FAA SHM RESEARCH PROGRAM

Presented to: A4A NDT Forum

By: Danielle Stephens, Paul Swindell

Date: Sept 18, 2019

Outline

- **SHM Program Overview**
- **Coupon Level – Sensitivity Assessment**
  - –Test Set Up
  - –SHM Systems
- **Full-Scale Level – SHM Support**
- **Applications – Present & Future**
- **Summary**

Purpose

- Help FAA sponsors have a better understanding of SHM as certification needs increase
- Produce data on SHM sensitivity, durability, and repeatability
- Provide a government database on SHM performance shareable with others to test algorithms/data analysis techniques
- Support SAE AISC standards development
  - Develop data to test SHM methodology for Probability of Detection (POD)
- Ensure SHM provides required level of confidence and reliability “as good as” or “better than” traditional NDI approaches

PROGRAM

POD/Sensitivity Assessment: Al-Li test pieces

FASTER Test: Aluminum Lithium skin structure

ABST: 18 Ply solid laminate

Outline

- SHM Program Overview
- Coupon Level – Sensitivity Assessment
  - Test Set Up
  - SHM Systems
- Full-Scale Level – SHM Support
- Applications – Present & Future
- Summary

Team Members/Collaborators

- **Federal Aviation Administration (FAA)**
  - Kelsey Warfle (Test Technician)
  - Paul Swindell (NDI/SHM)
  - Patrick Ray (Test Engineer)
  - Danielle Stephens (Test Engineer)
  - Dave Stanley (Test Engineer)
  - Kevin Stonaker (Test Engineer)
  - Greg Schneider (Sponsor)
  - Walt Sippel (Sponsor)
  - John Bakuckas (Structures Lead)
- **Drexel University**
  - Ali Raza (Student)
  - Jonathan Awerbuch
  - Tein-Min Tan

- Metis
  - Seth Kessler
- Acellent
  - Amrita Kumar
  - Susheel Kumar Yadav
- Structural Monitoring Systems
  - Trevor Lynch-Staunton

