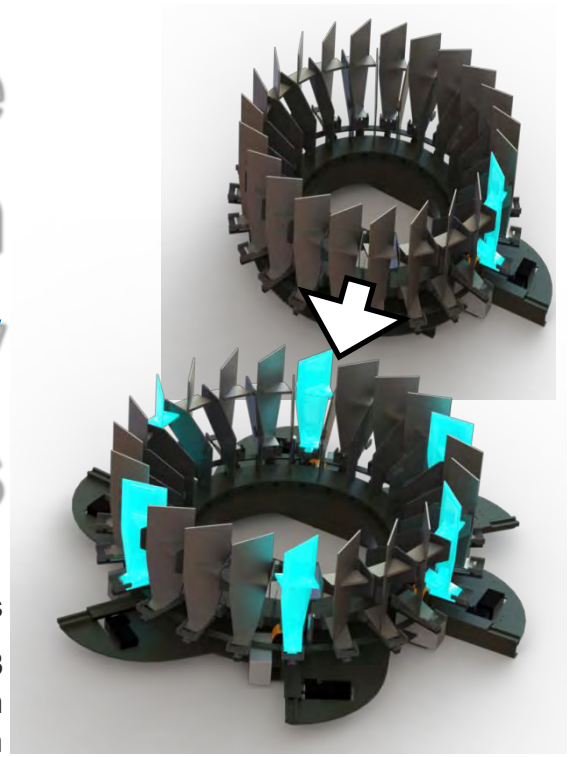
High Throughput Engine Component Inspection Using Massively Parallel Solutions



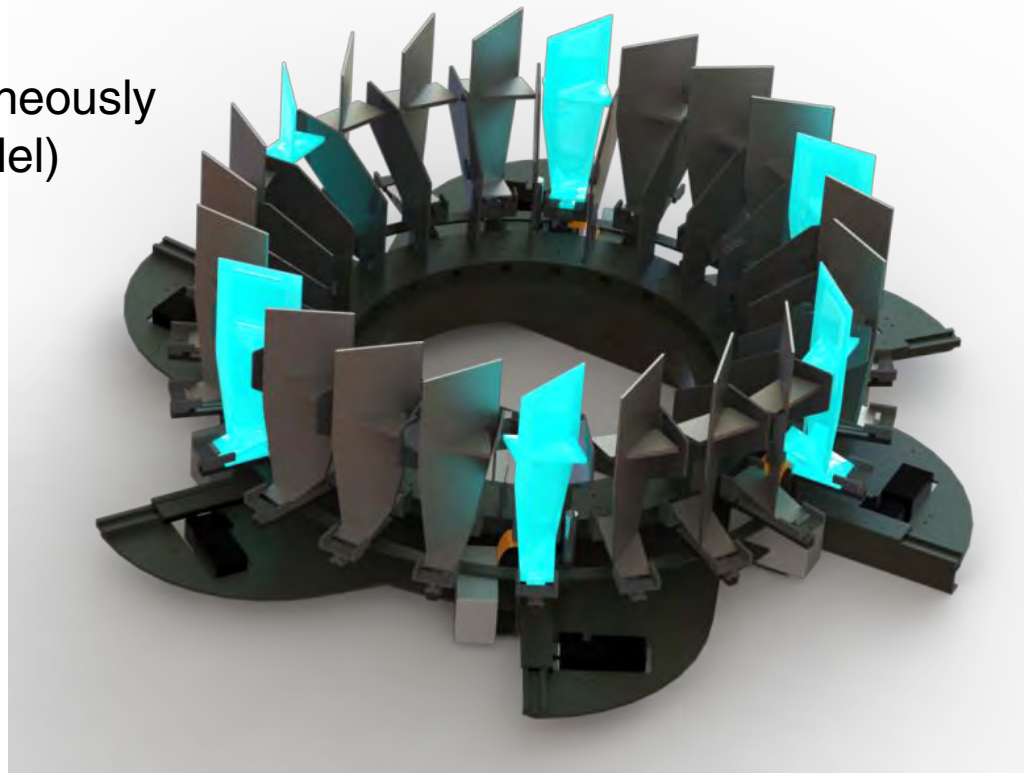
Neil Goldfine, Scott Denenberg, Yanko Sheiretov, Stuart Chaplan, Don Straney, Mark Windoloski, and Zachary Thomas

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:

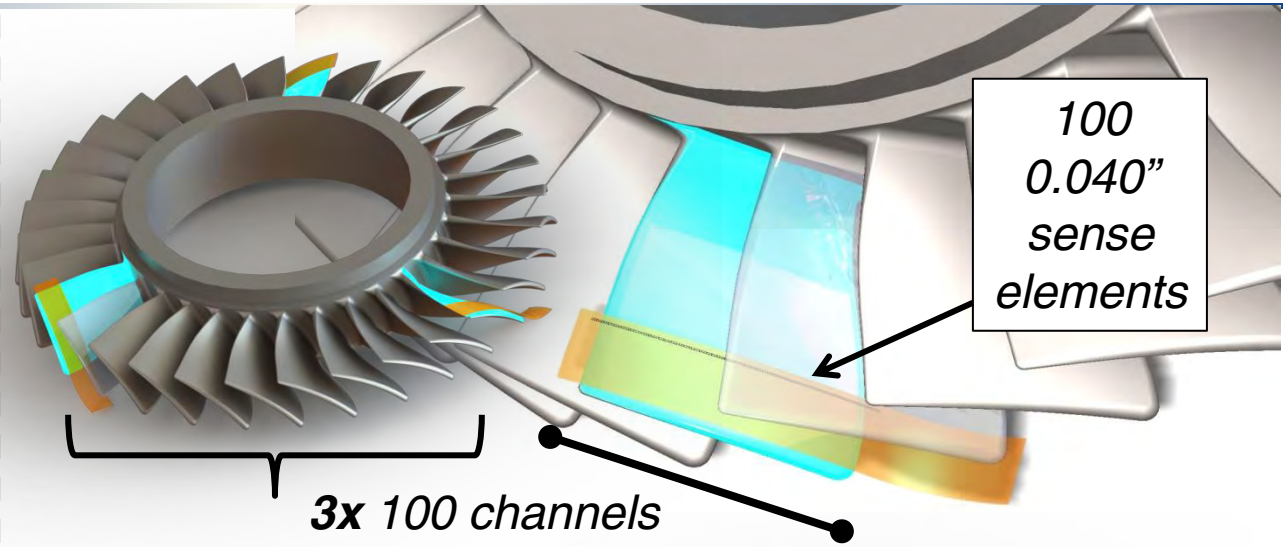
- **Reduce inspection time**
  - ✓ Inspect multiple features simultaneously (need many channels, fully parallel)
  - ✓ Inspect wide areas fast
  - ✓ MWM-Array reduces surface preparation requirements enabling practical high throughput inspection
- **Reduce costs**
  - ✓ Lower scanner complexity results 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



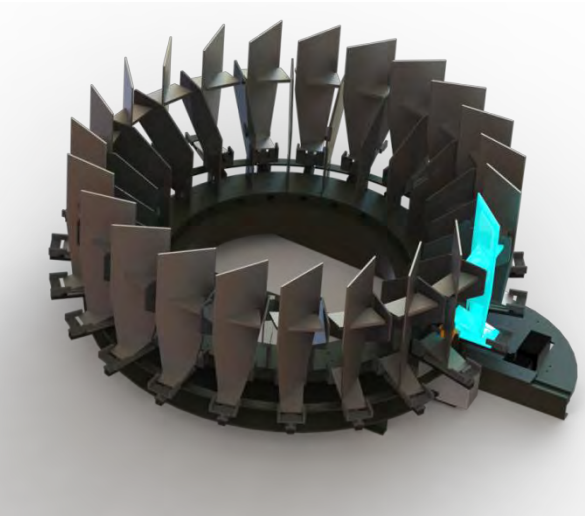
MWM-Array engine inspection is FAA approved on some commercial engines and has been in use by the US Navy for over 5 years with great success

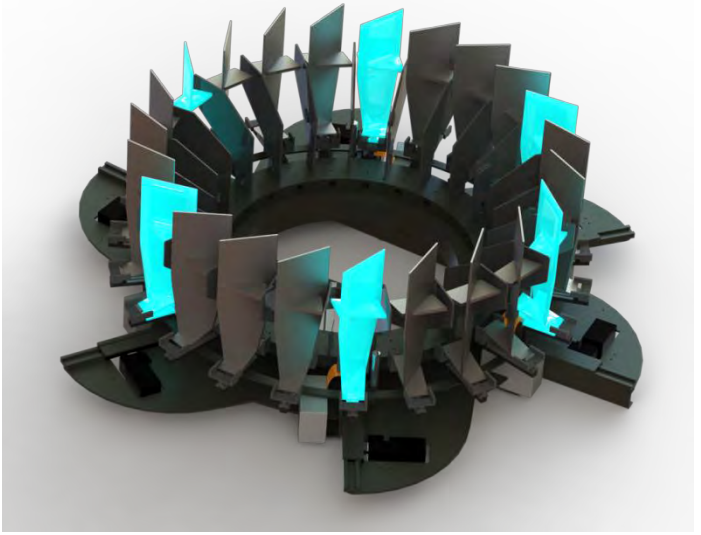
High Throughput Inspection Possibilities

