SAND2006-6187P

# FAA Airworthiness Assurance NDI Validation Center Operated by Sandia National Labs

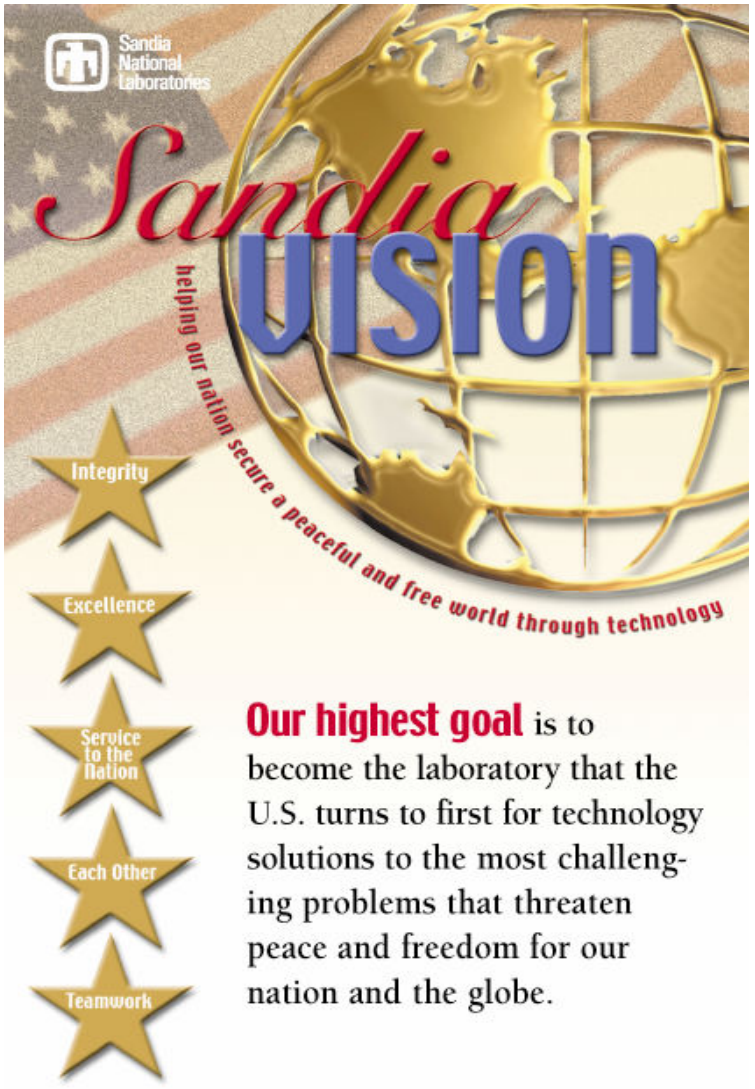
**Roger Hartman, Manager**
**Dennis Roach, Distinguished Member of Technical Staff**
**FAA Airworthiness Assurance Center**
**(505) 844-6078**
**dproach@sandia.gov**




Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

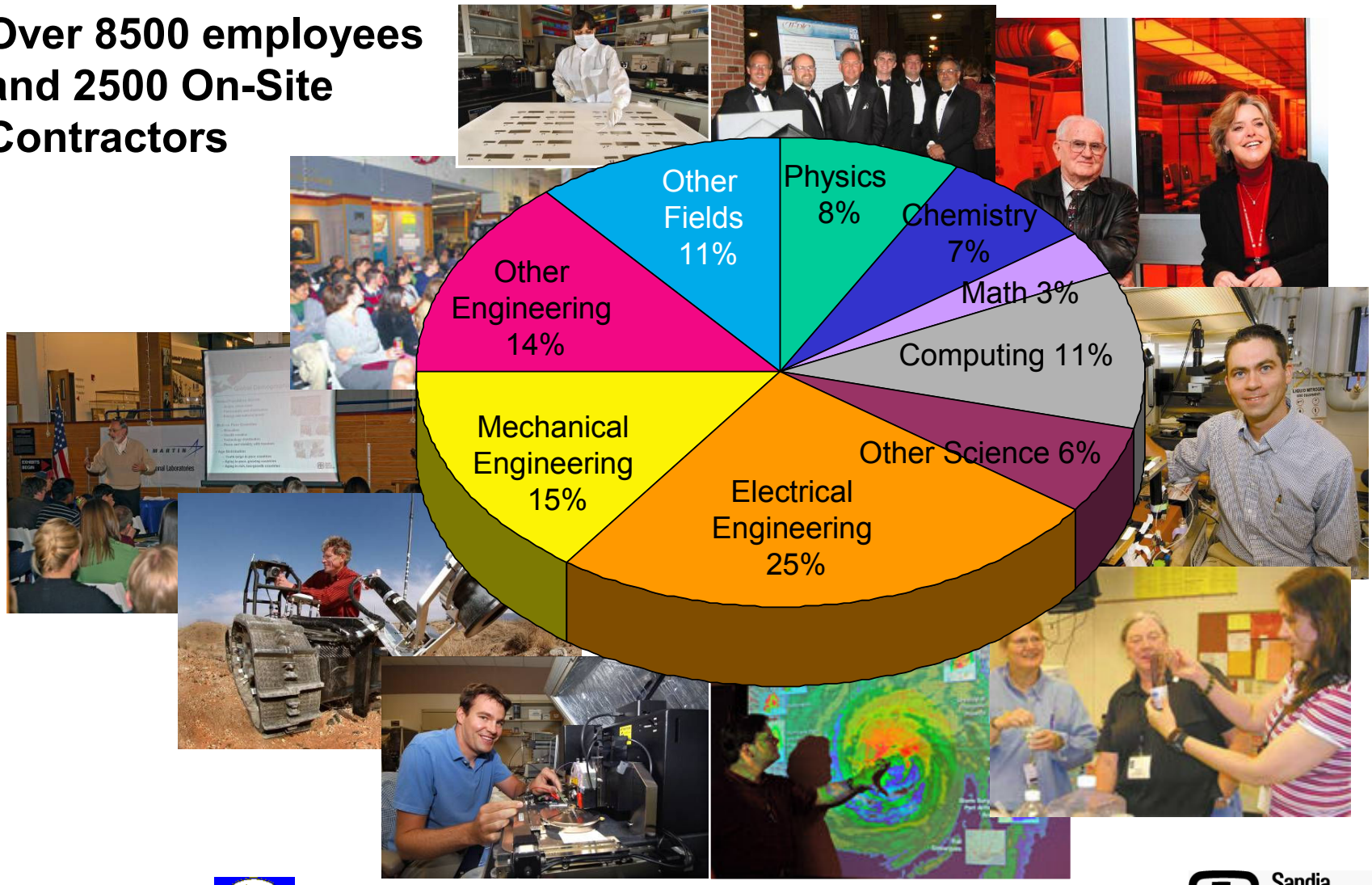
# What is Sandia National Labs?

- National security laboratory
- Core mission in nuclear weapons
- Broader mission in science and technology to meet national security needs



# Sandia People

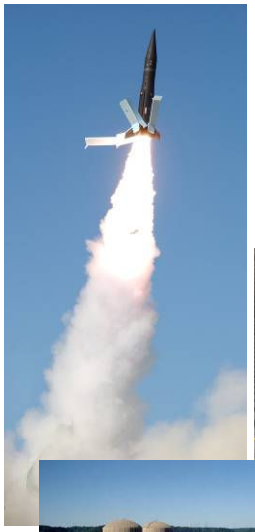
**Over 8500 employees and 2500 On-Site Contractors**

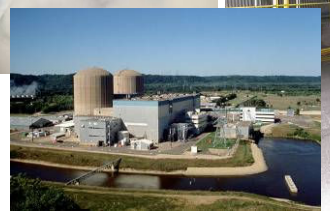


# Strategic Management Groups

## Integrated Technologies and Systems
Three Management Units

- *Energy, Resources, and Nonproliferation*
- *Homeland Security*
- *Defense Systems & Assessments*



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## Nuclear Weapons
One Management Unit

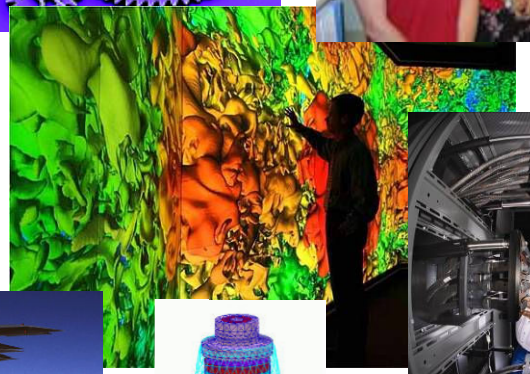
- *Nuclear Weapons*

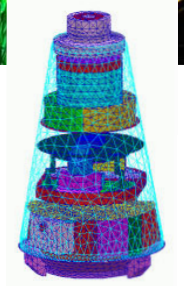



## Laboratory Transformation
Two Management Units

- *Integrated Enabling Services*
- *Science, Technology, and Engineering*







Sandia National Laboratories

# Sandia Labs Has Distributed Facilities to Meet National Needs

Kauai Test Facility, Hawaii

Albuquerque, New Mexico

WIPP, New Mexico

Livermore, California

Tonopah Test Range, Nevada

Pantex, Texas

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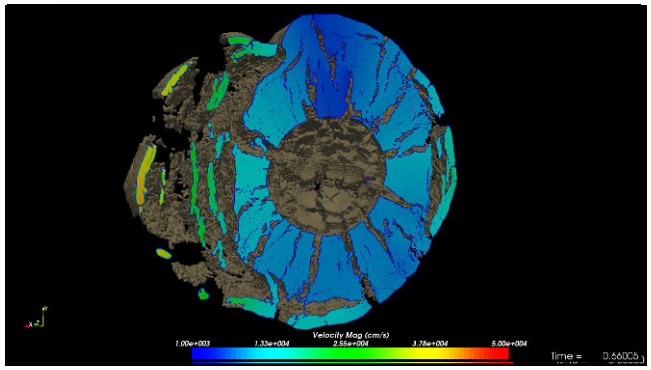
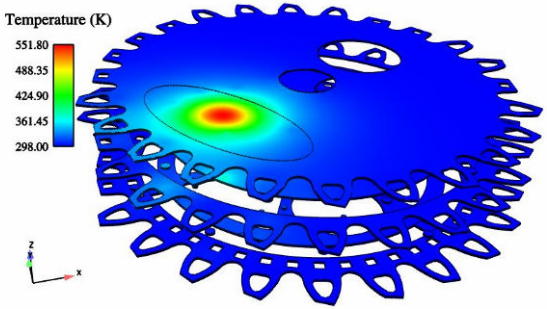
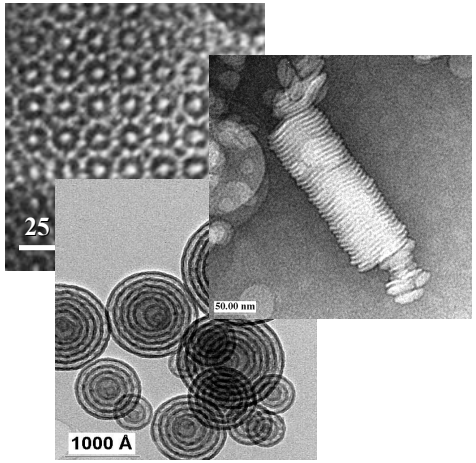
# Our Mission Focus Relies on Strong Science and Engineering