Project results herein are the product of a collaborative effort

Test Description

- Take SHM data at the predetermined intervals from the configuration tests

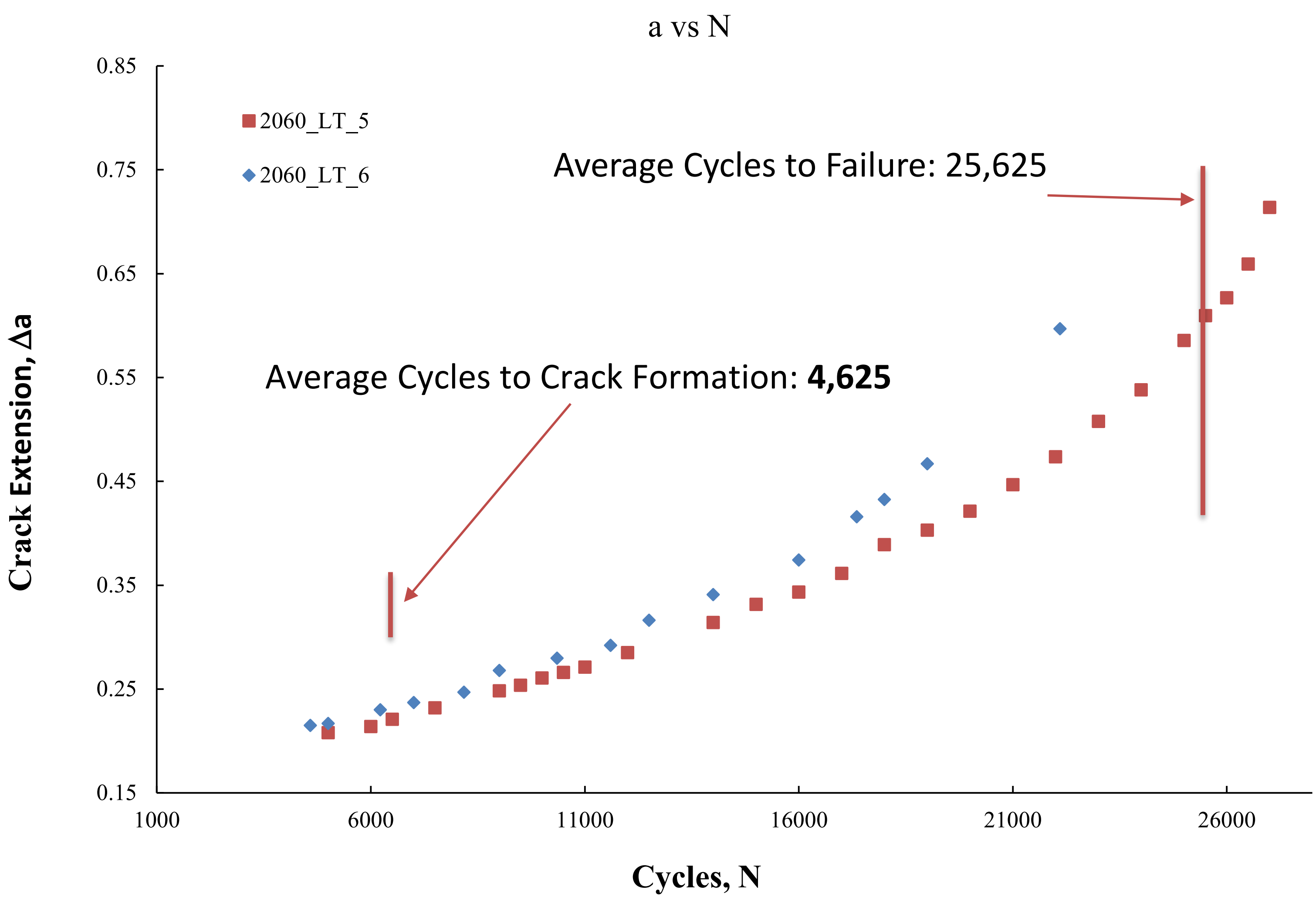
Test Parameters

- Total of two sets of 12 specimens affixed with several different SHM sensor technologies
- A minimum of three data points needed before and after crack formation observation
- Visual measurements were taken along with Eddy current inspections
- Consistent, steady crack formation and extension that fits methodology
- Visual measurements were taken for values of crack extension (a) at increased cycle intervals

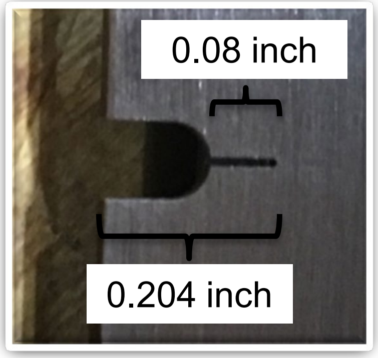
Configuration Test Observations

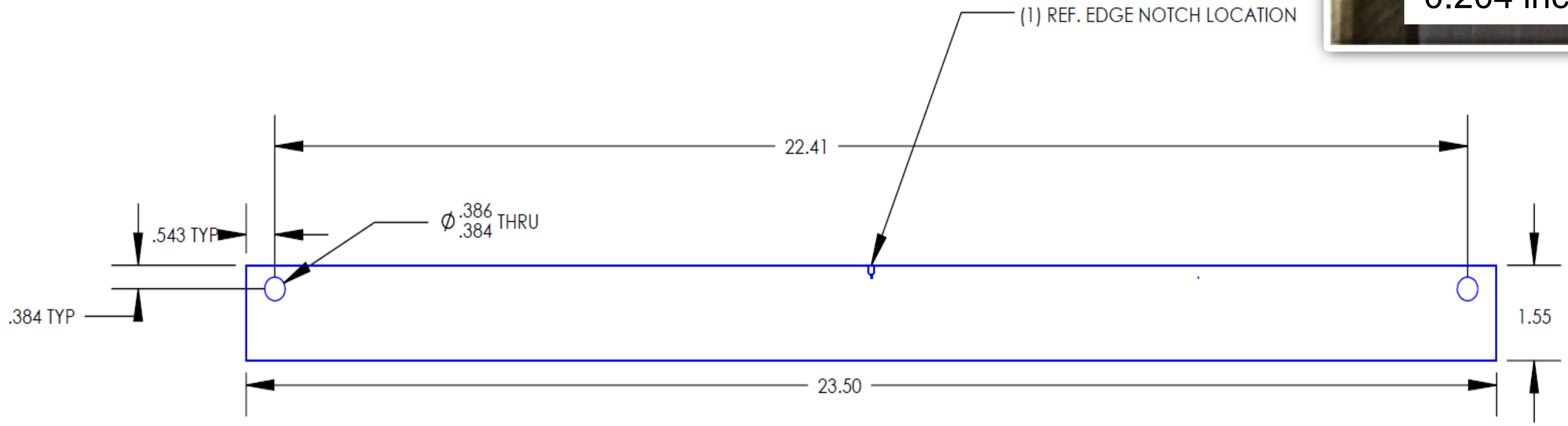
- 600 lb test loading was ideal to obtain sufficient data points before crack formation
- Crack extension over cycle data was consistent among tests
- Optimum frequency of 1 Hz determined for best test control and efficiency
- Strain level is within sensor requirements (below 1200 $\mu\varepsilon$)