37 channels



OLD **NEW**

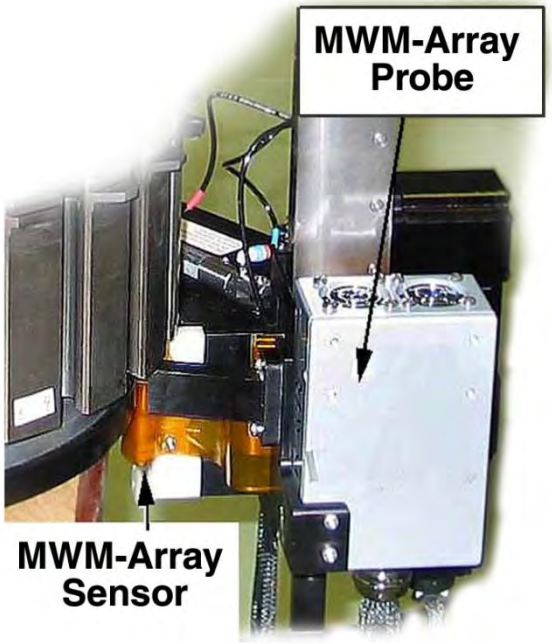




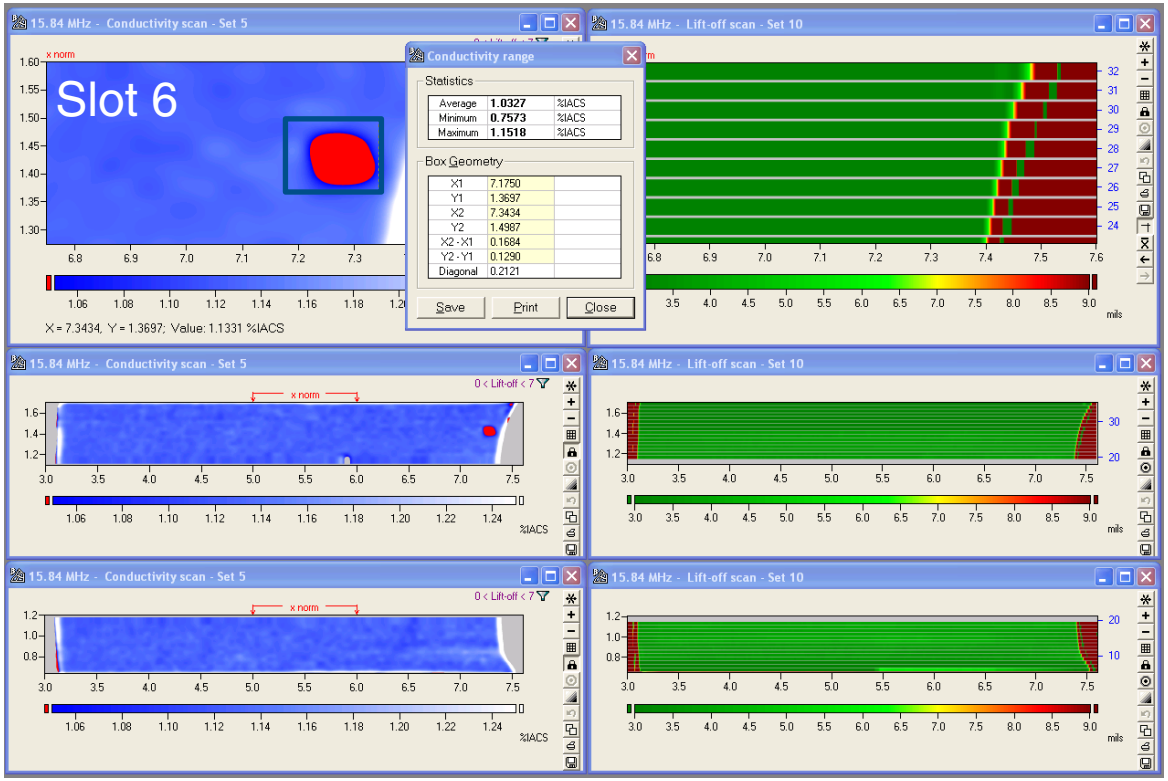
***6x** 39 channels*

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



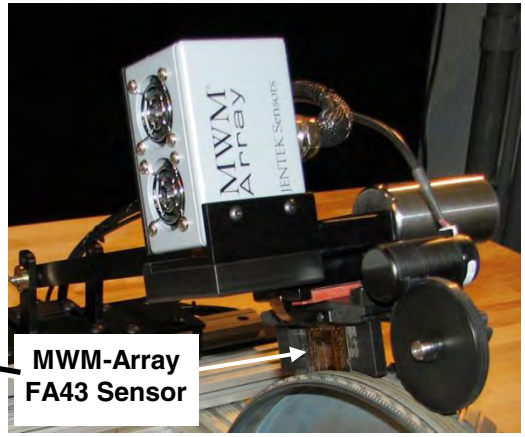
Conductivity **Lift-Off**



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"*

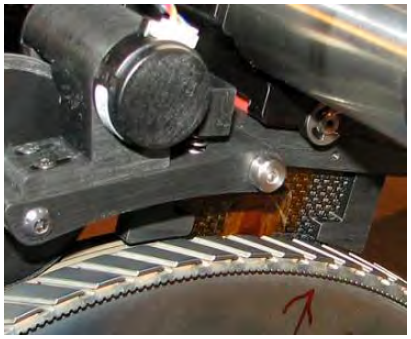


AE SERIES PROPULSION SYSTEM
Service Bulletin Index

Rolls-Royce

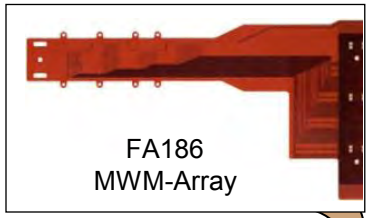
LIST OF AE 3007A SERIES SERVICE BULLETINS

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	)	Engine - 6th- thru 13th-Stage Compressor Wheel Knife Edge Seals - Jentek Eddy Current Inspection	B	09-May-11	7A, 7A1/1, 7A1/2, 7A1, 7A1E, 7A1P, 7A2, 7A3	72-37-00

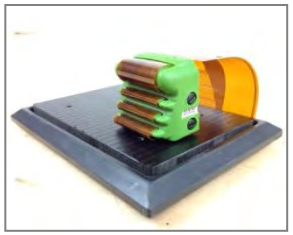


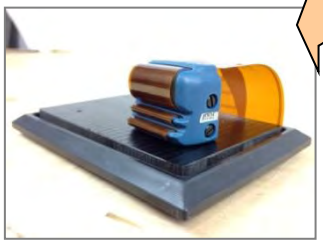
Fir Tree Inspection

- *Fully integrated, automated and transportable*

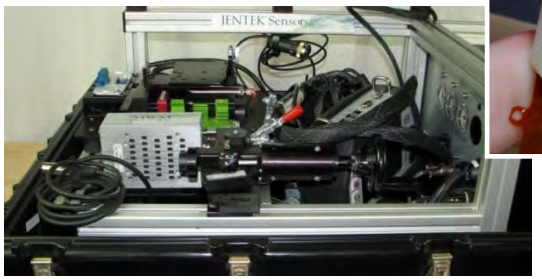


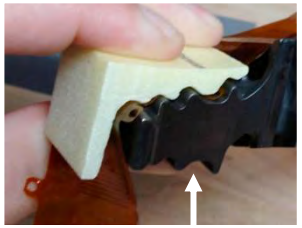
MWM-Array FA186 Sensor Cartridges





Packaged System



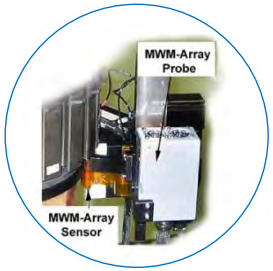


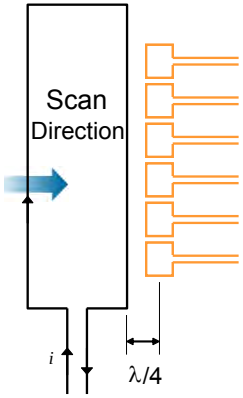
Non-application blade shown for prototyping reference