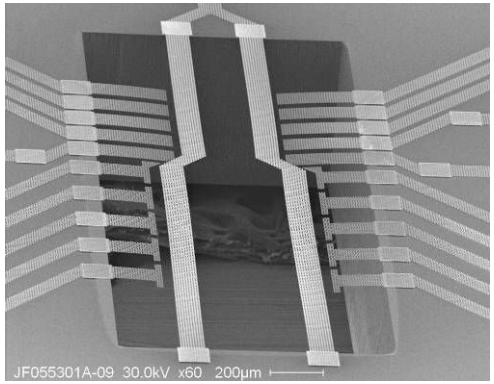
Computational and Information sciences



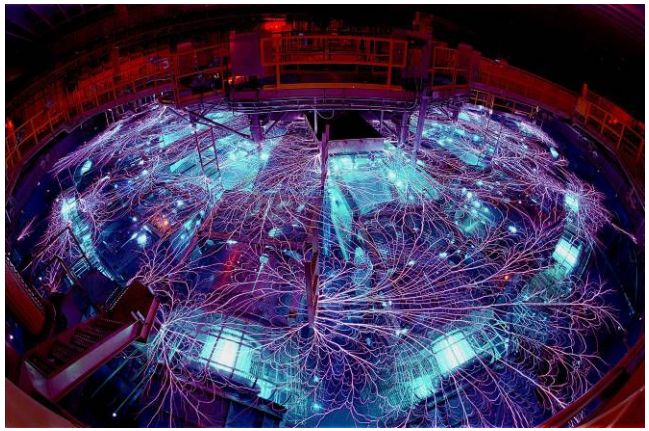

Engineering Sciences



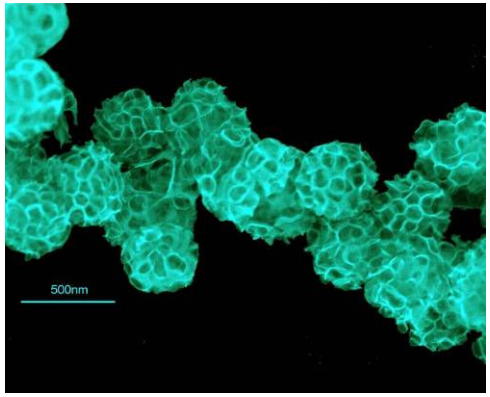

Materials Science and Technology




Microelectronics and Photonics



Pulsed Power




Biotechnology

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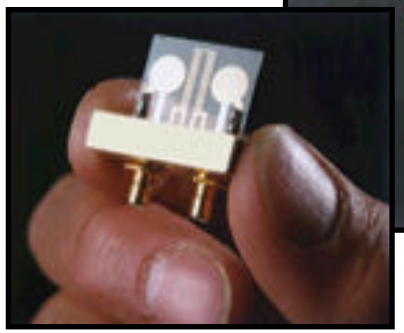
# Sandia performs other nationally important work when its capabilities can make significant contributions

- Vulnerabilities of critical infrastructures
- Risk assessment methodologies

- Safety of transportation Systems
- Aging studies and diagnostics


- Environmental studies

- Anti-crime and anti-terrorism technology



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# FAA Airworthiness Assurance Center

- Initiated in 1988 under the Aviation Safety Act
- Provides a mechanism to develop, evaluate, and bring new aircraft technologies to market
- Partnerships with industry, academia, and government

B737-200
Test Bed



Fairchild Metro II
Test Bed

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# AANC Objectives

- Enhance aircraft safety and reliability
- Aid in the development of advanced aircraft designs and maintenance techniques
- Provide our customers with comprehensive, independent, and qualitative evaluations of new and enhanced inspection, maintenance, and repair techniques
- Facilitate the transfer of effective technologies into the aviation industry
- Support FAA rulemaking process by providing guidance on content & necessary tools to meet requirements or recommendations of FARs, ADs, ACs, SBs, SSIDs, CPCP, and WFD
- Coordinate with and respond to Airworthiness Assurance Working Group (AAWG) in support of FAA Aviation Rulemaking Advisory Committee (ARAC)

# AANC Programs Cover a Wide Array of Airworthiness Assurance Issues

**Sandia Charter with FAA includes:**

| | |
|---|---|
| Adv. Materials & Structures | Crashworthiness |
| Inspection, Maint., Repair | Landing Gears |
| Propulsion & Fuel Systems | Nonstructural Systems |

***Sample Advisory Circulars Supported by AANC Project Information:***

*AC 91-60A "Continued Airworthiness of Older Airplanes"*

*AC 120-16C "Continued Airworthiness Maintenance Programs"*

*AC 135-10A "Approved Aircraft Inspection Program"*

*AC 125-1, 129-4 "Maint. & Operation of Aircraft Under FAR Part 125/129"*

*AC 91-56B "Struc. Integrity Program for Transport Airplanes"*

# Summary of Programs

- Federal Aviation Administration
  - Airworthiness Assurance Center
    - Airframe Inspection, Maintenance, and Repair
    - Advanced Materials and Health Monitoring
    - Non-Structural Systems (Flight Controls, Wiring, Engines)
    - Smoke Transport Code Development
    - Specialty Alloys for Propulsion Applications
- Dept. of Defense - Air Force, Navy, Army
- US Coast Guard, Civil Aviation Industry, US Forest Service
- DoE Defense and Energy Programs
- NASA – Space Shuttle and Aging Aircraft
- Private Industry – e.g. Boeing, Bell Helicopter, Lockheed-Martin, Exxon, General Motors
- Universities – WSU, NWU, NC A&T, ISU, UW, NMSU, UNM

# AANC - Teaming for Success

**Teams have incorporated over 150 agencies**

**DC-9 Tee Cap**
Northwestern University
Northwest Airlines
Douglas Aircraft
SAIC Ultralmage

**Rotorcraft Inspection**
Bell Helicopter
Sikorsky Aircraft
Petroleum Helicopters
Army/Navy
Olympus

**Sensor & NDI Development**
Boeing
General Electric
Delta Air Lines
Northwest Airlines
Jentek
Innovative Materials Testing

**Engine Bearing Cleaning**
GE Engines
Lewis Corporation
MRC Bearings

**Halon Bottle Tester**
Air Transport Association
Walter Kidde
Pacific Scientific
Physical Acoustics

**Widespread Fatigue Damage**
Boeing Commercial Aircraft
Delta Air Lines
NRC Canada
Iowa State University

**Boron Epoxy Repairs**
Boeing
Lockheed-Martin
Delta Air Lines
Federal Express
Textron
Air Force

**NDI of Advanced Composite Structures**
Boeing Commercial Aircraft
Airbus
United Airlines
Delta Air Lines
American Airlines
Air France
Lufthansa
Wichita State University
North Carolina A&T

**Commuter Program**
Cessna
Raytheon
Fairchild
Northwestern University

**MOI for Corrosion Inspection**
Boeing Commercial Aircraft
United Airlines
Physical Research Inc.

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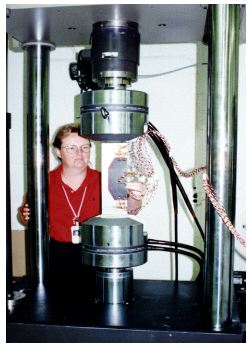
# Summary of AANC Accomplishments and Work to Address Aviation Safety Concerns

Halon Bottle Tester

Fatigue Tests on Composite Specimens



Thermal Wave Imaging

AANC Multidisciplinary Projects

L-1011 Composite Doubler

DC-9 T-cap Inspection

USCG Window Post Inspection

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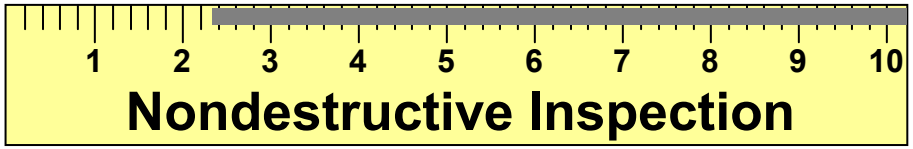
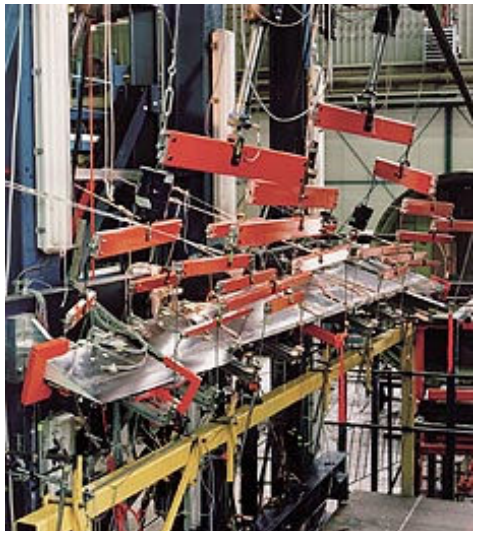
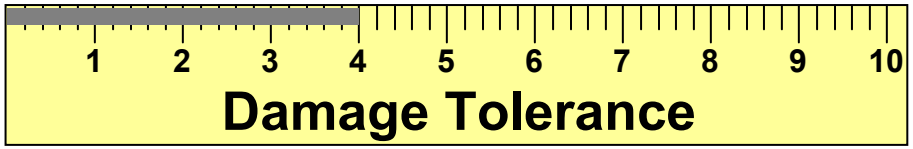
# Required Relationship Between Structural Integrity and Inspection Sensitivity

*Detectable Flaw Size*






*Allowable Flaw Size*

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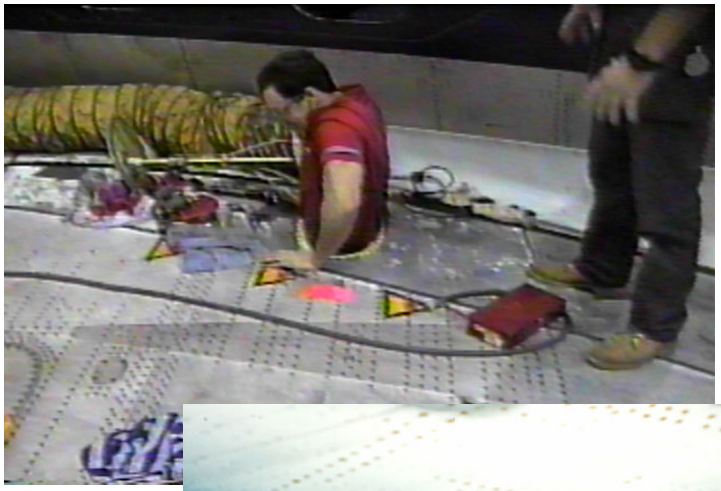
# DC-9 Wingbox Tee Cap Inspection

**DC-9 Wingbox Tee Cap Crack Inspection**

- **Ultrasonic technique replaces visual inspection**
- **Eliminates need for exposure to hazardous material in a confined space**
- **Doubles inspection area and increases resolution**
- **Produced AMOC for Boeing AD while providing better NDI information**
- **Aging Aircraft FAR & SSID**

***Before* - 800 hours Visual Inspection**



***Northwest Airlines Inspector scanning DC-9 Tee Cap with new ultrasonic technique***

***After* - 80 hours**

# Repair of Commercial Aircraft Using Bonded Composite Doublers




- Safely introduced new aircraft repair technology that provides both engineering and economic benefits
- Entire process, including advanced inspection methods, is aiding Service Life Extension Programs
- Produced Boeing Structural Repair & NDT Manual revisions and FAA guidelines to assure continued airworthiness; AMOC for AD 94-05-01
- Aging Aircraft FAR & associated ACs

*Technology proven to be viable for the commercial aircraft industry - Pilot Programs, Boeing NDI and SRM Manual revisions*

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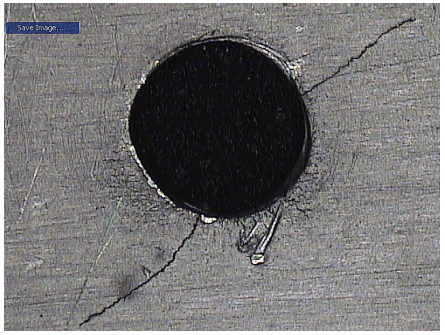
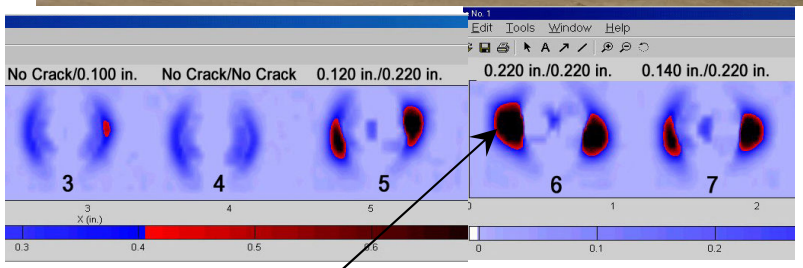
# Widespread Fatigue Damage