Crack Length vs. Cycles Data From 900με (600lb) Tests



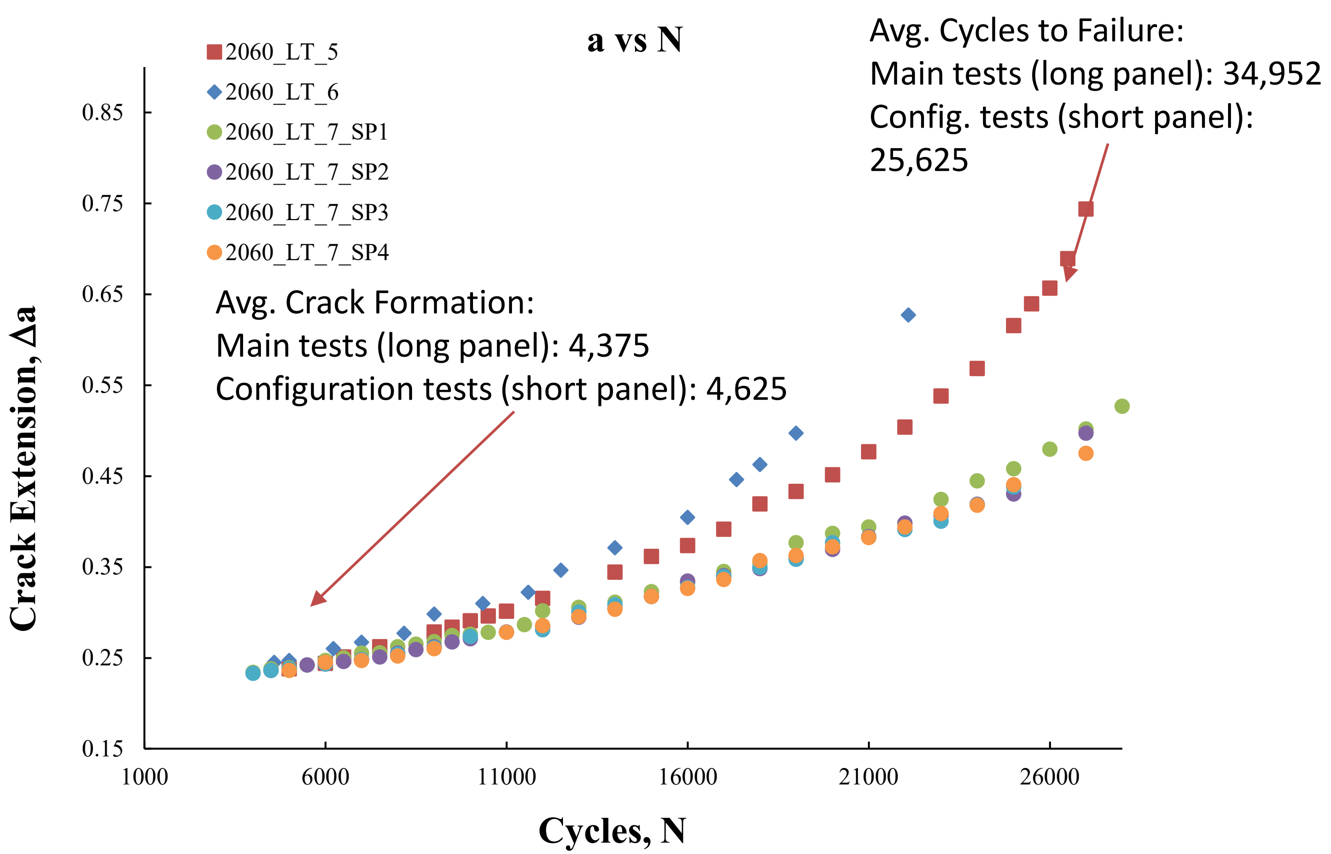
Specimen Dimensions
Main Tests



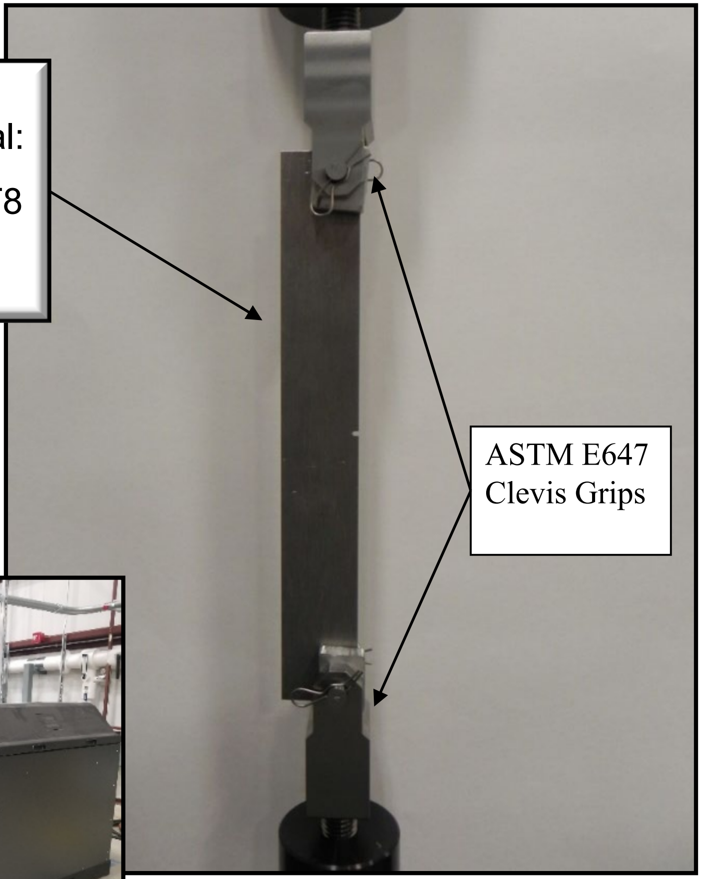


Specimen length increased to 23.5" fit sensors and to minimize effects of grips which could alter signals to/from sensors