Technology Summary / Overview

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

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





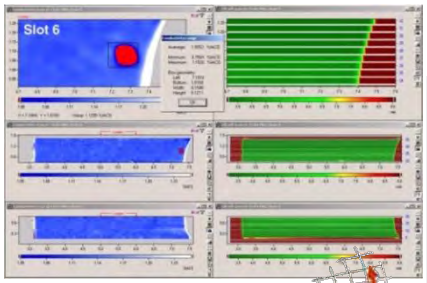
2. Next Generation 8200α GridStation® Electronics

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

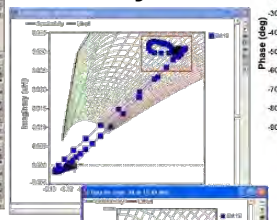
3. GridStation® Software using Hyperlattices™

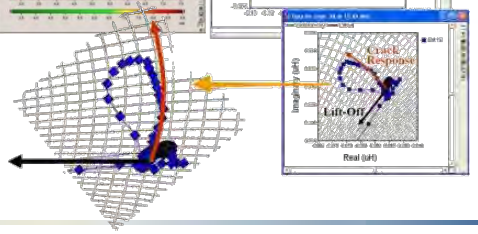
- **Rapid, autonomous data analysis**
  Performs multivariate inverse method (MIM) using precomputed databases
  - Defect Images
  - Performance Diagnostics
  - Noise Suppression

Images

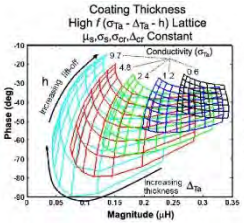


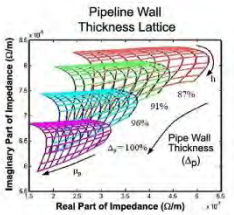
Analysis

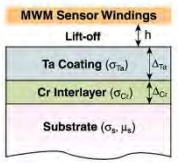


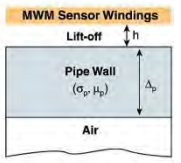


Solve Multiple Unknown Problems MIM



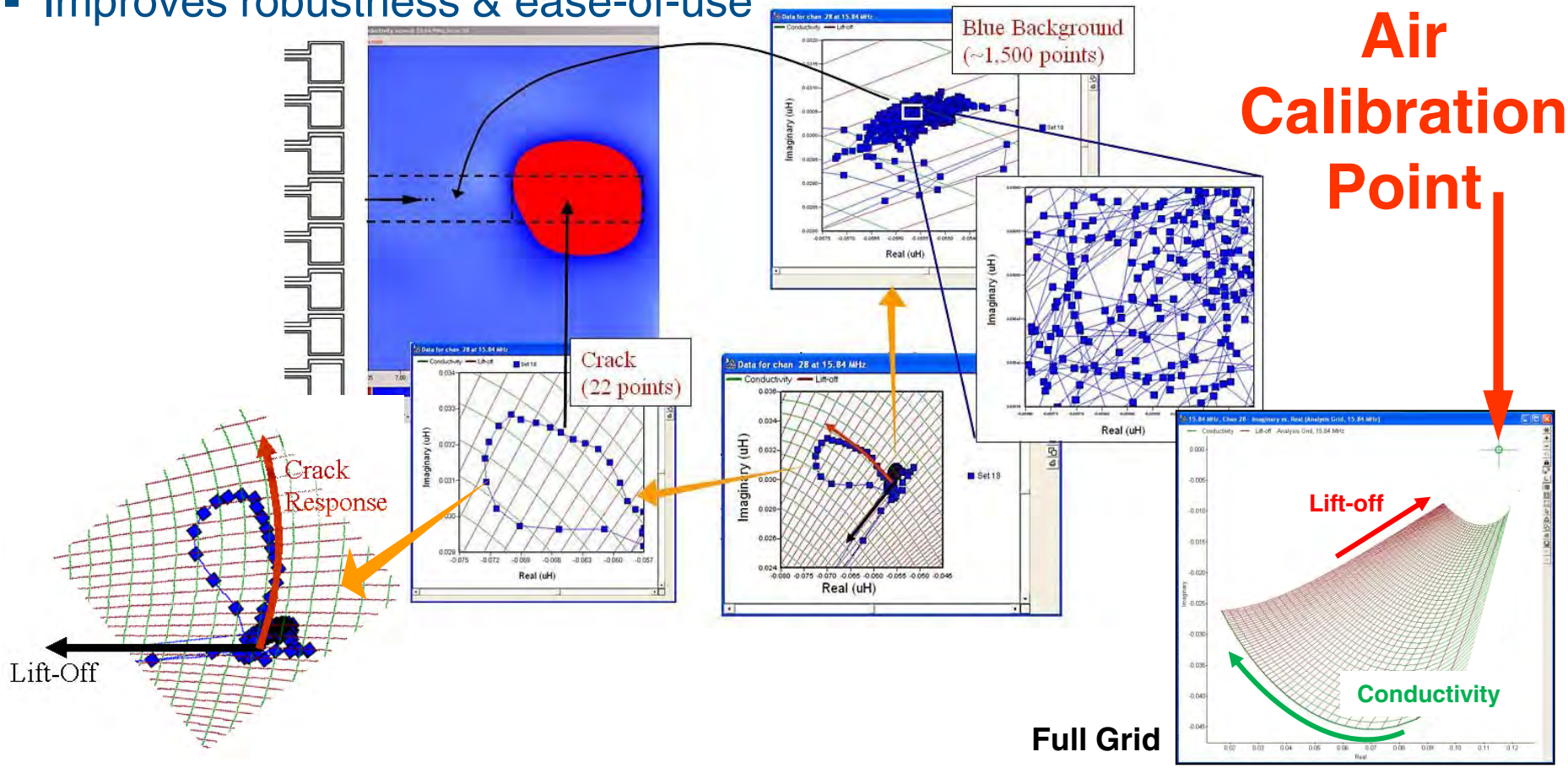






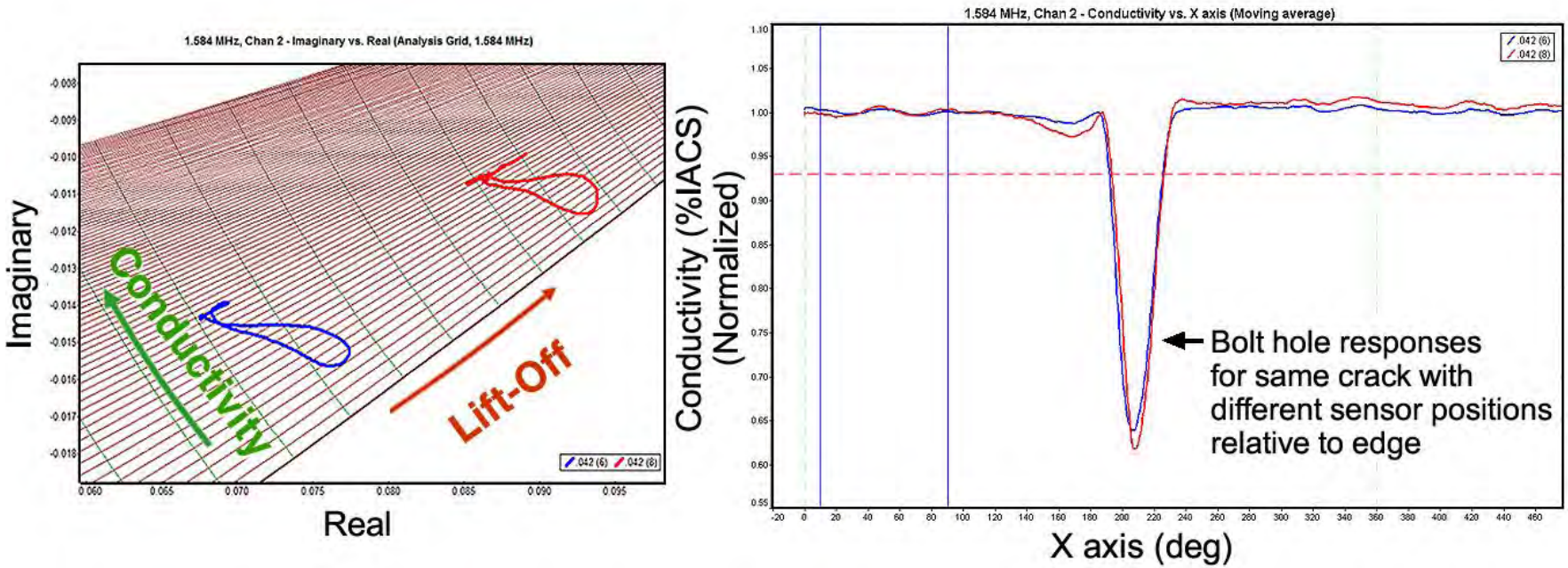
“Air” Calibration and Rapid Data Analysis