- Response to AAWG and ARAC request
- Understand WFD phenomena through lab and field studies; aging aircraft teardown inspections
- Advanced NDI has produced order of magnitude improvements to create risk management options
- Program is producing guidelines for assessing continued airworthiness
- Effort supports NPRM regulations in Widespread Fatigue Damage (FAA-2006-24281) & Damage Tolerance Data for Repairs & Alterations (FAA-2005-21693)

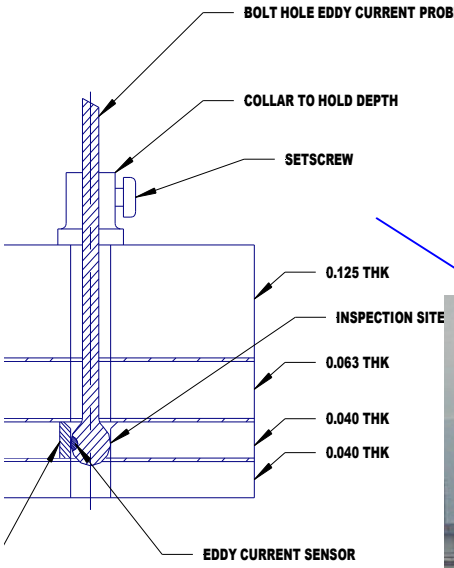


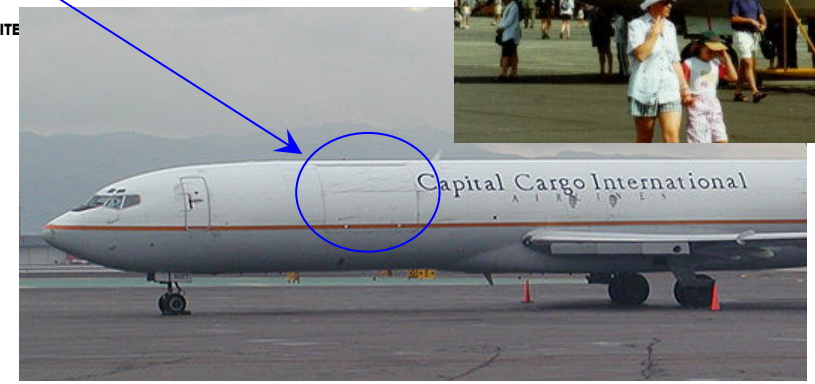



Fatigue Cracks

# Quick Response Project – Emergency Inspection of B727 Cargo Door Modification

- Modification from passenger to cargo door covered lap splice joints involved in crack terminating action (AD 91-06-06 from Aloha accident)
- Program requested NDI method for immediate application to avoid grounding cargo fleet of 727 aircraft
- Bolt hole eddy current method was developed and validated
- Inspection was incorporated into Boeing Alert Service Bulletin & approved as Alternate Means of Compliance for AD T98-23-51 and AD 99-04-22

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# Quick Response Project for NTSB – AA587 Crash Investigation

- Developed inspection method to address post-accident AD
- Ongoing support for Airbus Alert SB (rudder)

*MAUS MIA C-Scan of Airbus Rudder*


*Developed P-E UT inspection – added for carbon laminate lug*

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# Commuter NDI Program


**Supporting Commuter SSID Advisory Document**

- **Development and implementation of new NDI techniques allows aging commuter fleets to safely extend the life of their aircraft**
- **Move beyond visual – advanced NDI reduces inspection times/costs and lengthens the required inspection intervals**
- **Aging Aircraft FAR; information for AC-135-7, FAR 135**

***Inspection of lower wing spar testbed (Fairchild SA226)***

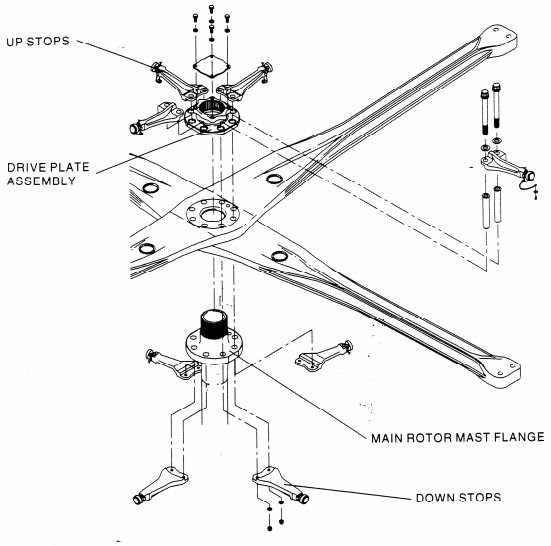
***Field testing of eddy current inspection being completed on SA226 aircraft***

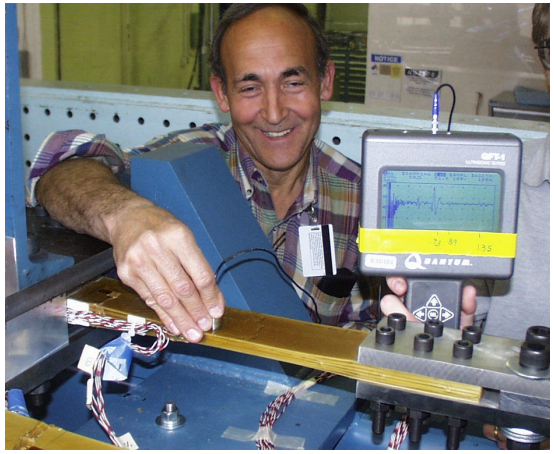
**Detect 0.100” cracks in 3rd, 4th, and 5th layer of spar assembly**

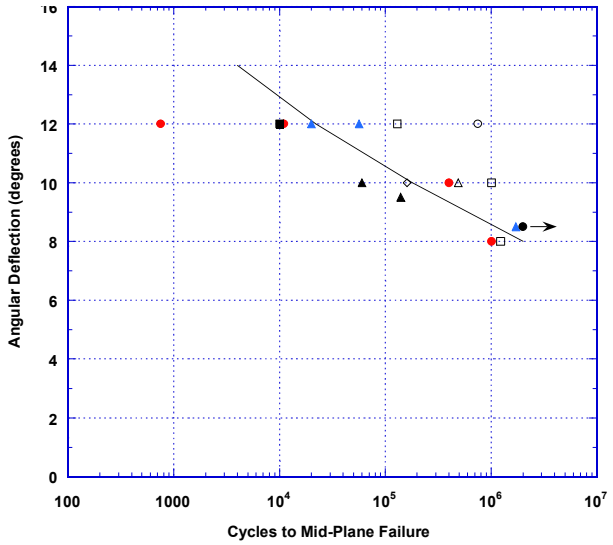
# Rotorcraft Inspection & Damage Tolerance Program

- Allows advanced rotorcraft design concepts to be safely integrated into routine use
- Produce regulatory measures to meet new NDI demands stemming from damage tolerance analysis approach
- Results integrated into maintenance depots (training, procedures)
- Supports Aging Aircraft FAR and design per DT FAR (14 CFR 29.571); AC 29-2C; AC 27-1B

## Damage Tolerance & NDI Assessment of Composite Rotor Hubs






Cycles to onset of delamination in high cycle fatigue) environment

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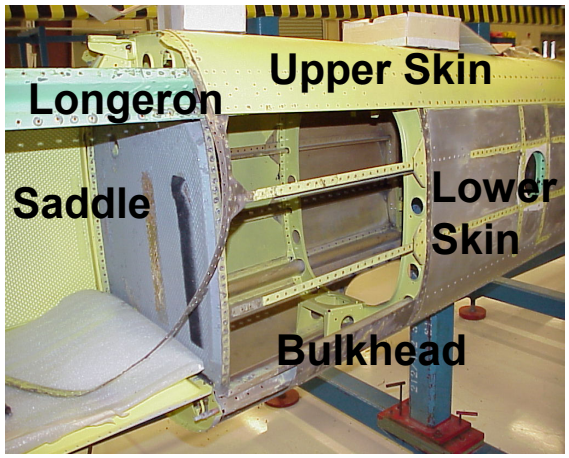
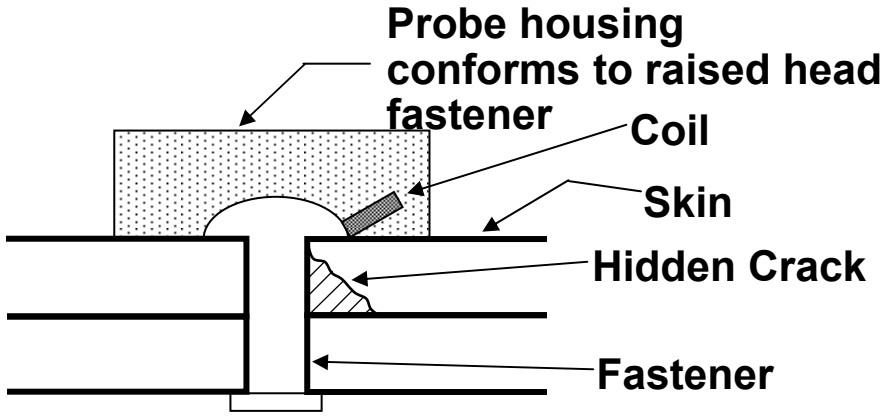
# Rotorcraft Inspection & Damage Tolerance Program

## Flaw Detection Studies - Cracks (high cycle fatigue) and Corrosion (multi-layered joints)




- Dual frequency EC method can detect <10% corrosion (0.002” th. loss)
- Custom probes developed to detect cracks under raised head fasteners
- Enhances safety, reduces repair costs, eliminates need to remove fasteners for inspections
- Aging Aircraft/DT FAR; 8300.12 Flight Standard Infor. Bulletin on corrosion

Training for Beta Site Testing at PHI




Angled Surface Crack

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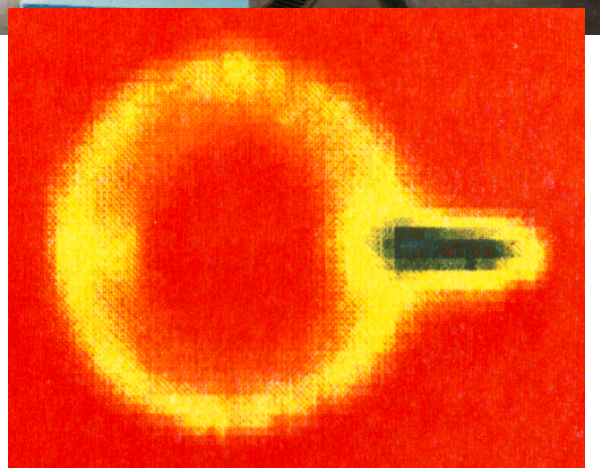
# Eddy Current Inspection Reliability Experiment

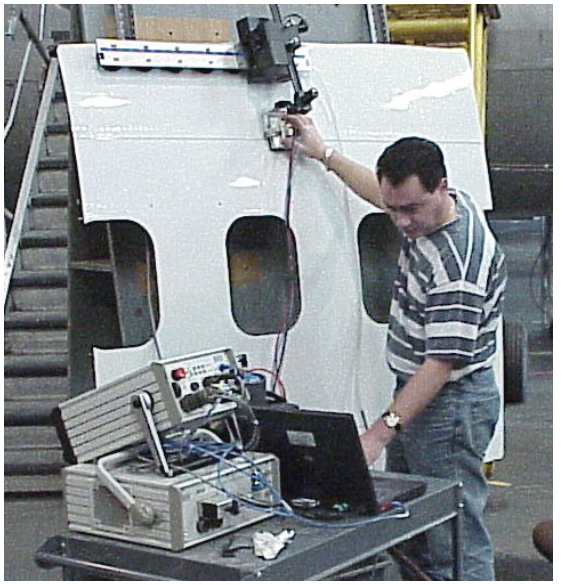
- Evaluated the performance of conventional eddy current devices at aircraft maintenance depots to detect fuselage cracks
- Demonstrated the need for better imaging capabilities to interpret eddy current measurements
- Led to development of new imaging technologies which will allow operators with less expertise to use the technology
- Supports AD 91-06-06 (terminating action) & subsequent Boeing Alert SB 737-53A1224 (AD 99-04-22)