Comparison of Configuration Tests & Main Tests
Crack Length vs. Cycles Data



Test Fixture Set-Up - ASTM E647 ESE(T)

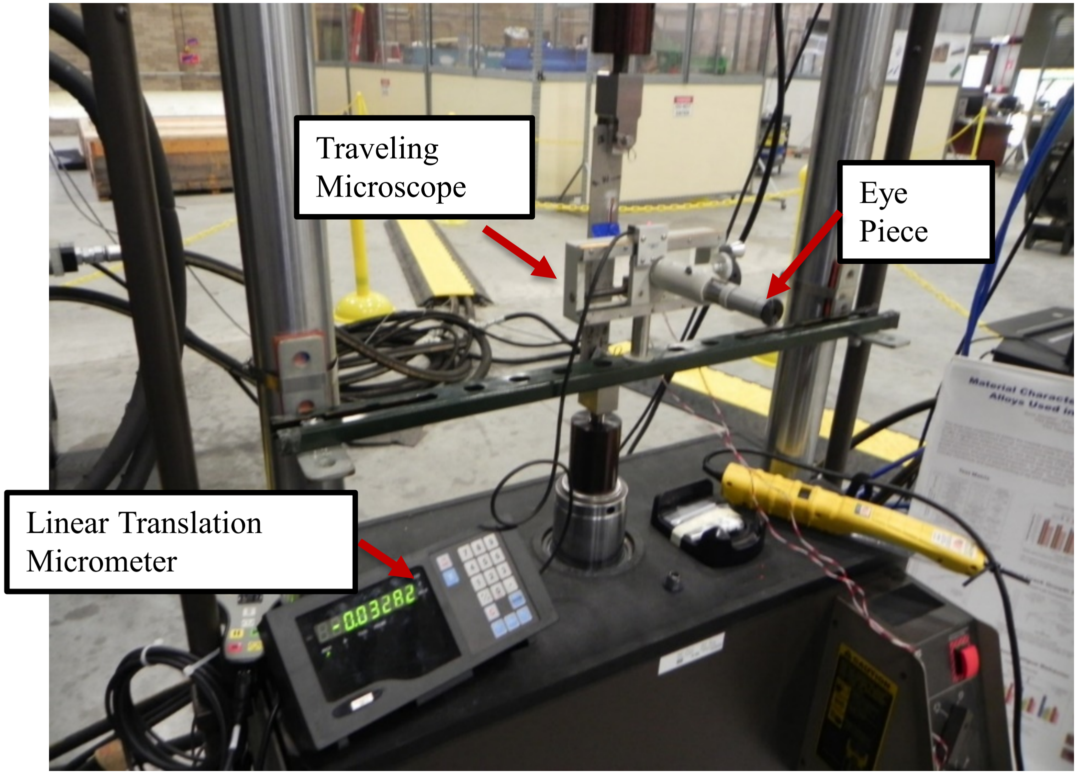


<u>Test Parameters</u>

- Test Frame:
  55kip capacity
- Test Frequency:
  1 Hz.
- Clevis Pin:
  D = 0.384 in.
- Loading Scenario: R=0.1
  Main Tests
  - Loads corresponding to 800 $\mu\varepsilon$

Data Collection Setup

- **Data was collected using visual and NDI methods**
  - Visual: Traveling microscope with linear digital micrometer
  - NDI: Using a High Frequency Eddy current probe
  - Camera: Visual observations of crack formation were made with a microscope camera affixed to the traveling microscope eye piece



Outline

- SHM Program Overview
- Coupon Level – Sensitivity Assessment
  - Test Set Up
  - SHM Systems
- Full-Scale Level – SHM Support
- Applications – Present & Future
- Summary