- 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



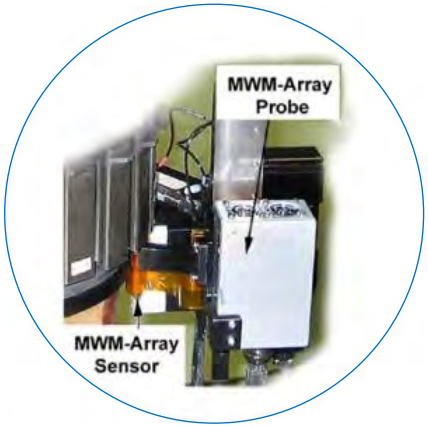
Grid Method Advantage

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

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- Disks with verified cracks detected, several of these verified large and small cracks **not detected by conventional ET and LPT**
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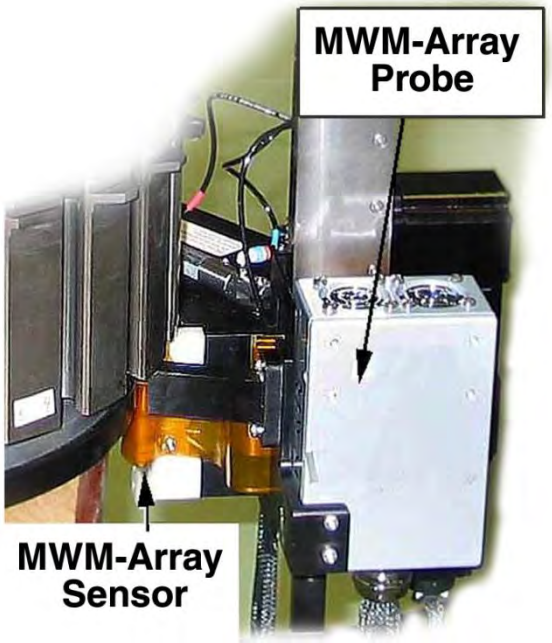
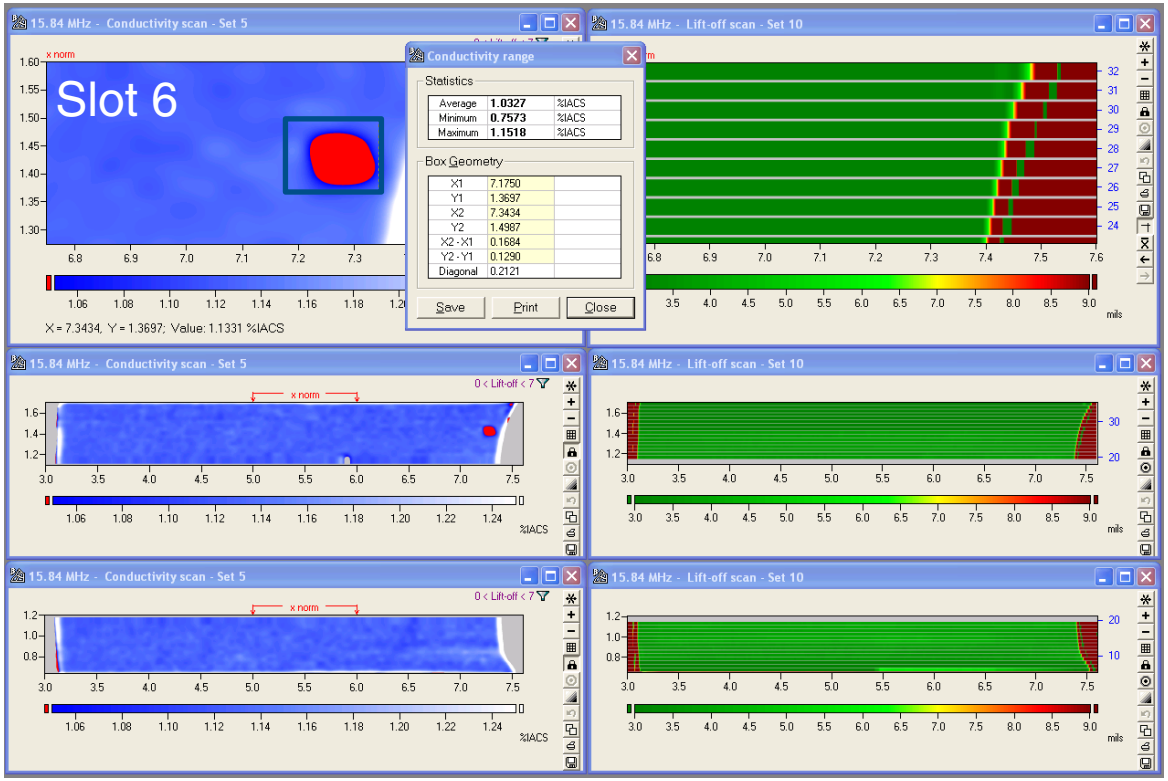
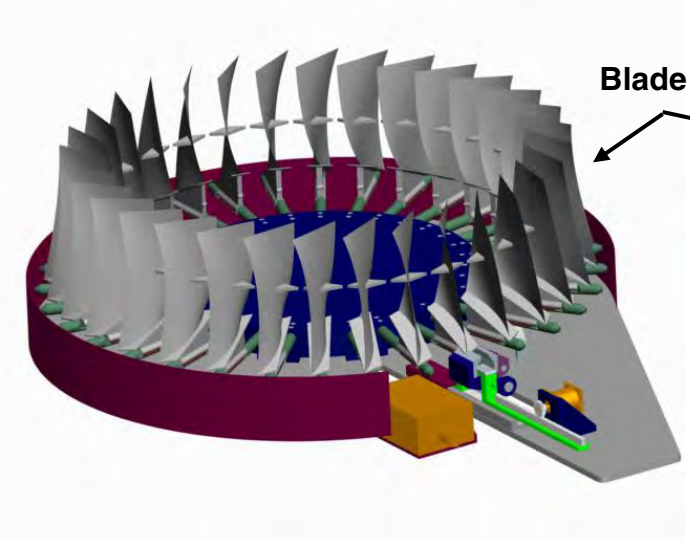