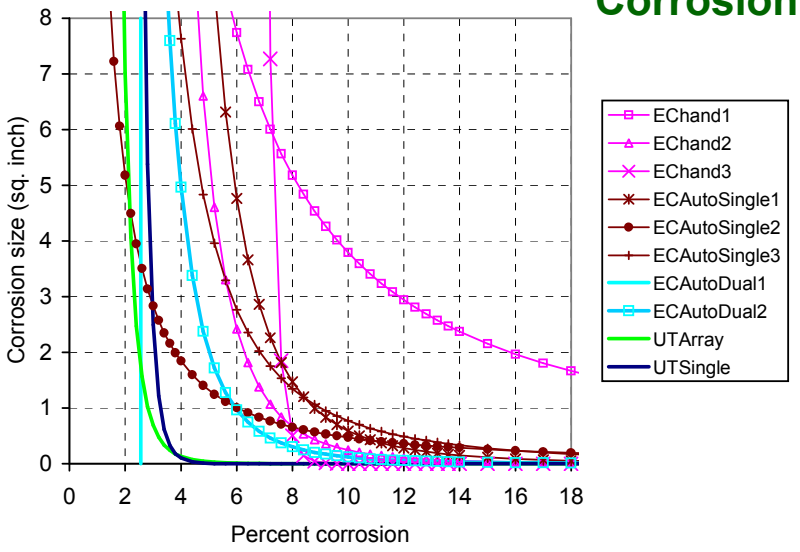
Eddy current imaging technology for crack length measurement

# NDI Validation Experiment - Detection of Hidden Corrosion

- Response to AAWG and ARAC request
- Assess the performance of conventional and emerging NDI techniques & integrate equipment into aircraft maintenance depots
- Aid NDI development, directs application to appropriate inspections
- Support Aging Aircraft FAR, 8300.12 Flight Standard Infor. Bulletin on corrosion, and corrosion inspection SSIDs



RD Tech Performing Blind Corrosion Detection Study


Probability of Flaw Detection Contours

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# Composite Initiatives








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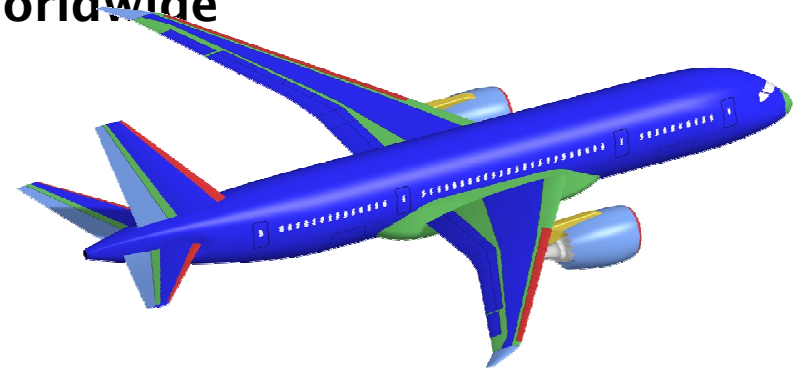
# Composite Inspections & Reference Standards

- Industry-wide composite reference standards developed to support damage assessment & inspection
- SAE Aerospace Recommended Practices (ARP 5605 & 5606) - adopted into Boeing and Airbus NDT Manuals
- Improve inspections of composite structures via introduction of advanced NDI methods
- Provides consistent approach to composite inspections - harmonized approach by OEMs worldwide

**Optimized NDT Reference Standards**

*Composite Structures on Boeing 787 Aircraft*

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# Assessing Composite Inspections

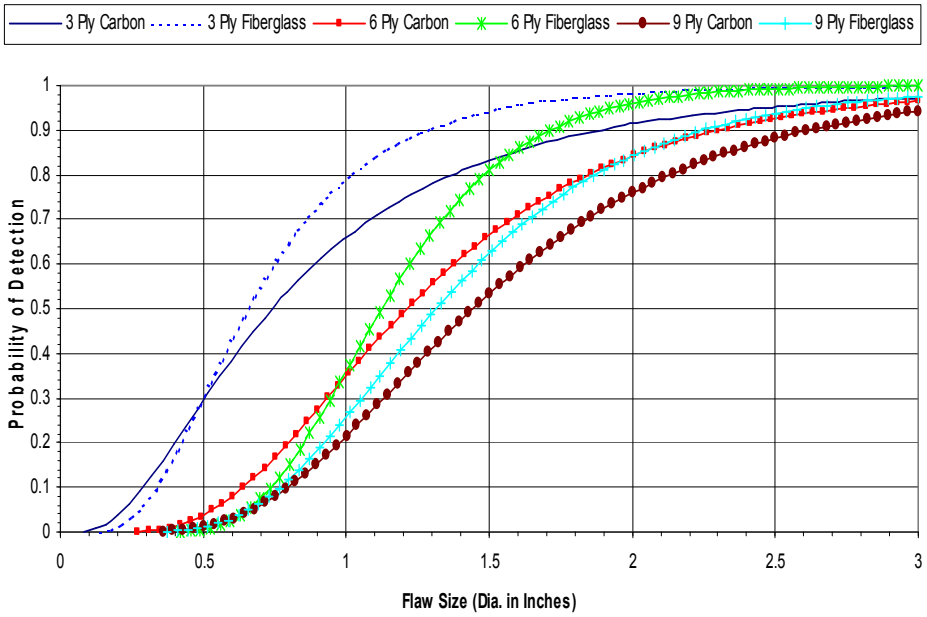
## Composite Flaw Detection Experiment

**Participation from over 25 airlines and maintenance depots**

**Industry-wide performance curves generated to quantify:**

- **how well current inspection techniques are able to reliably find flaws in composite honeycomb structure**

- **the degree of improvements possible through the integration of more advanced NDI techniques and procedures.**




**NDI technology insertion to support Aging Aircraft FAR & SSID program and provide proactive approach for next-generation aircraft**

**Experiment to Assess Flaw Detection Performance**

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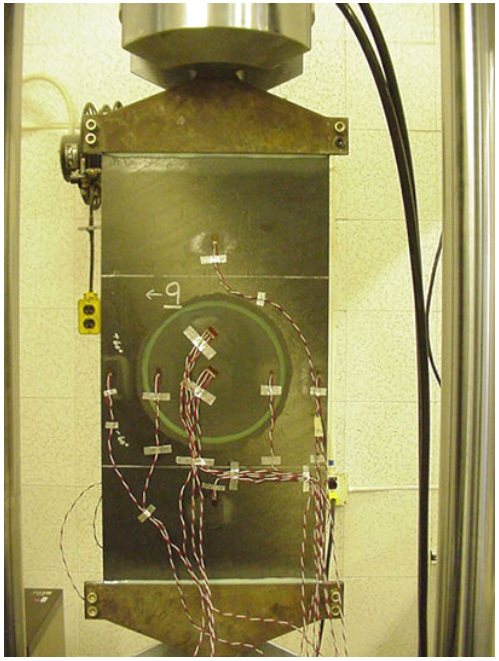
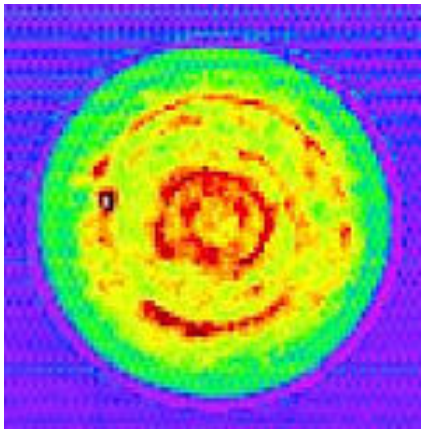
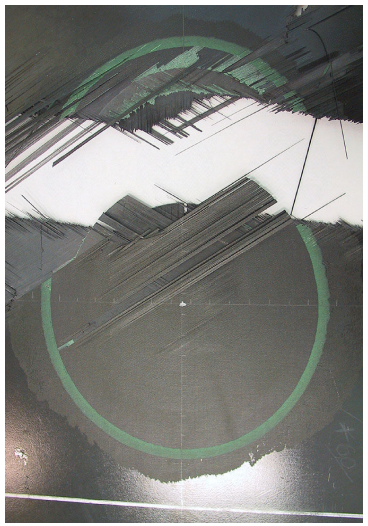
# Composite NDI & Laminate Repair Systems – Compare Mechanical & NDI Performance

***Joint program with North Carolina A&T***

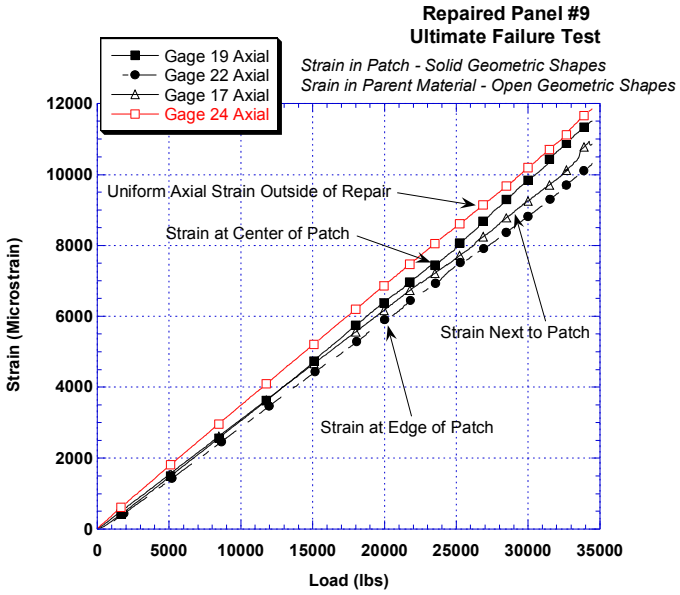






Strain field & repair efficiency assessment vs. NDI findings

***Comprehensive evaluation of composite repair and associated NDI technology to ensure proper mesh between structural integrity & flaw detection***

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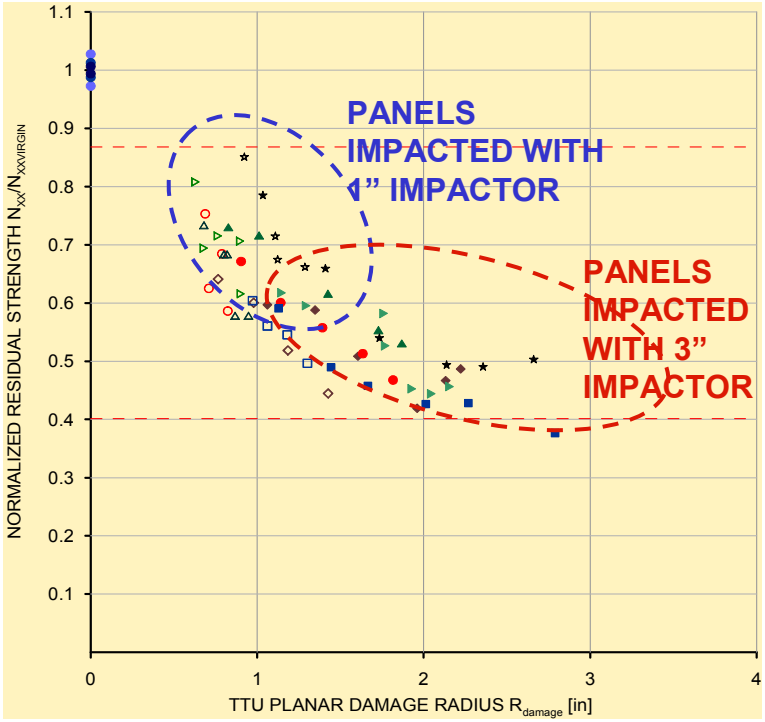
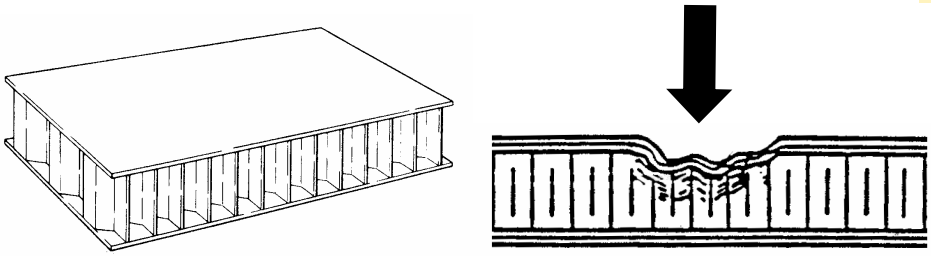
# Impact, Repair & Damage Tolerance of Airframe Composites