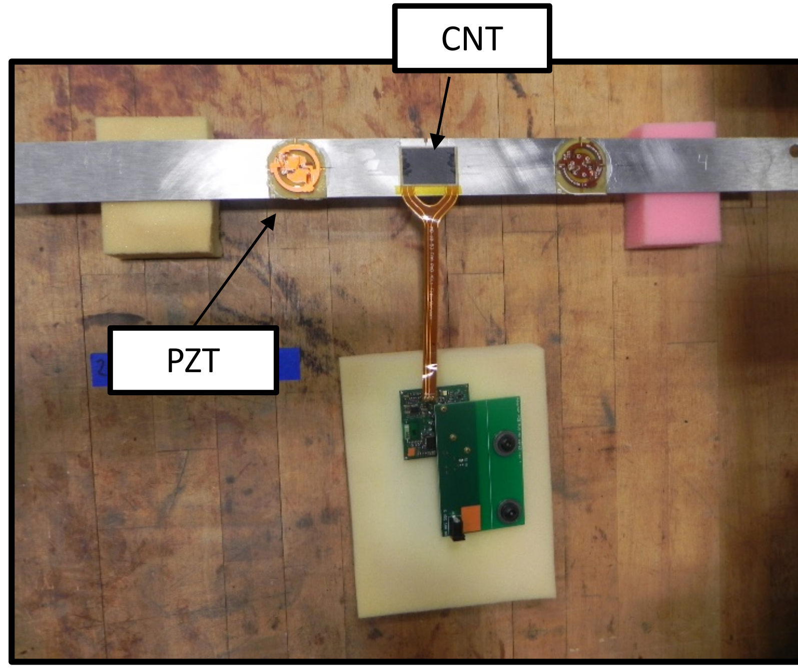
Main Testing
POD/Sensitivity Assessment

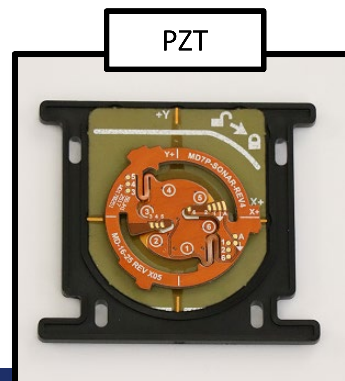
- Fixed sensors placed on notched Al-Li test specimens

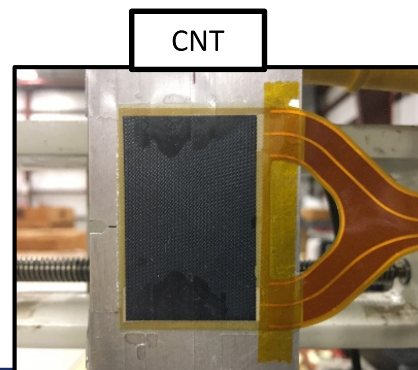
- 24 Test Specimens
  - 12 with Piezoelectric Transducers (PZT) and Carbon Nanotube (CNT) Sensors
  - 12 with PZT and Comparative Vacuum Monitoring (CVM) Sensors

- Testing Interval
  - Intervals of 1000 cycles before crack formation
  - Intervals of 1500 cycles after crack formation, until a crack extension of ~0.125 inches