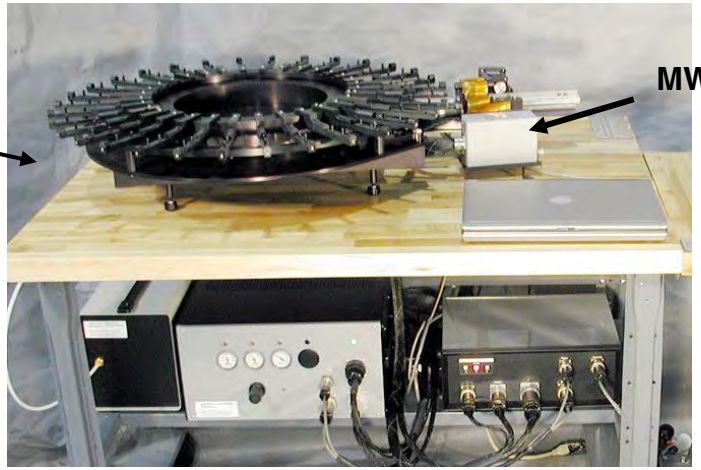
Conductivity **Lift-Off**

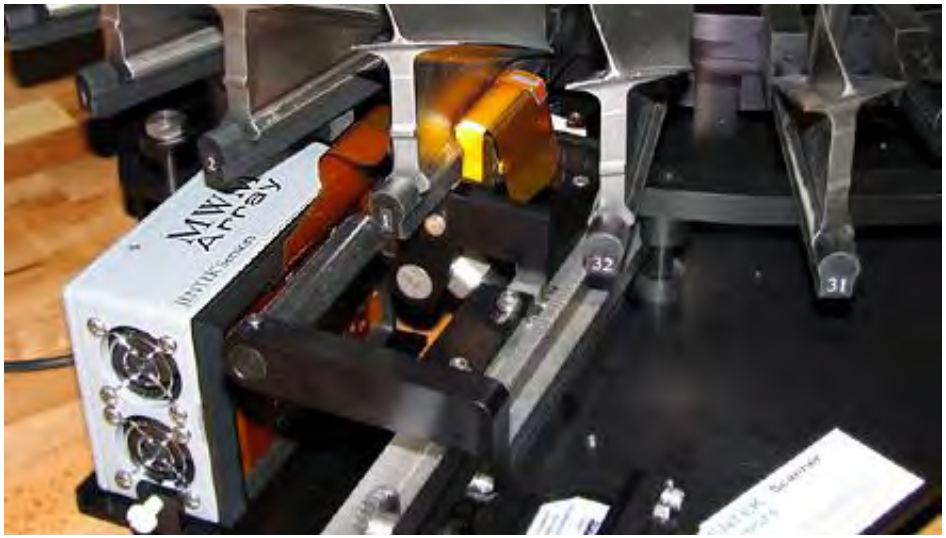


Automated Blade Dovetail Inspection

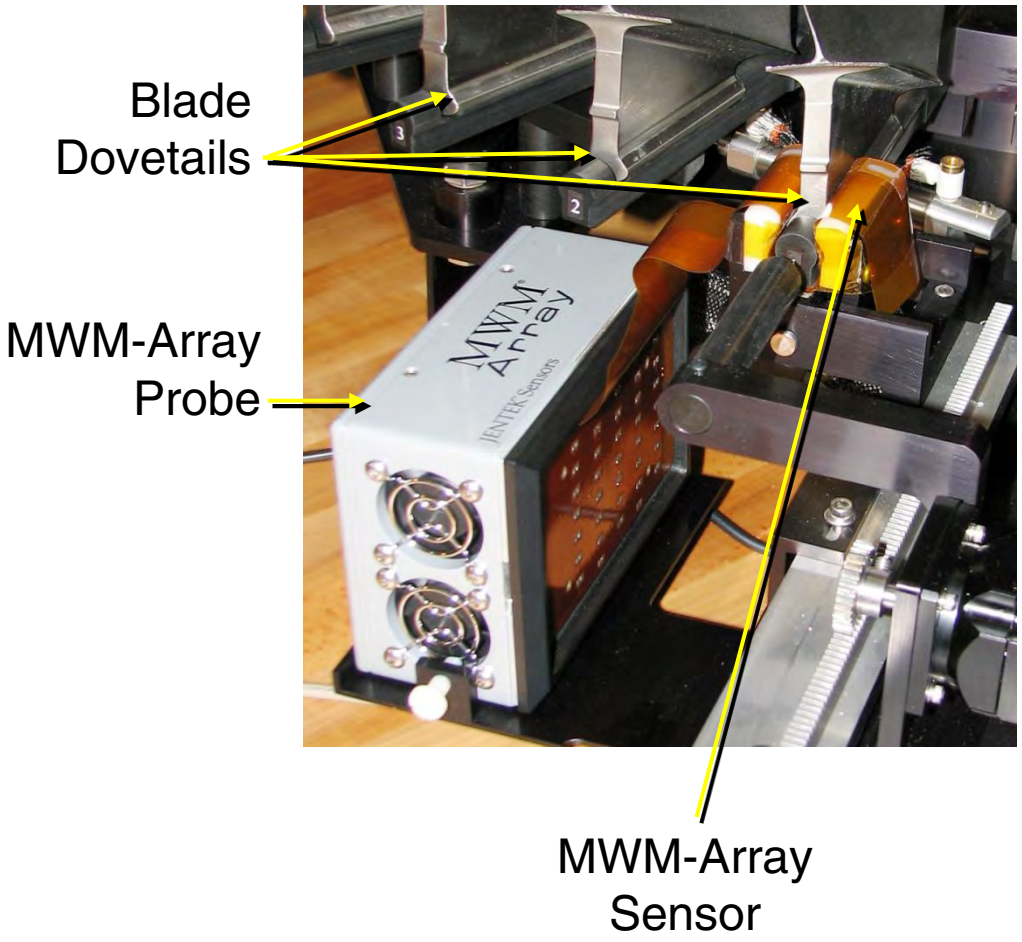
Engine Components at FRC-SE Jacksonville, FL





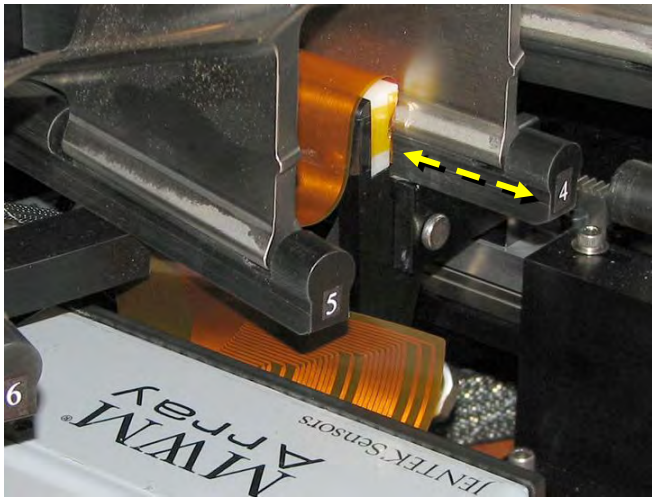


Automated MWM-Array Blade Dovetail Inspection



Sensor position at edge of dovetail

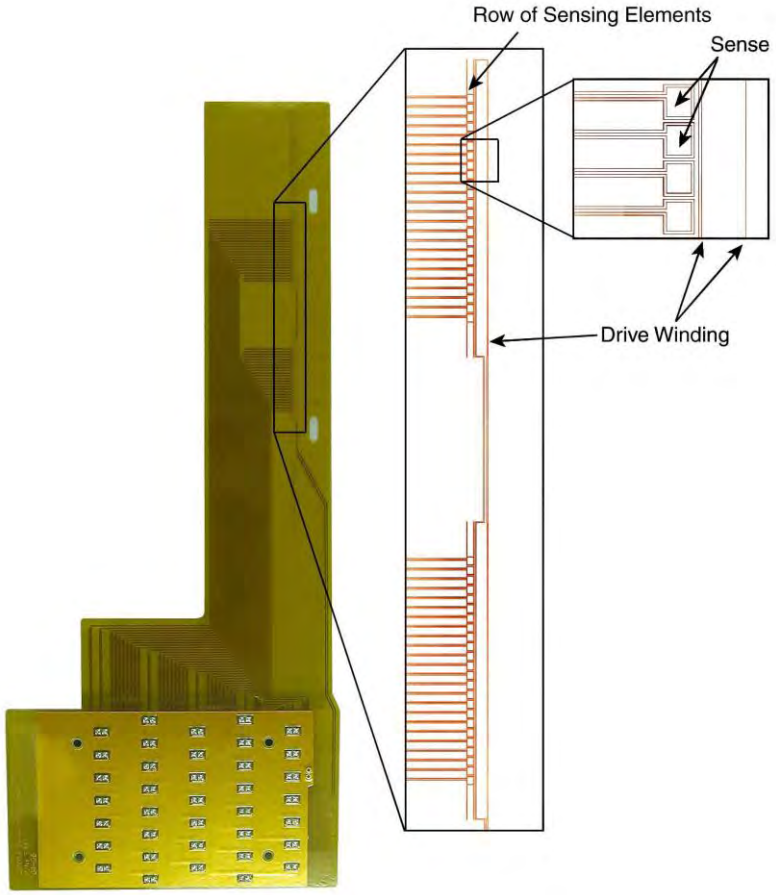
Sensor position halfway down dovetail



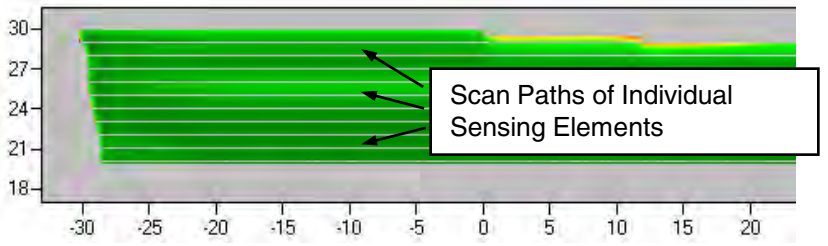
Automated Blade Dovetail Inspection

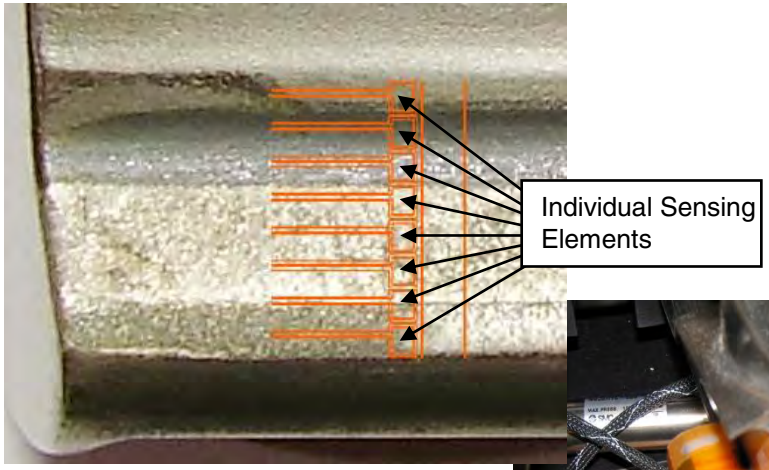
- Inspect for cracks (goal: 0.015 in. x 0.008 in.)