*Joint program with Wichita State NIAR & Boeing*

**Goals and Objectives:**

- To understand critical impact threats, residual strength and reliable inspection methods for aircraft sandwich designs
- Damage tolerance guidelines for AC revisions and/or ongoing certification programs
- Correlation of field damage detection with residual strength
- Evaluation of repair strength and NDI



**Relation Between NDI Flaw Detection/Sizing And Residual Strength**

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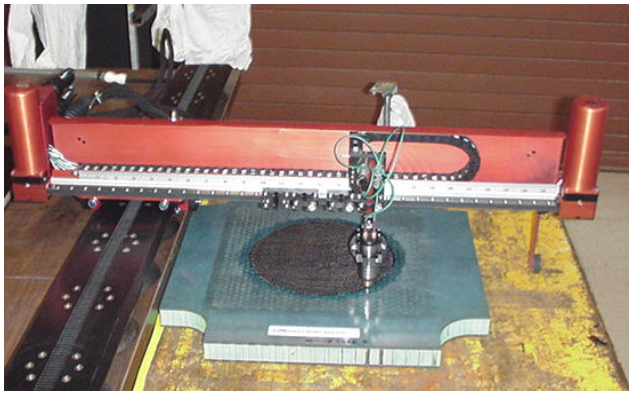
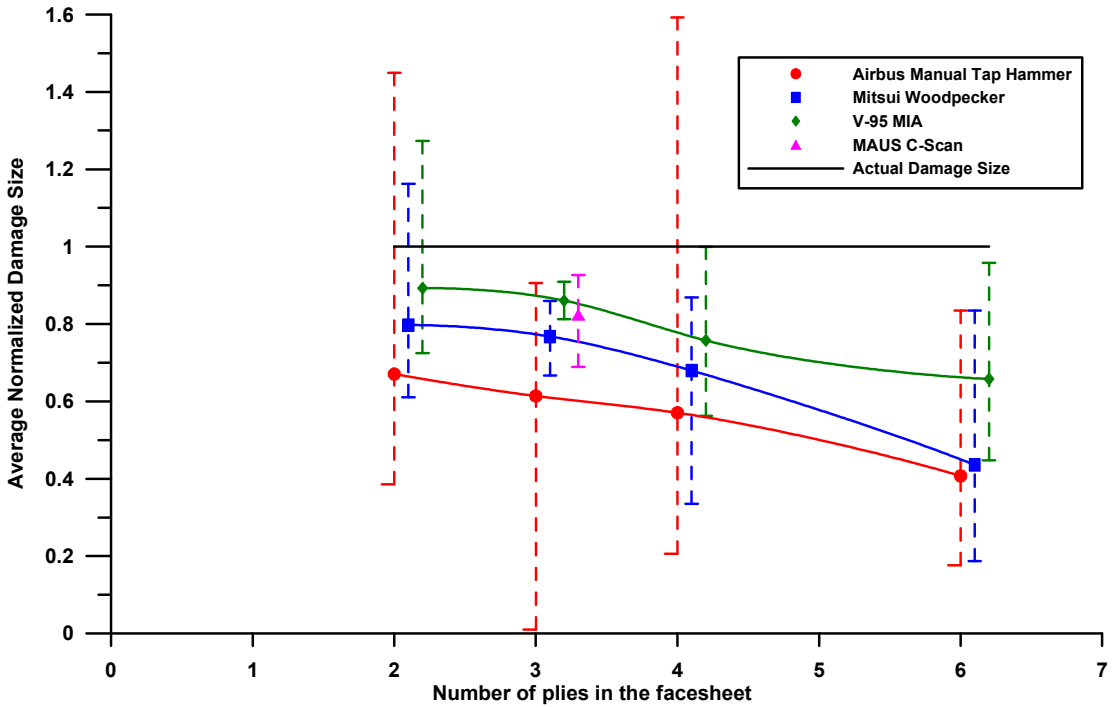
# Impact, Repair & Damage Tolerance of Airframe Composites (cont.)



MAUS Inspections of Repaired Composite Sandwich Structures

**Supports DT rulemaking (including 14 CFR 29.571), composite repair design and inspection (SSIDs)**



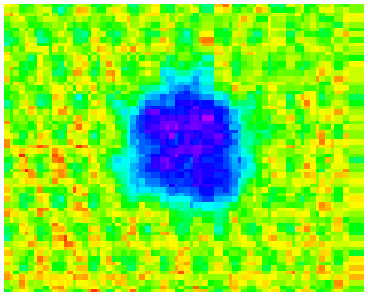



Image of Impact Damage

EVALUATION OF FIELD INSPECTION TECHNIQUES FOR IMPACT DAMAGE DETECTION

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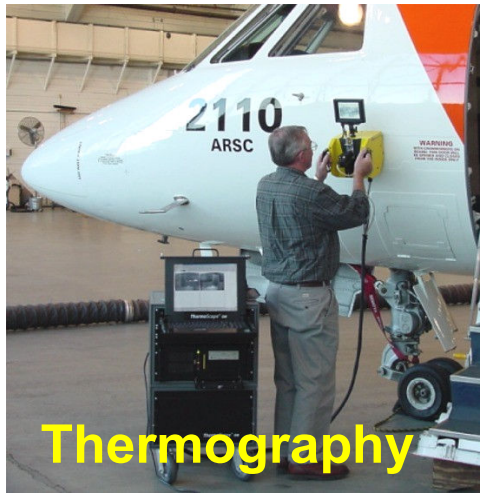
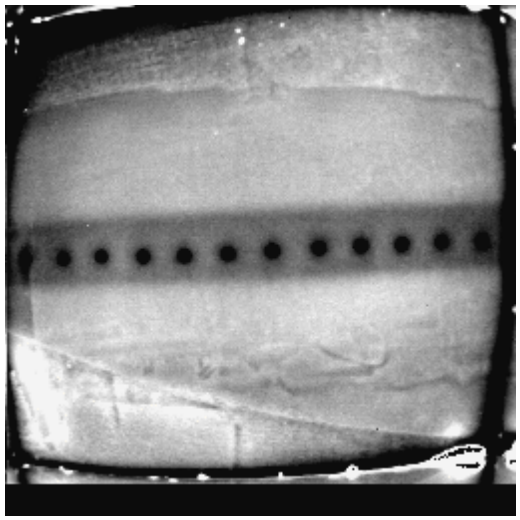
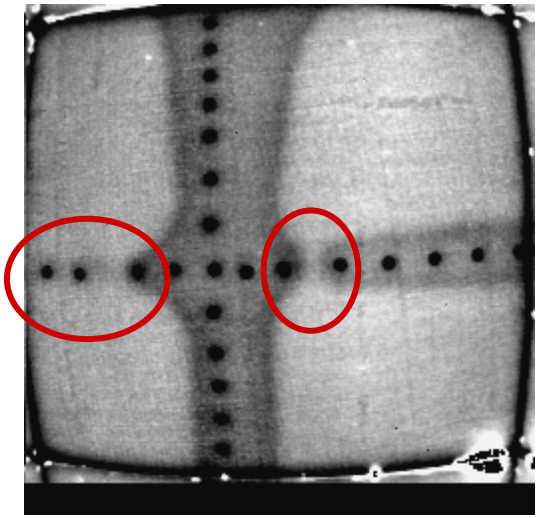
# Fuselage Inspection Using Pulsed Thermography

- Improved corrosion & disbond detection
- Developed in partnership with (CASR) Wayne State Univ., Boeing and Northwest Airlines
- Boeing-approved method (NDI Manual revision) for fuselage disbond detection; addresses AD for over 2000 aircraft