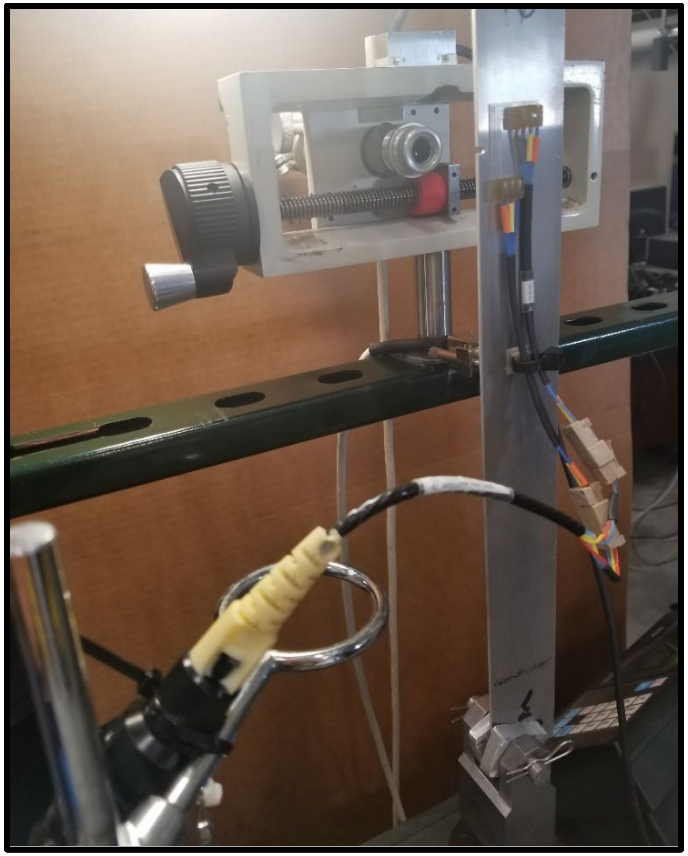
Sample in MTS: PZT & CNT

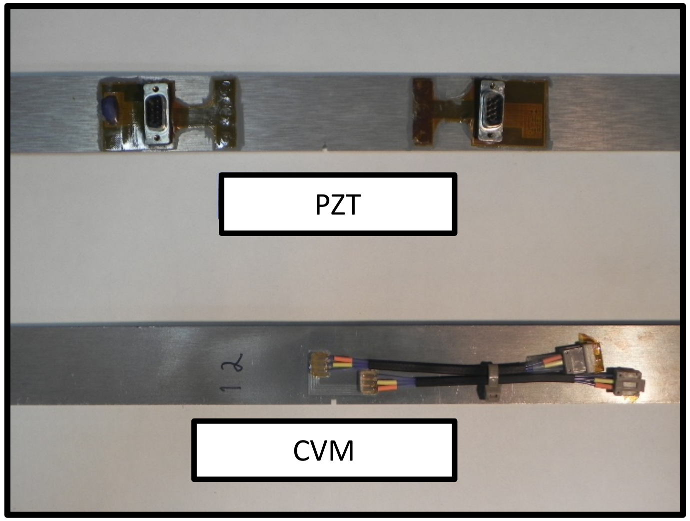


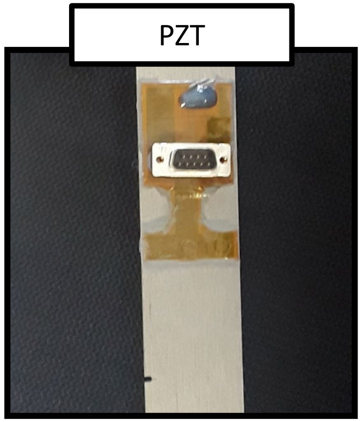




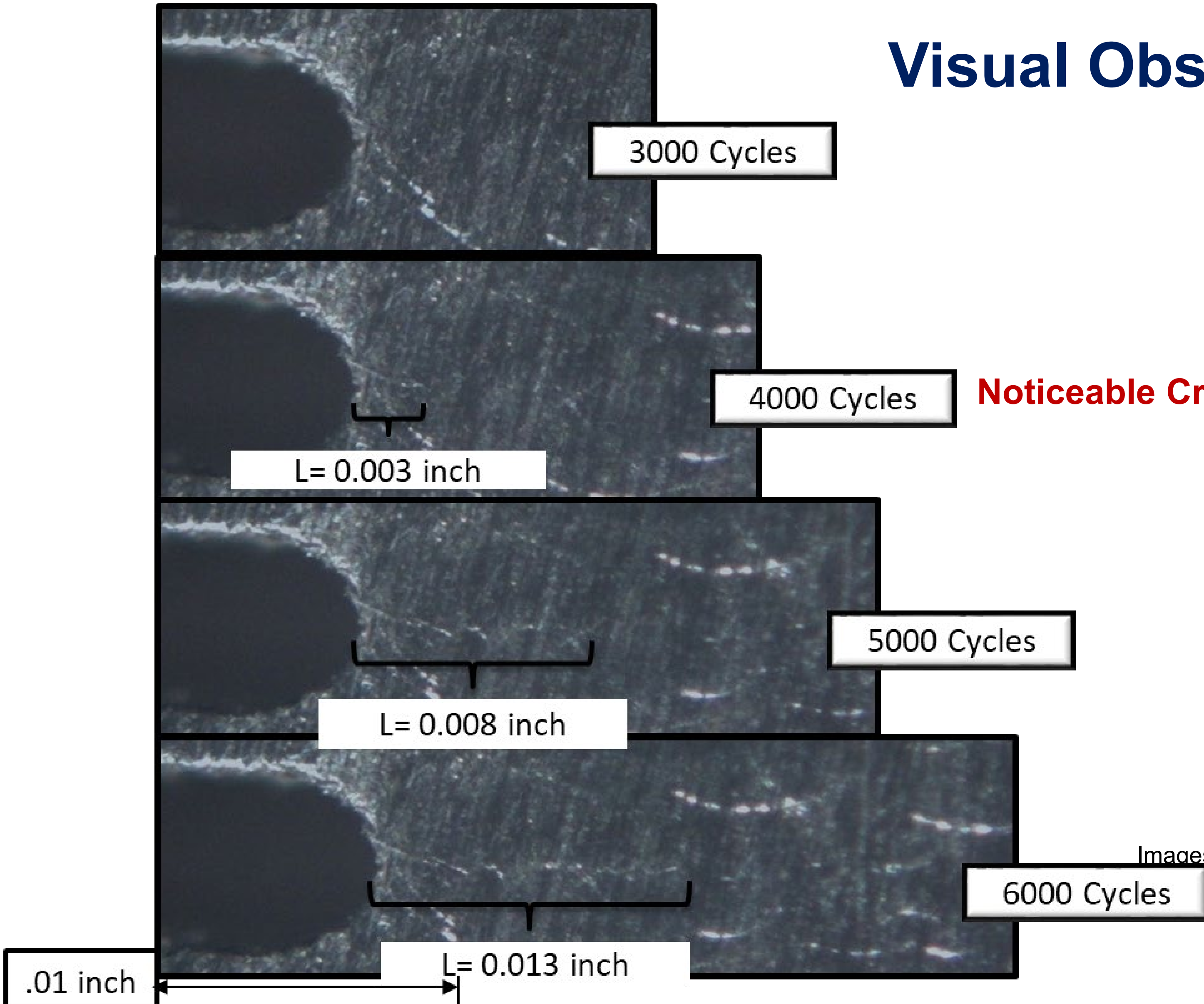
Sample in MTS: PZT & CVM







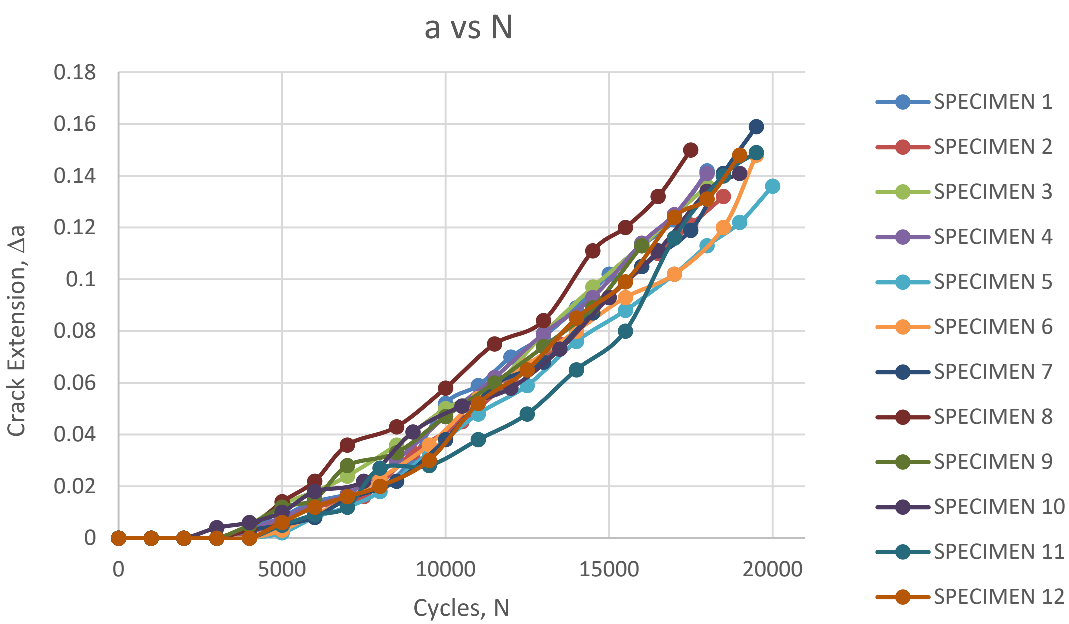
Visual Observations