MWM-Array FA57



Sensor Coverage





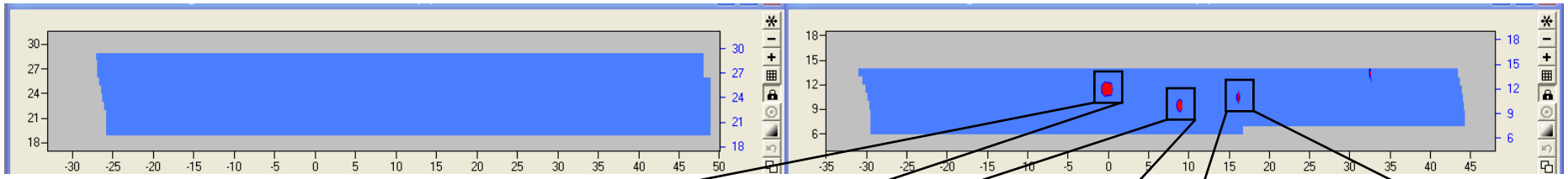
Filtered MWM-Array Results

Note:

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

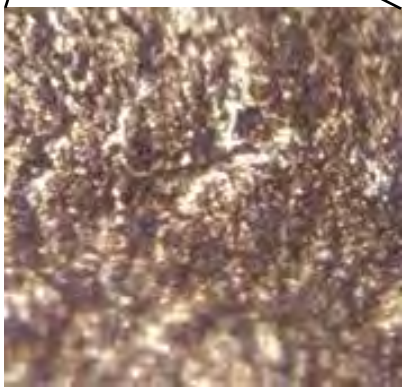
Convex Side

Concave Side



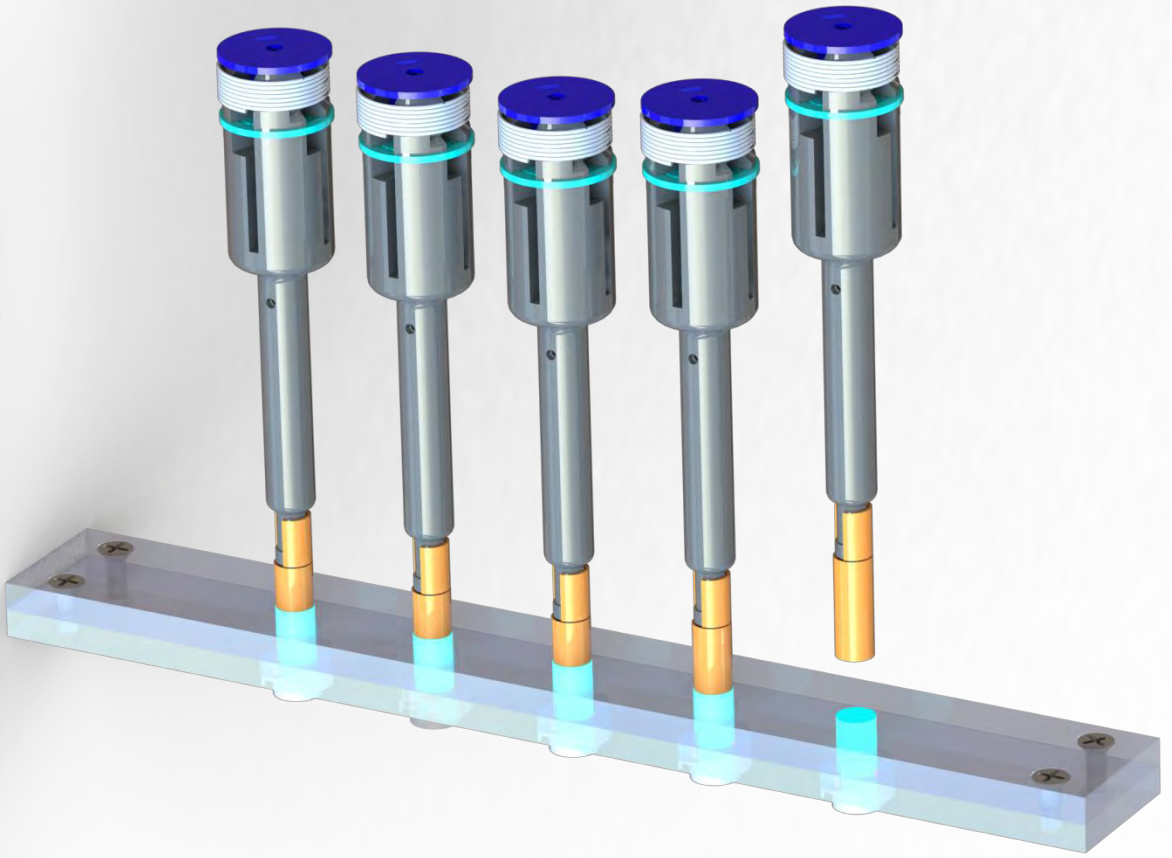
20-mil Crack

15-mil Crack



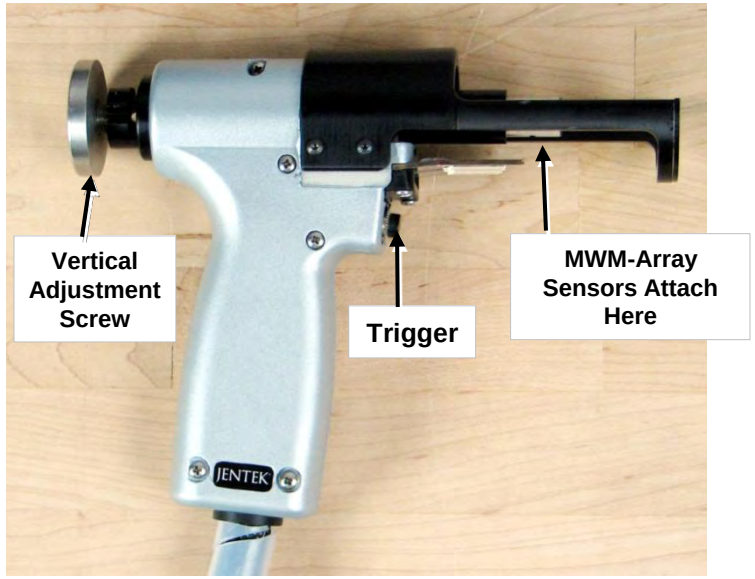
15-mil Crack

Bolt-Hole Inspection and Other Applications

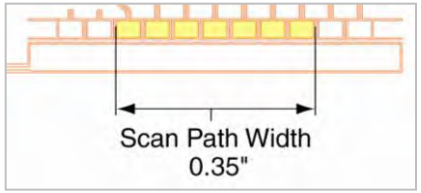


Previous Bolt-Hole Scanner Design

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