Bonded Doubler

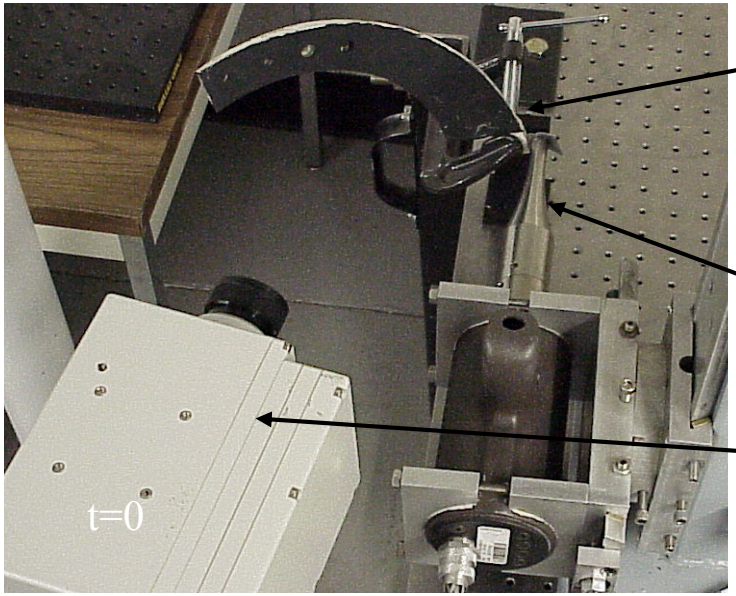


Disbonded/Bonded Doubler

# Sonic Thermography for Crack Detection

***Has found niche in engine parts where cracks are invisible to traditional dye penetrant methods***

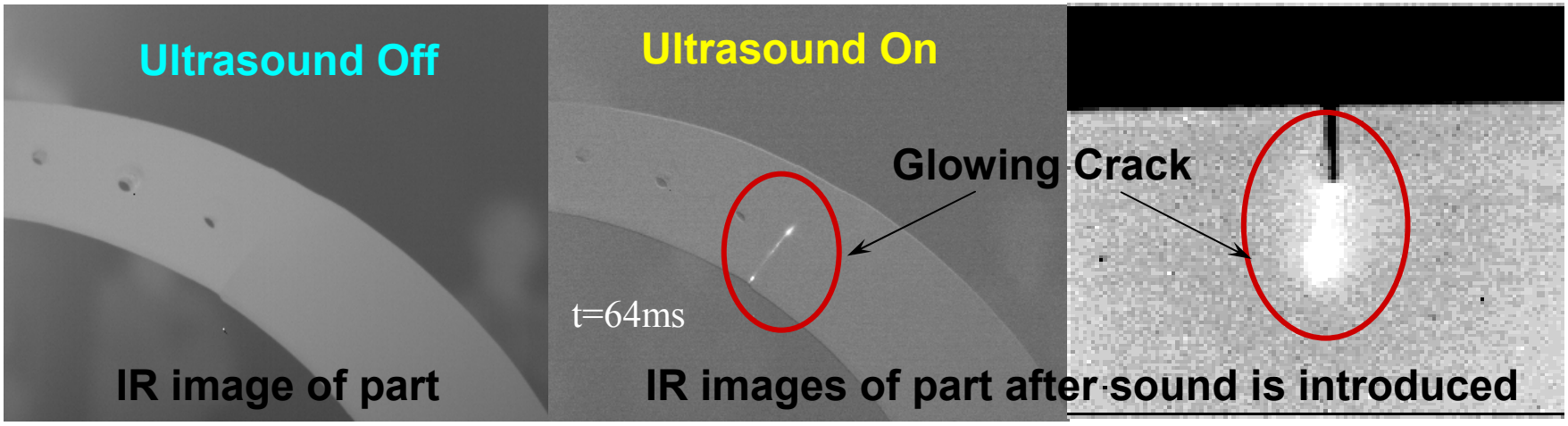
***(supports AC 33.14-1)***




Part being inspected

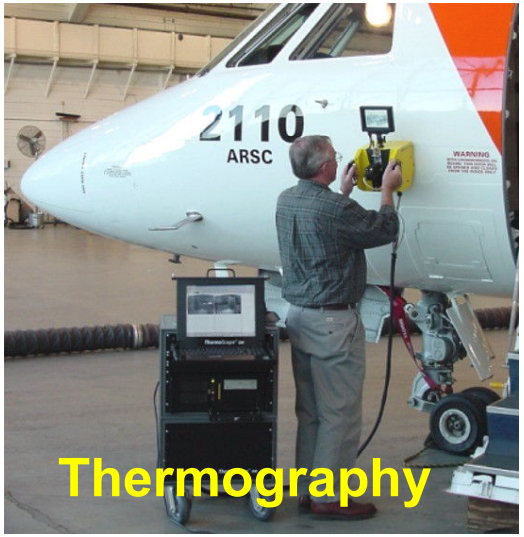
20 kHz
Ultrasonic Source

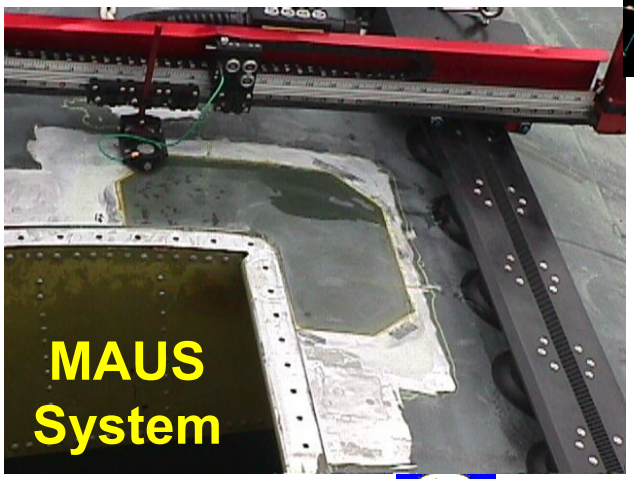
Infrared Camera



# Wide Area and C-Scan Inspection Methods





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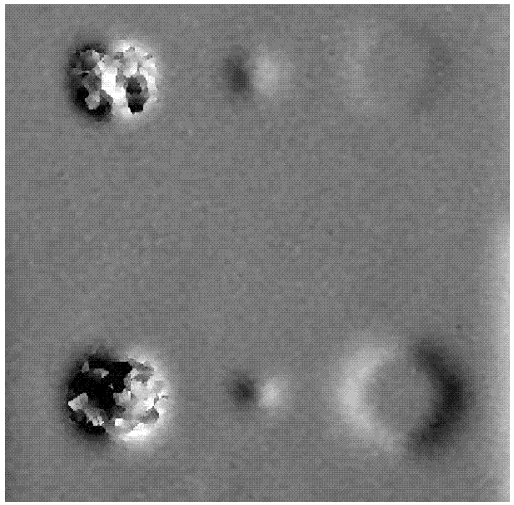
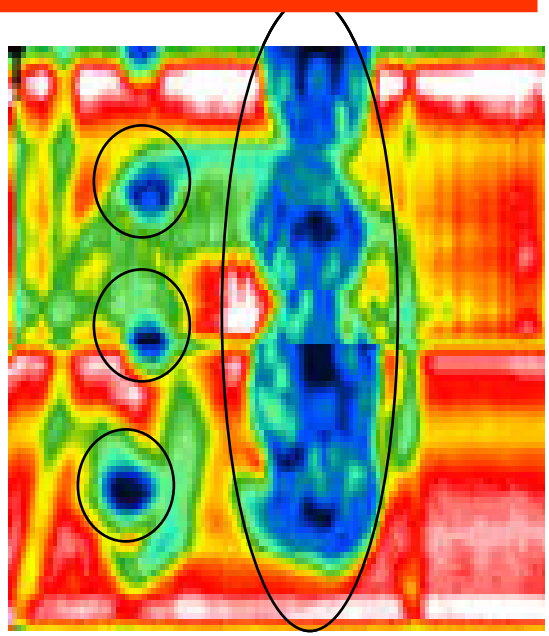
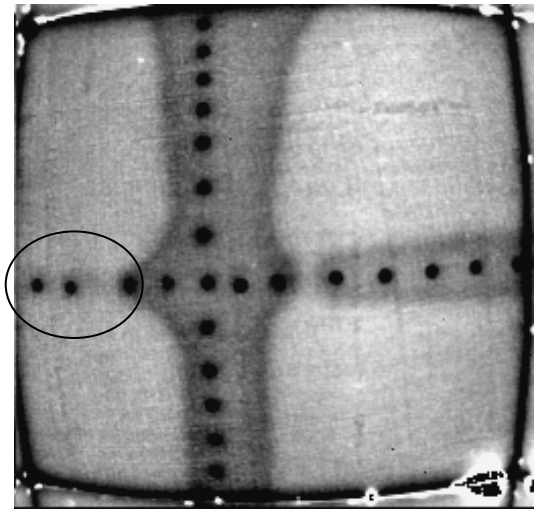
# Sample C-Scan Images Showing Presence of Flaws

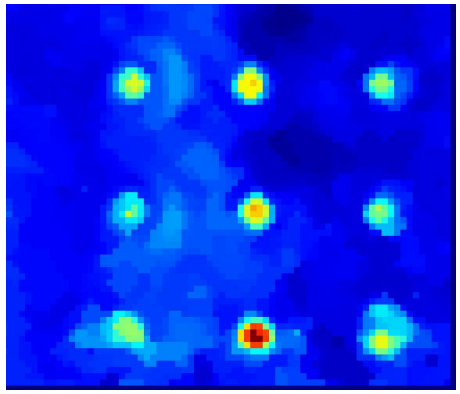
Shearography (LTI) Image



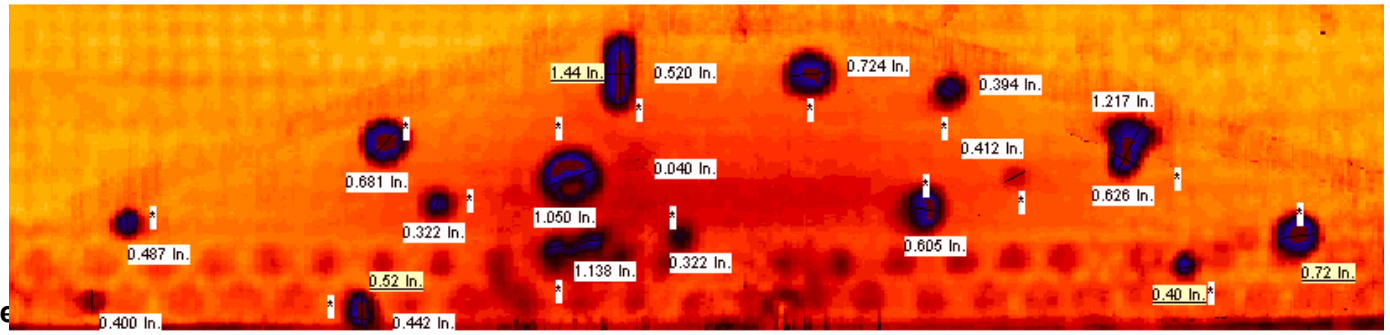


Thermography (TWI) Image





SAM Image




MAUS Image



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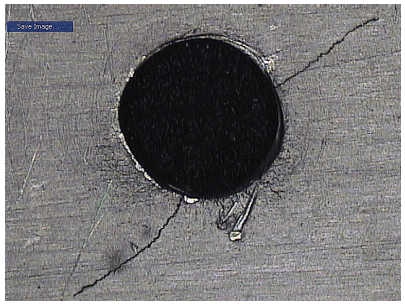
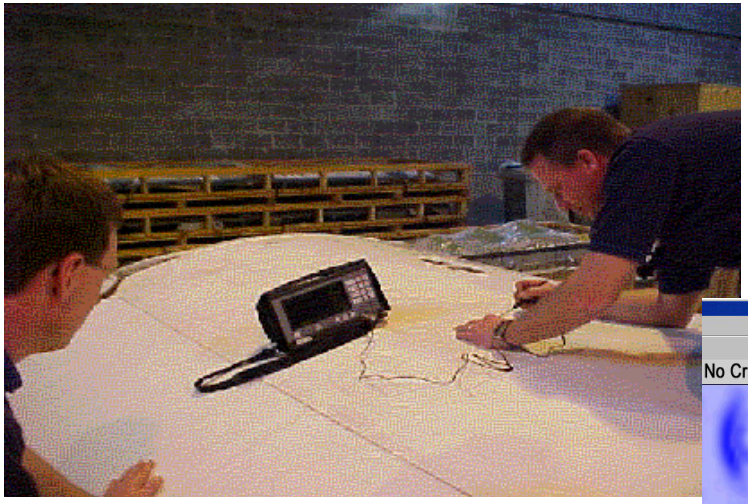
# AANC – Addressing Tomorrow's Concerns

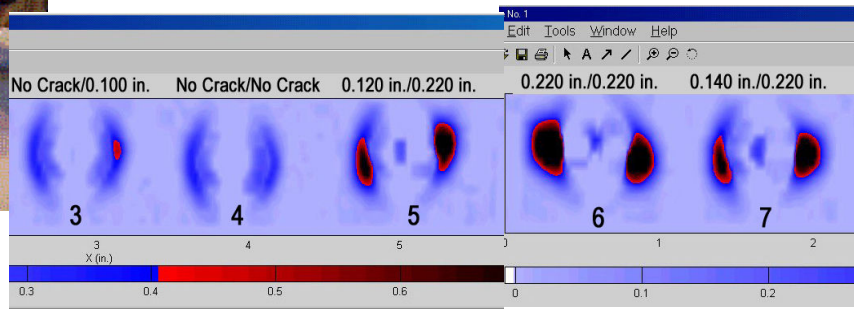
***Proactive approach to improve transportation safety and support aviation industry while growing private companies in a wide range of industries***

## Widespread Fatigue Damage

- **Understand WFD phenomena through lab and field studies**
- **Advanced NDI has produced order of magnitude improvements to create risk management options**

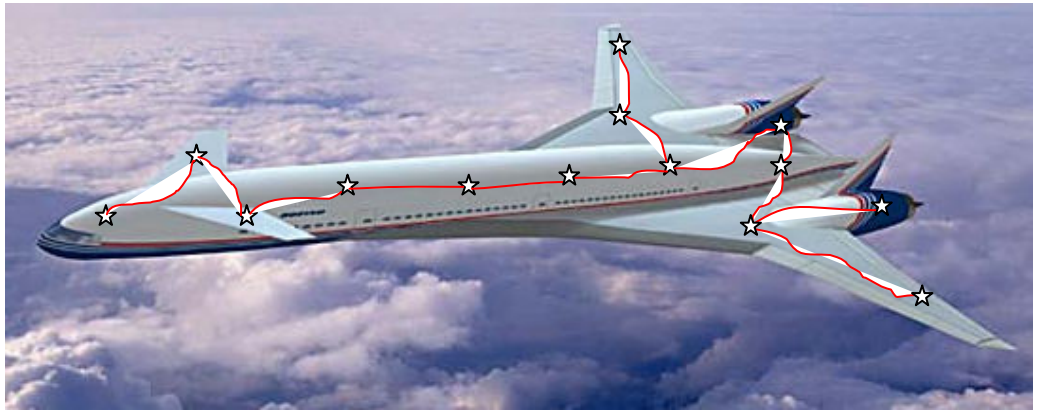


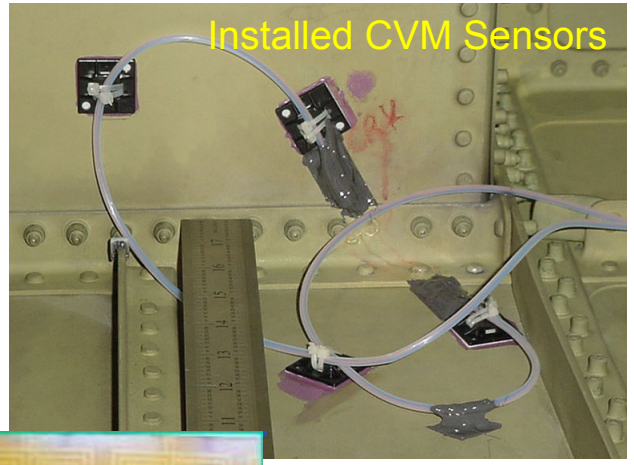


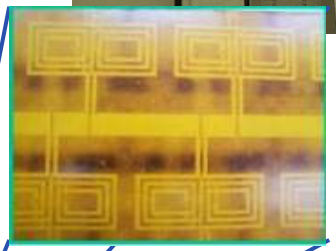


# Distributed Sensor Networks for Structural Health Monitoring

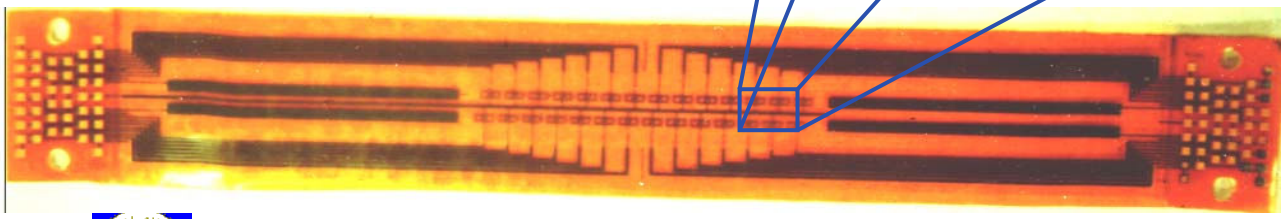
- In-situ sensors for rapid, remote (real-time) monitoring
- Allows for condition-based maintenance
- Evolution of rotorcraft HUMS