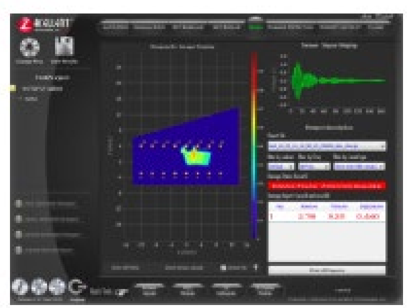
Noticeable Crack Formation

Images captured with a Dinolite
cope camera, 42x mag

Truth Data vs Sensor Data



PZT



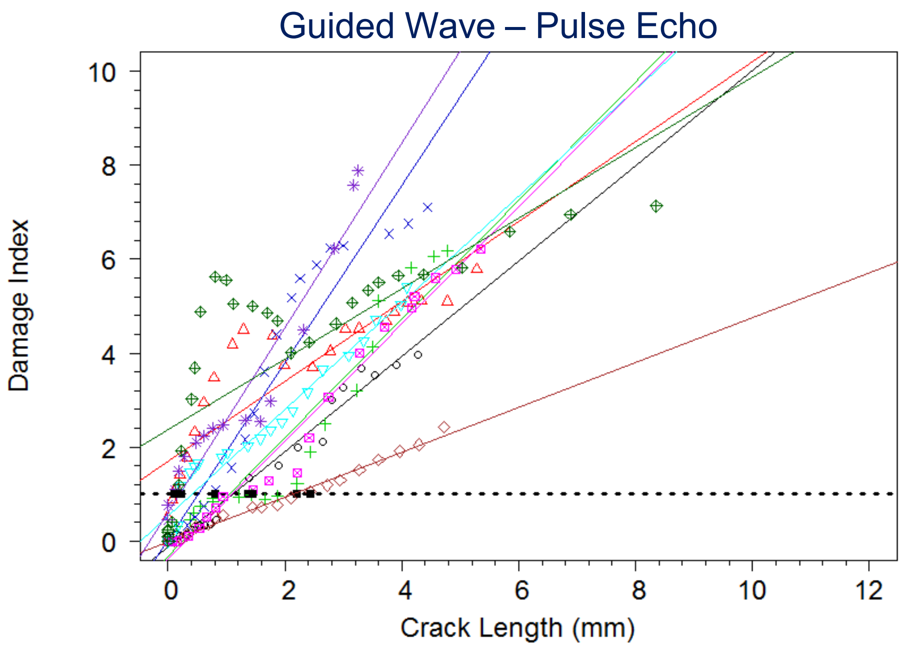
PZT

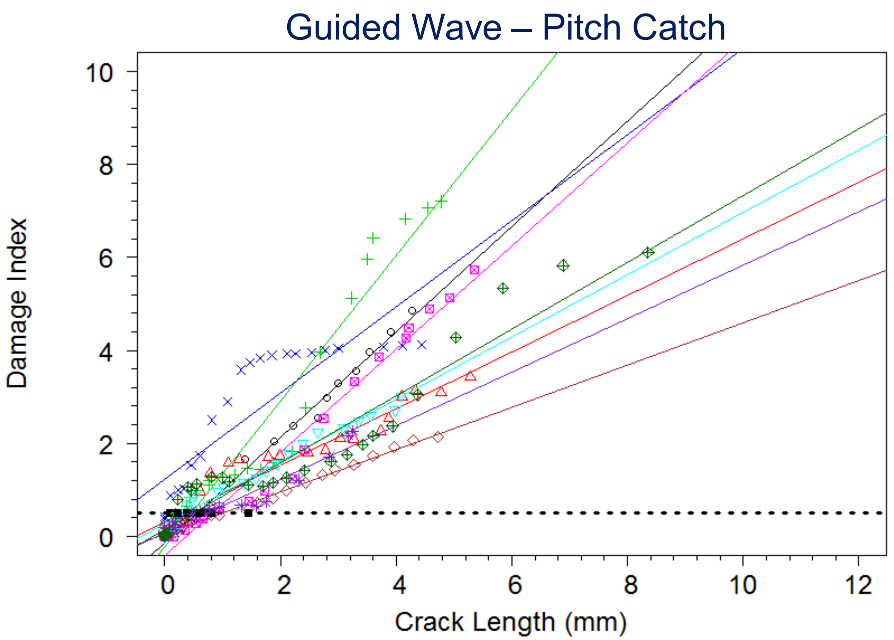
Correlating different sensor technologies with measured crack growth