FA43 Sensor Detail



Mandrel Assembly with interchangeable MWM-Arrays

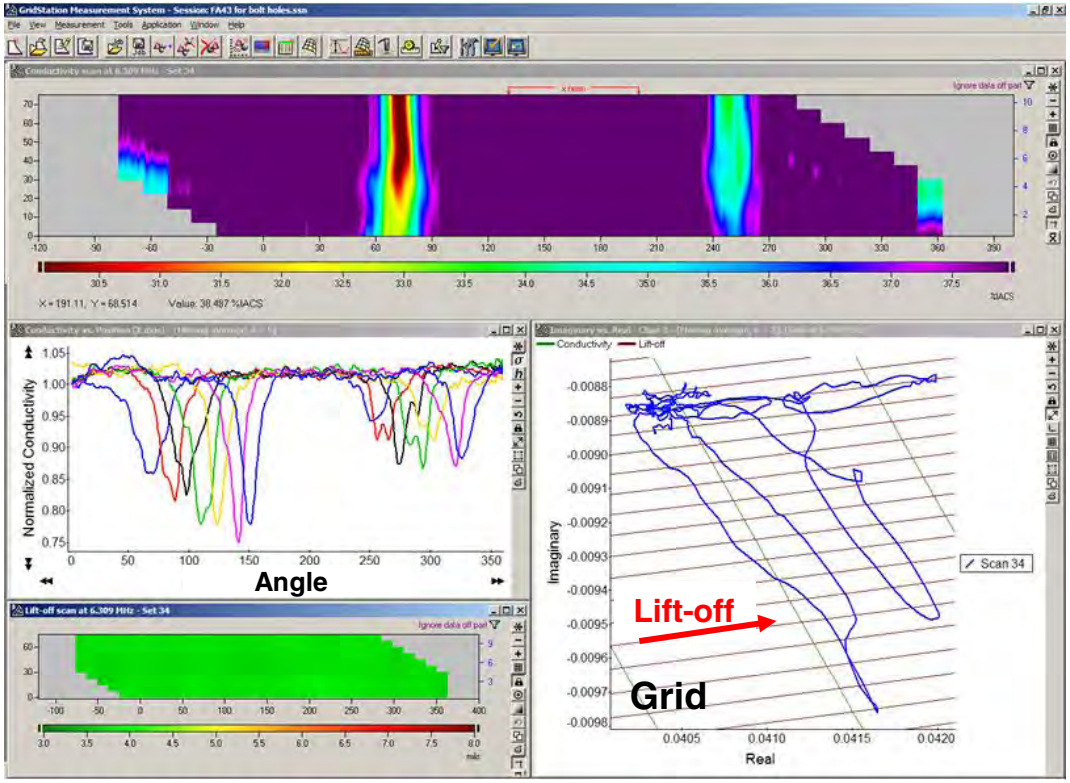
FA166 **FA182** **FA43**

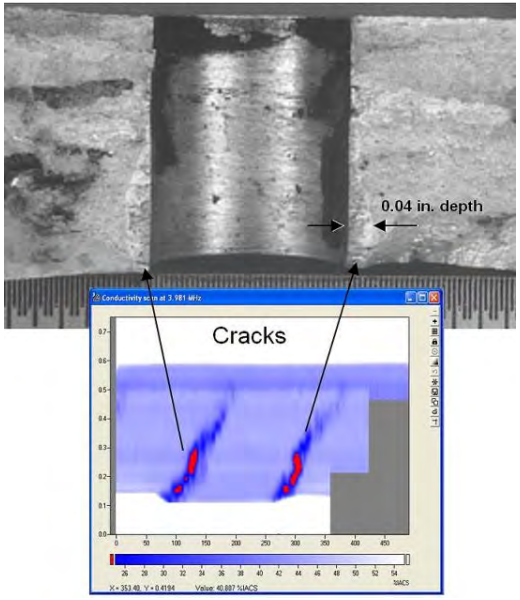
Crack Detection / C-Scan Imaging for Bolt-Holes Without bushings

C-Scan

B-Scan

Lift-Off

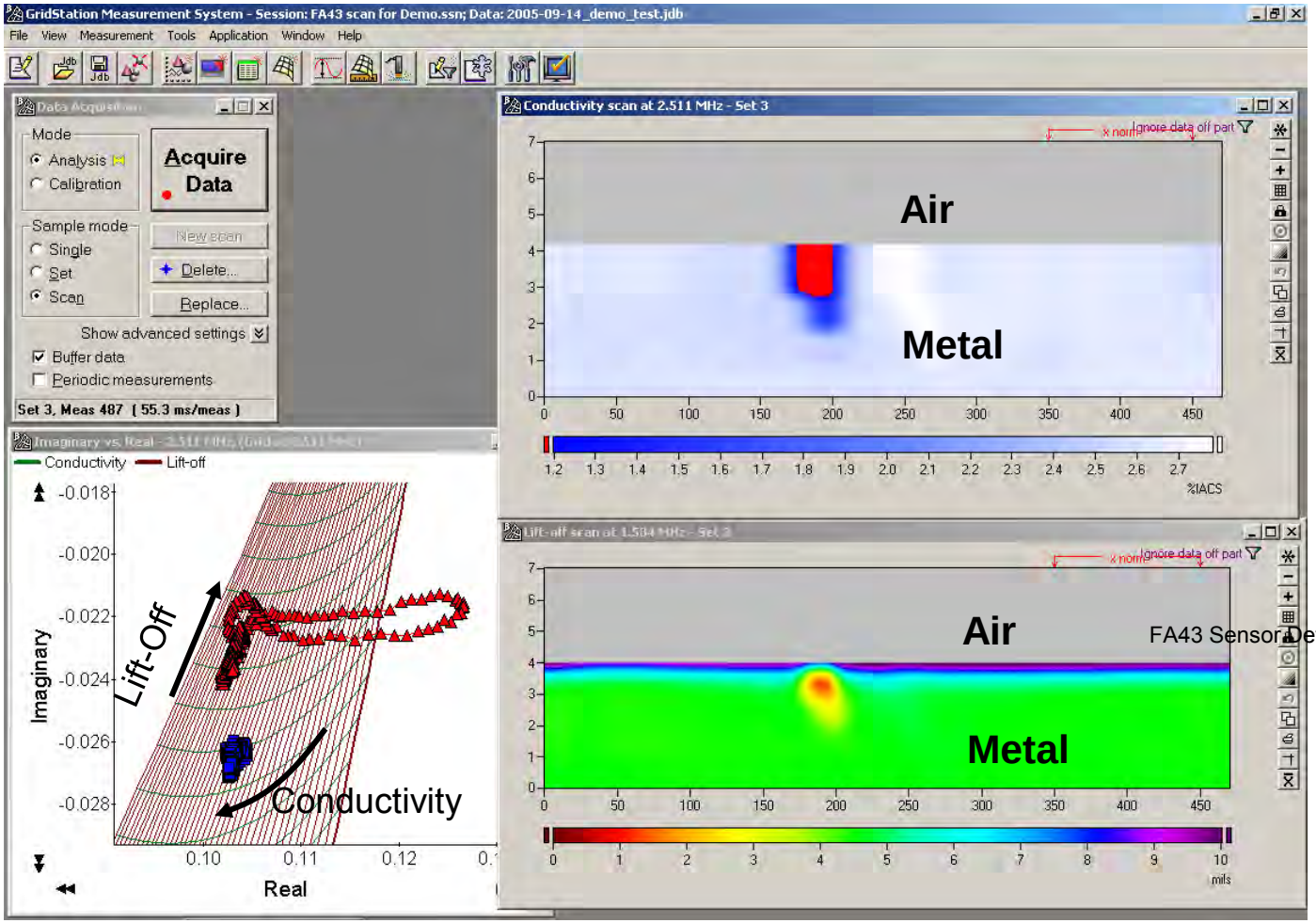




Detection of Cracks at Edges

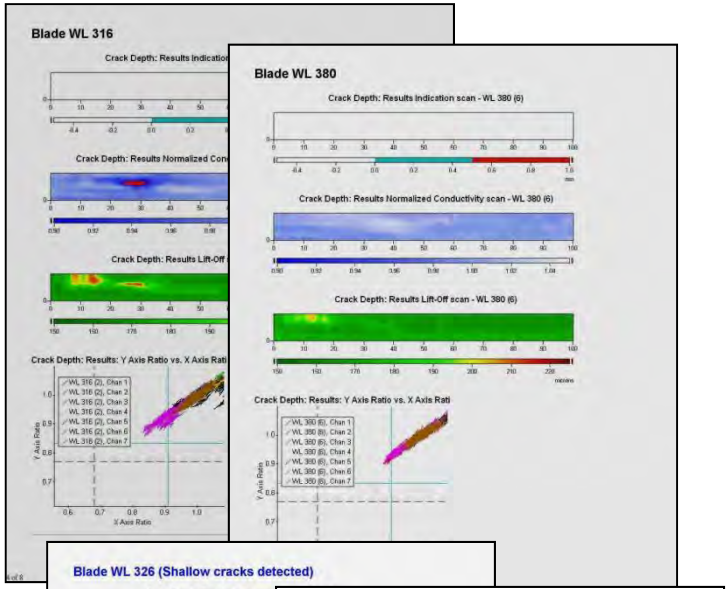
with GridStation Edge Location Correction

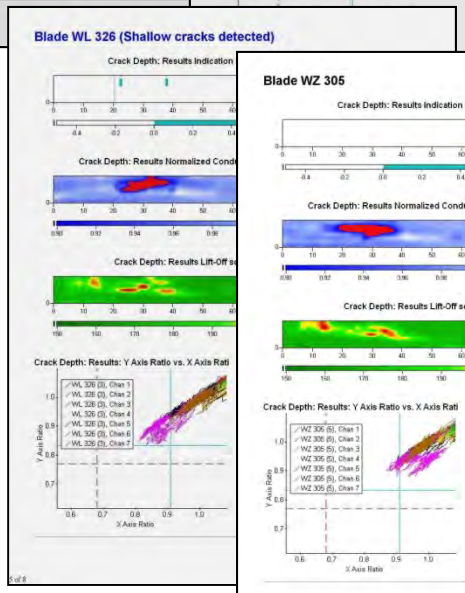
GridStation Conductivity/Lift-Off Images (Unfiltered)