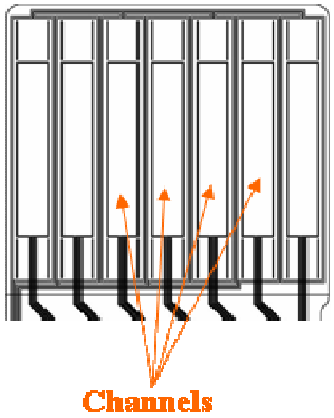


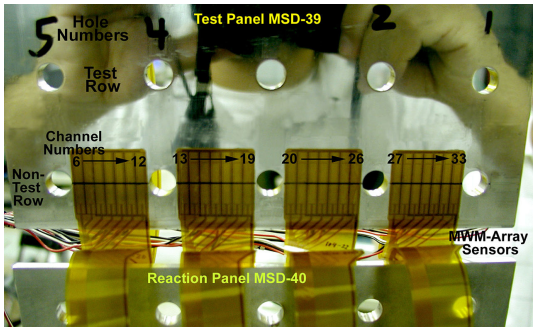



*Flexible Eddy Current Array*

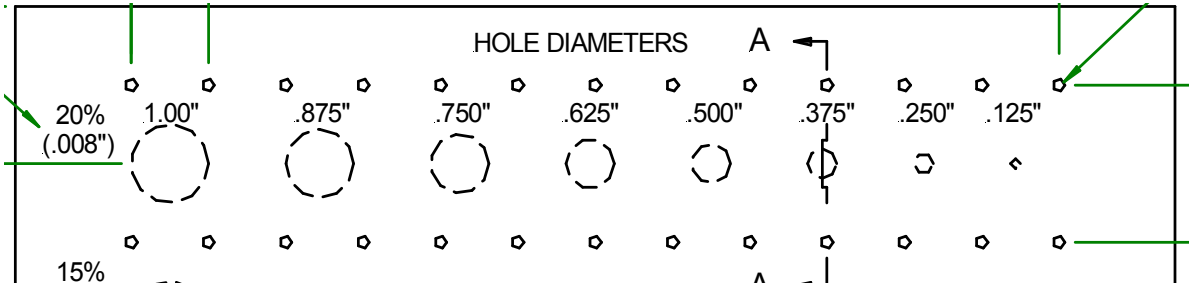


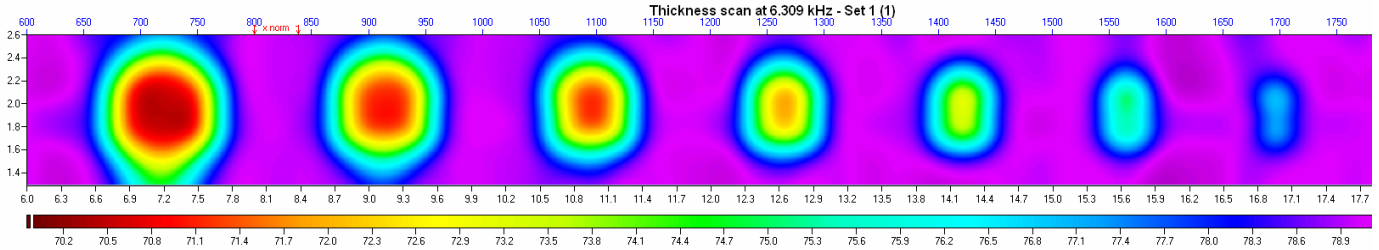
# Corrosion Imaging with MWM Mountable Sensors




**Multi-Channel MWM Arrays**

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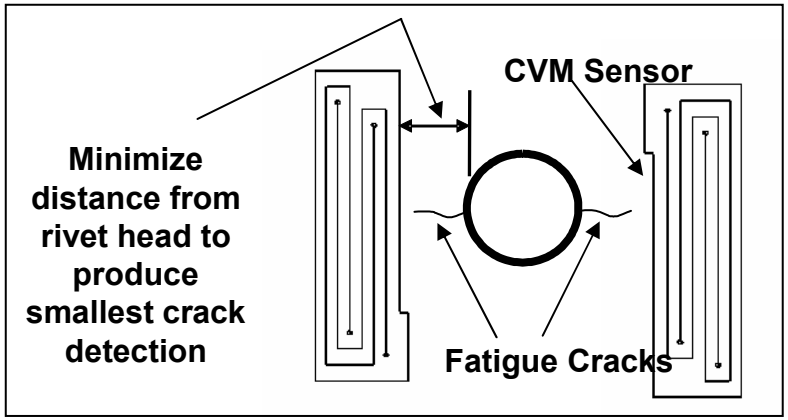
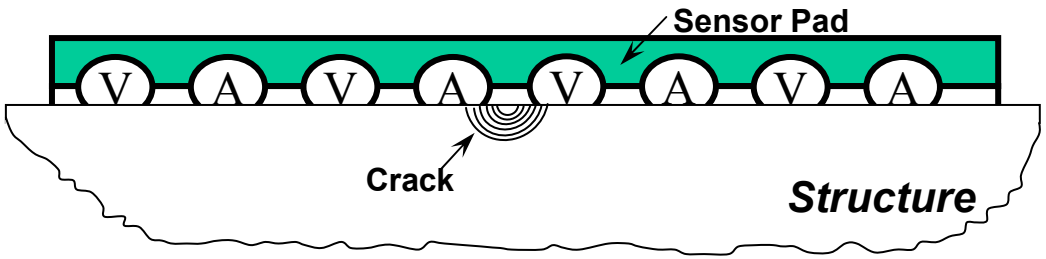
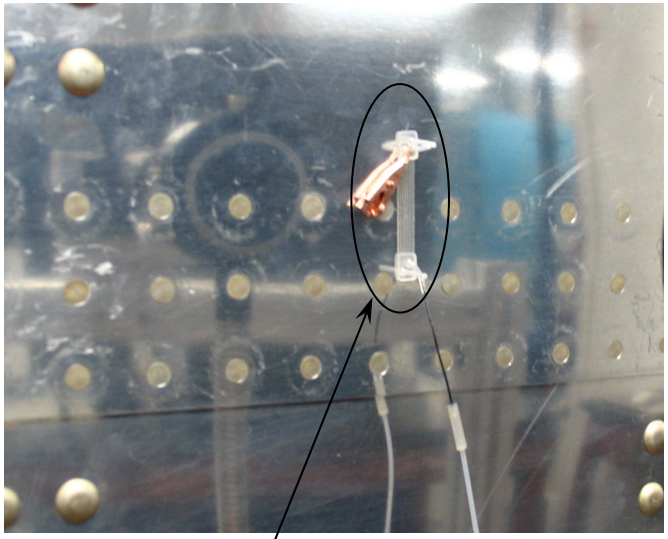
# Comparative Vacuum Monitoring System

- Sensors with fine channels on the adhesive face - applies a vacuum to a thin film sensor with embedded galleries open to the surface
- Leakage path between the atmospheric and vacuum galleries producing a measurable change in the vacuum level
- Doesn't require electrical excitation or couplant/contact
- 90% Probability of Flaw Detection level = 0.025" L cracks



CVM Sensor Adjacent to Crack Initiation Site

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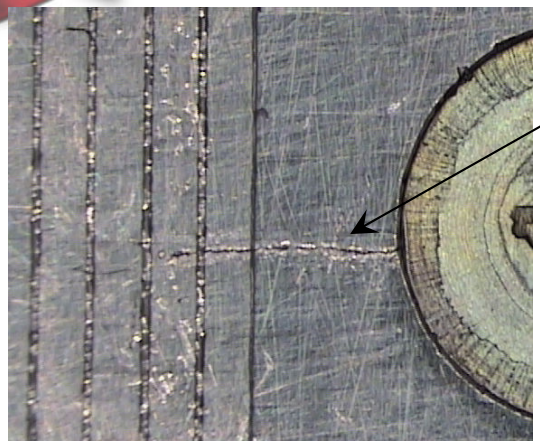
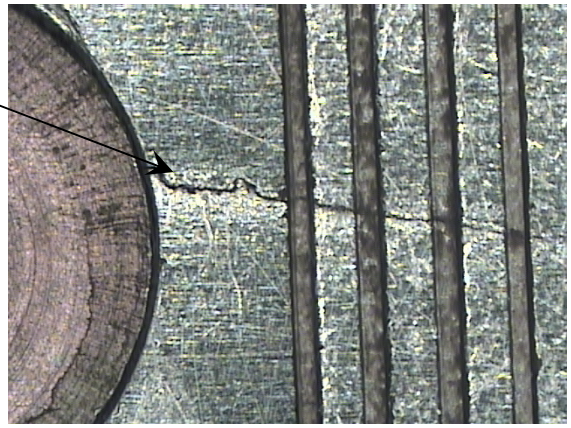
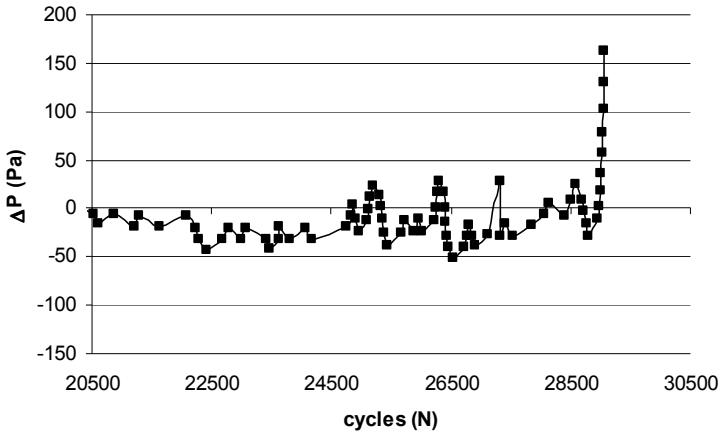
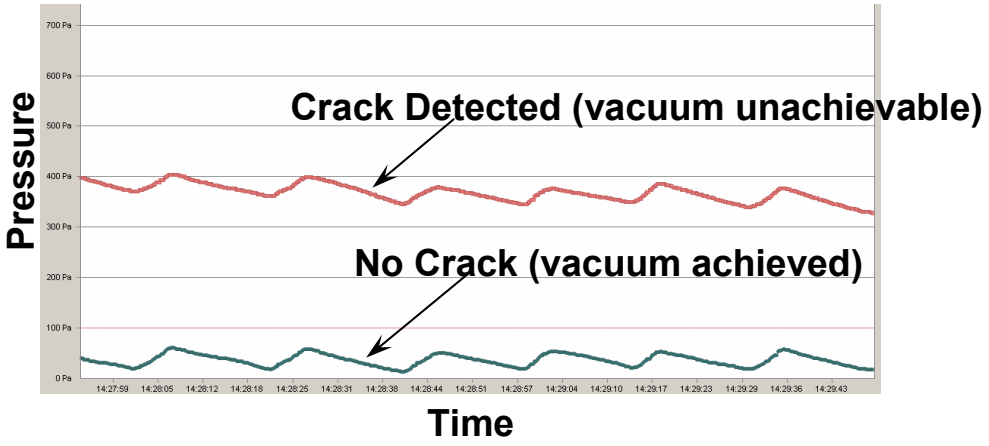
# Comparative Vacuum Monitoring System



Fatigue crack engaging CVM sensors






**CVM introduced into Boeing NDI Standard Practices Manual – first embedded sensor approved for in-situ structural health monitoring (Aging Aircraft FAR; AMOC to ADs)**

