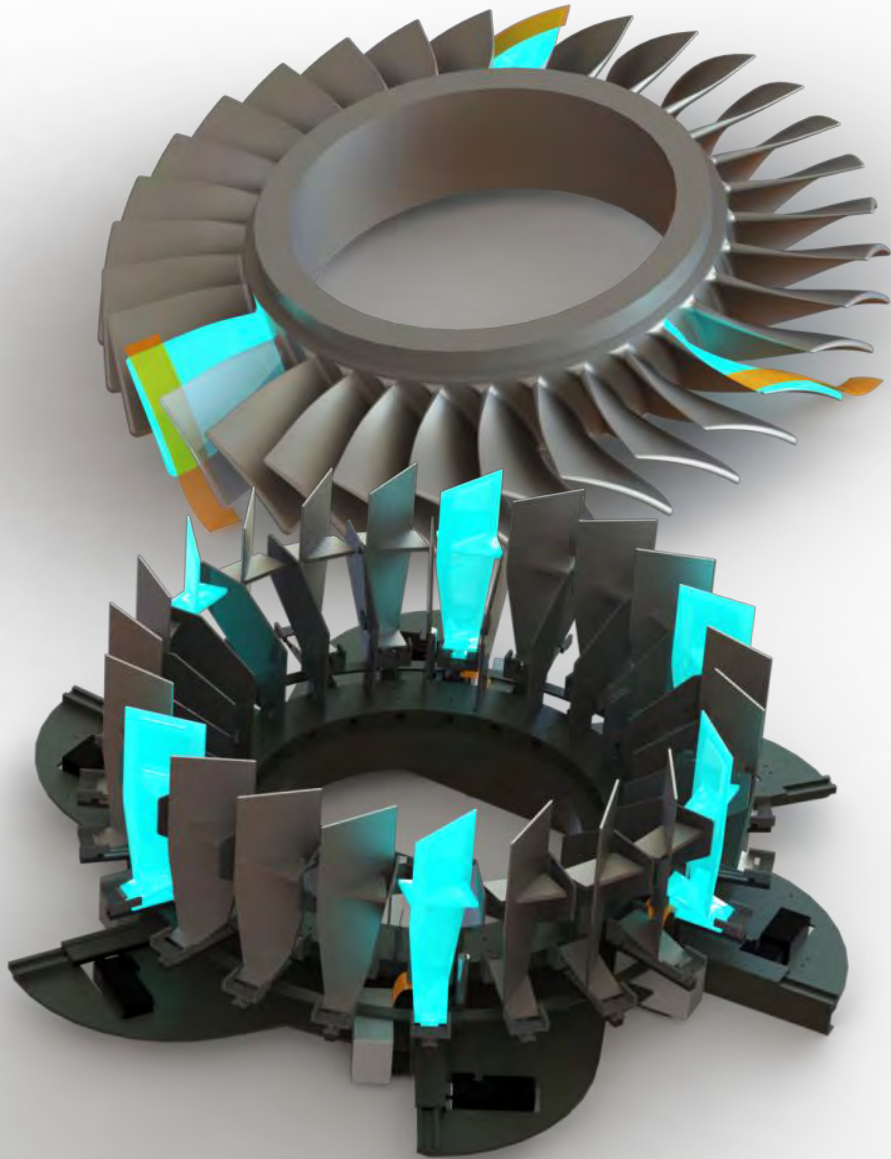
Results

Part set number:	Test Set	Parts scanned	6
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Part No.	Set No.	Indication
ZK 957	1	Deep
WL 316	2	Deep
WL 326	3	Shallow
WZ 317	4	Shallow
WZ 305	5	Shallow

JENTEK Sensors, Inc. GRIDSTATION Report
Telephone: 781-642-9666, Email: jentek@shore.net
Indications are reported based on customer-approved thresholds.

Summary of High Throughput Goals



Goals:

- ✓ Inspect multiple features and/or parts simultaneously, reducing inspection time
- ✓ High resolution + wide scan path, reducing scanner complexity
- ✓ Minimal data interpretation required
- ✓ Minimal training required