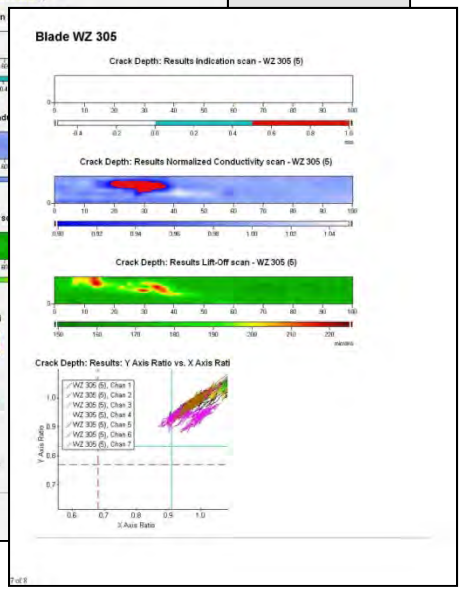


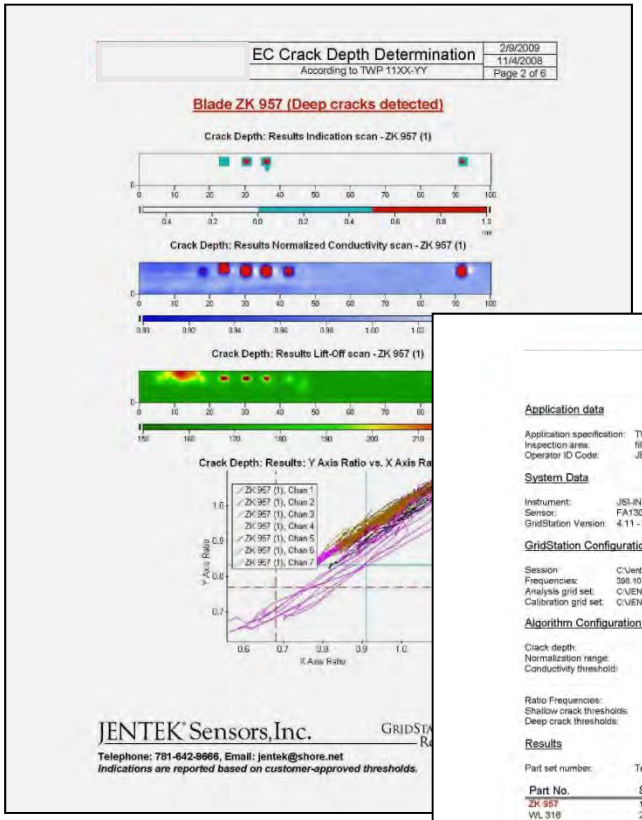
FA43 Sensor Detail

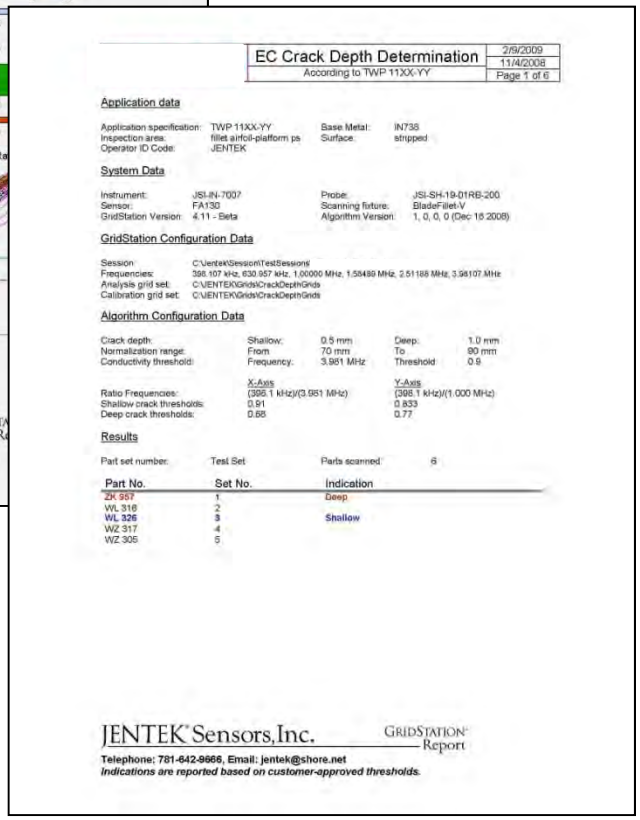
Automated Crack Depth Reporting Example



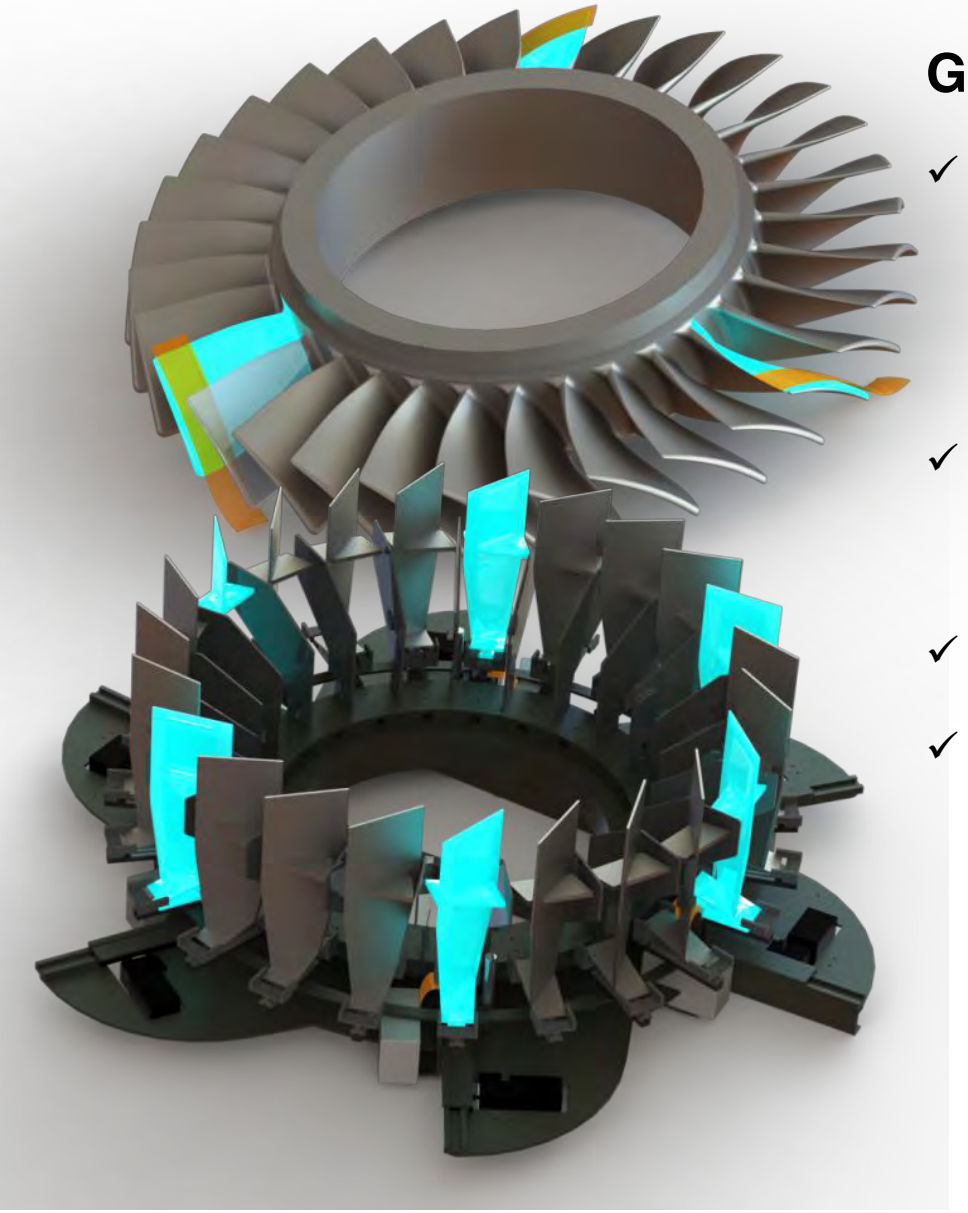








Summary of High Throughput Goals



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