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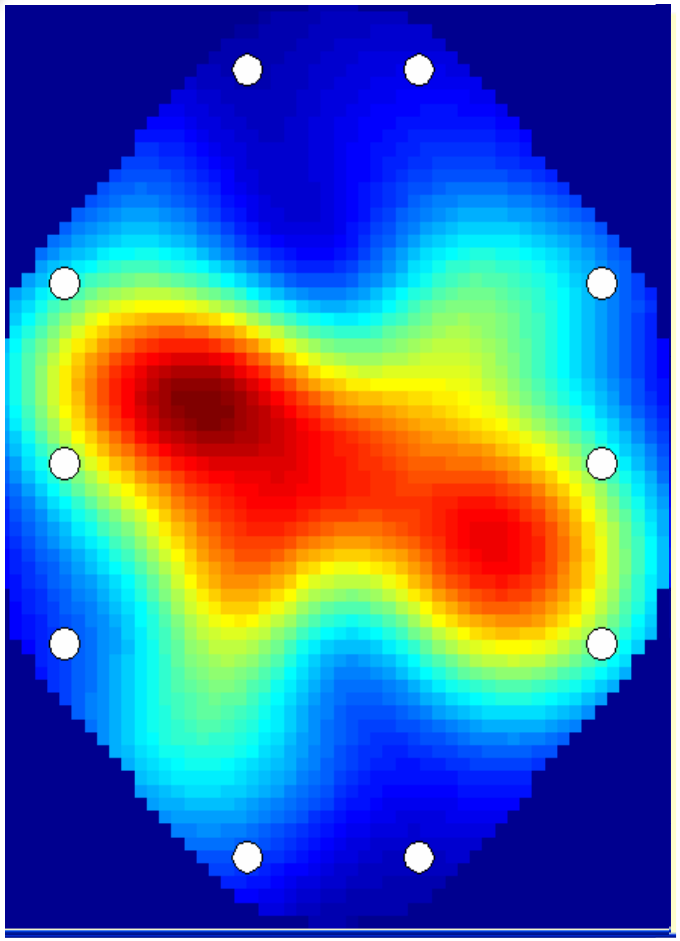
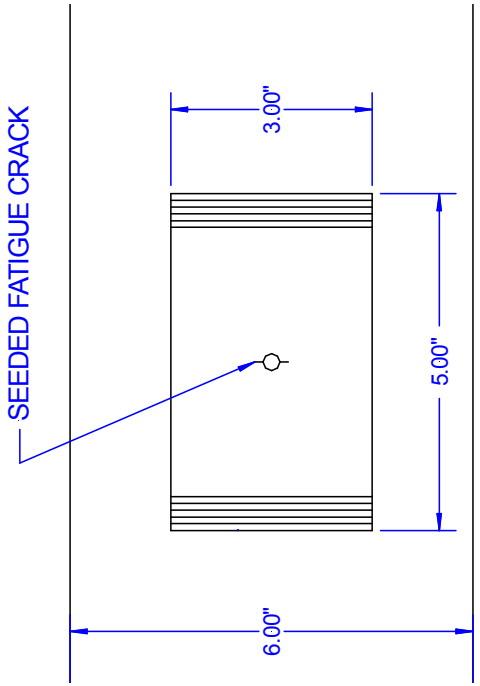
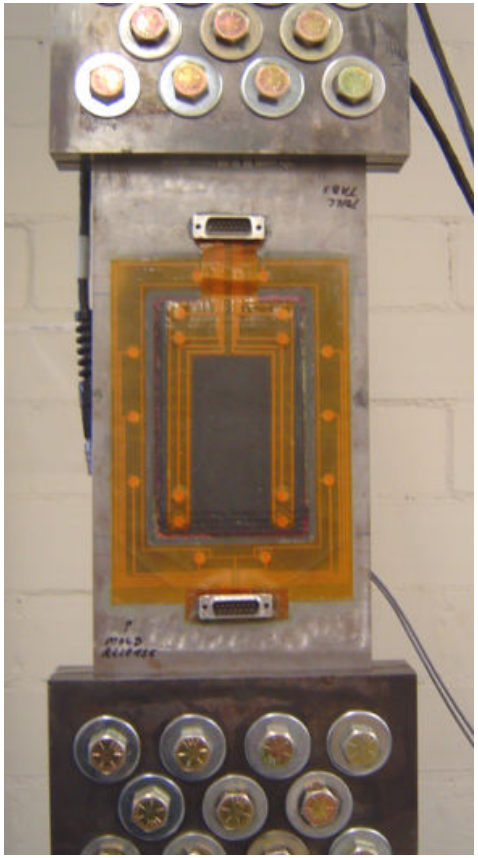
# Crack Detection & Growth Monitoring with Piezoelectric Sensors



87K Cycles



***PZT crack length estimates within 5% of measured***

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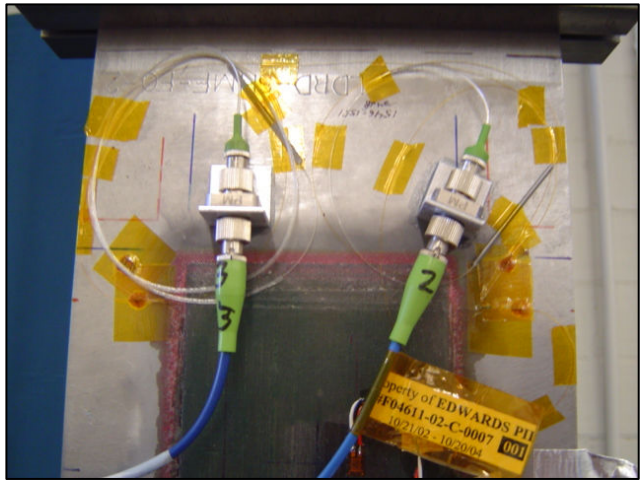
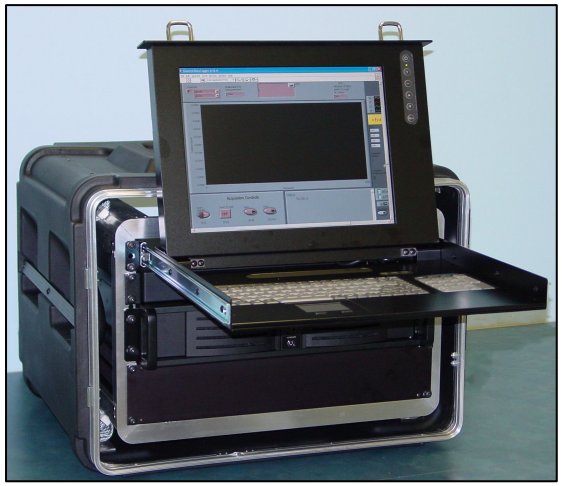
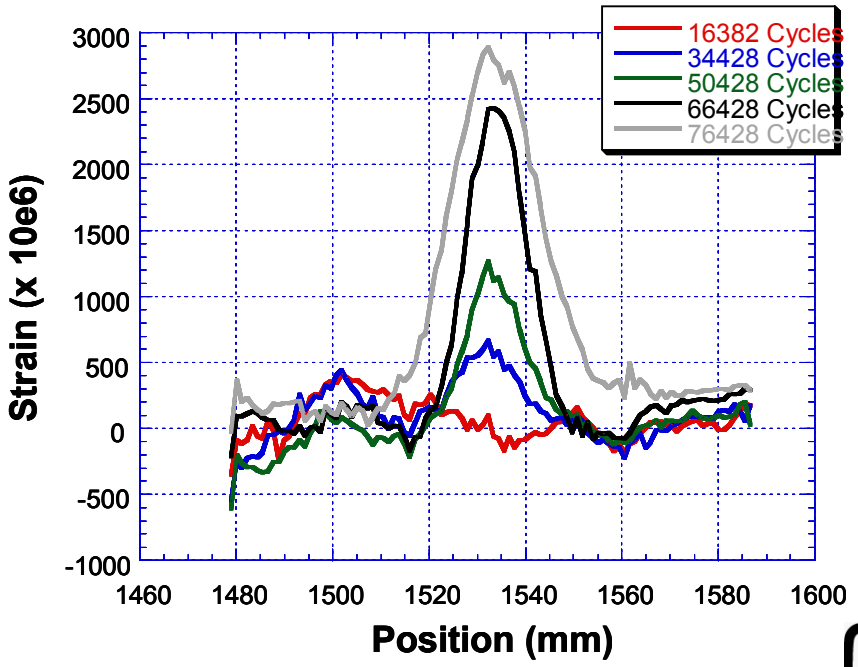
# Health Monitoring with Fiber Optic Sensors



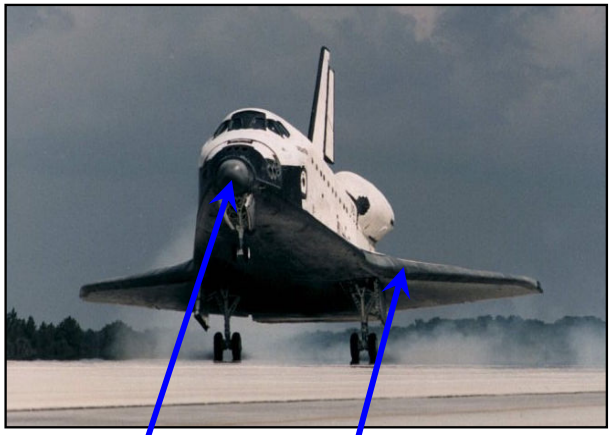


**Axial Strain Distribution Along Sensor D as a Crack Tip Approaches**



# Pulse-Echo Ultrasonic Method for Health Monitoring of Space Shuttle Thermal Protection System

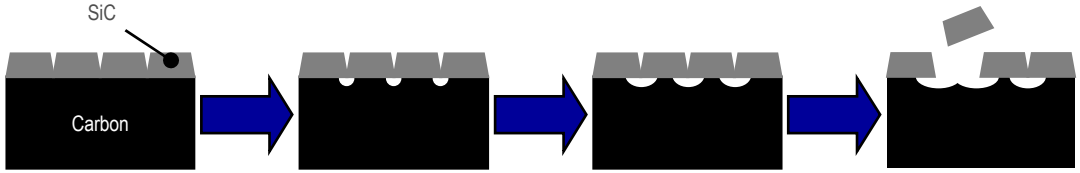
- **Example of FAA AANC expertise applied to solve NASA problem**

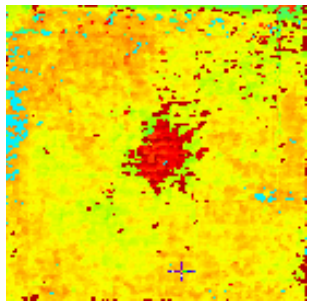


**Wing Leading Edge & Nose Cap RCC Panels**

**Photo of Impact - RCC Front Surface**

**SiC Coating Loss Mechanism via Convective Mass Loss**



**UT Image of Flaw**

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# AANC Work in Other Industries

*Tailor successful aviation technology to meet the needs of other industries*

## Exxon/Syncrude

**Composite repair & structural health monitoring**




## US Auto (Ford, GM, Chrysler)

**Production of stiffer and stronger automobile bodies using advanced bonding methods**

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# AANC Meets the Needs of FAA While Aiding and Leveraging Programs with DoD, NASA & Private Industry

# Wide Range of Uses for AANC Technology




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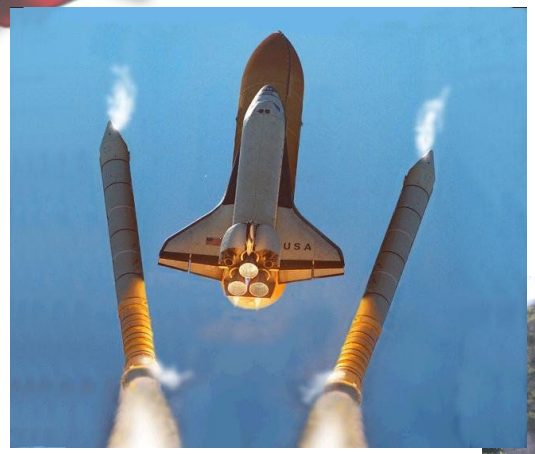



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