Results: Disclaimer

- Not an “apples” to “apples” comparison of results
- Ideally – need more samples
- Test results do not account for probability of false alarms

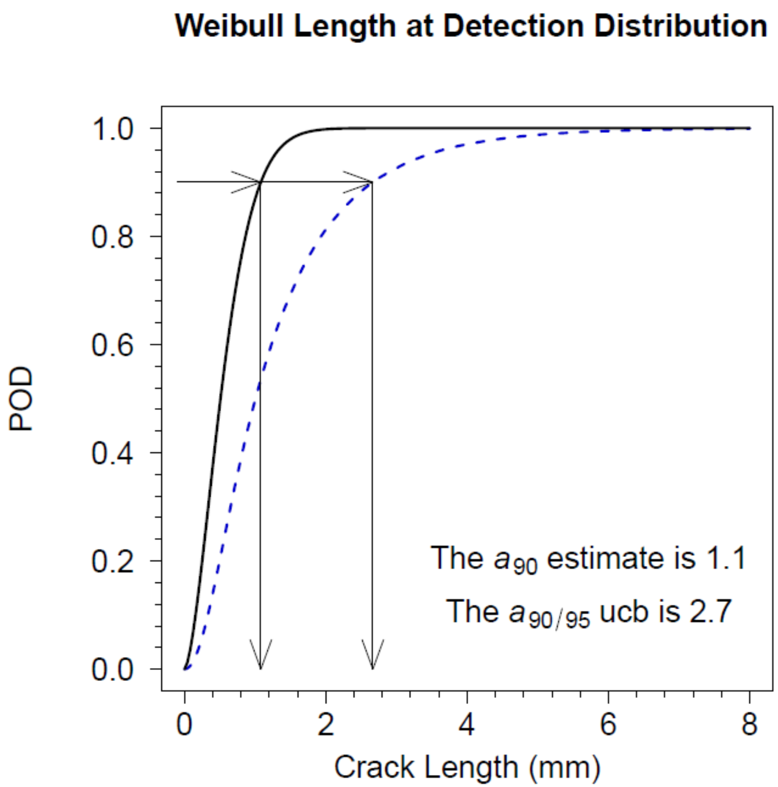
PZT – Length at Detection Plots

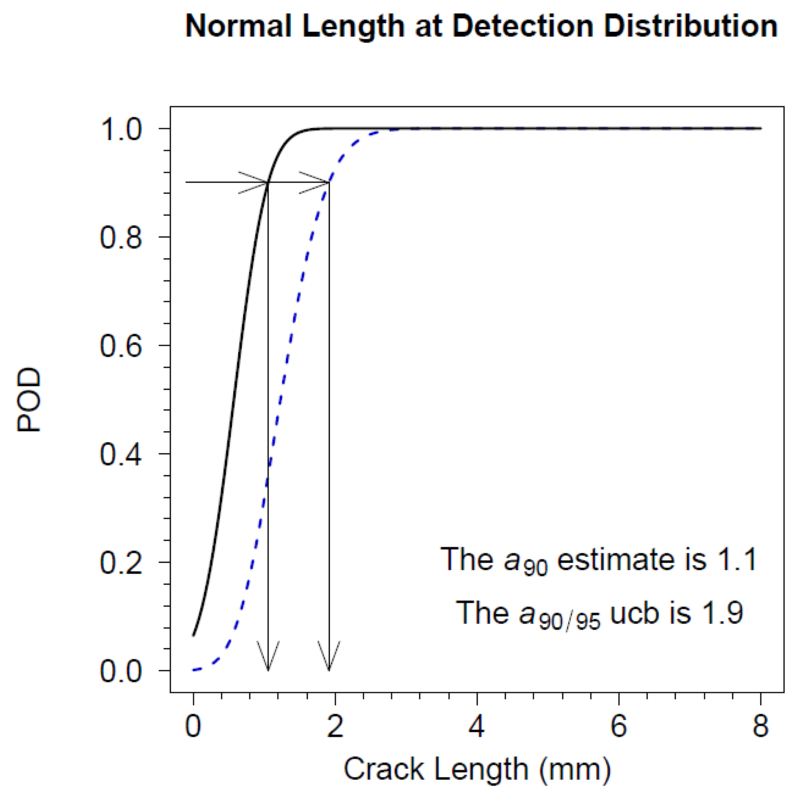




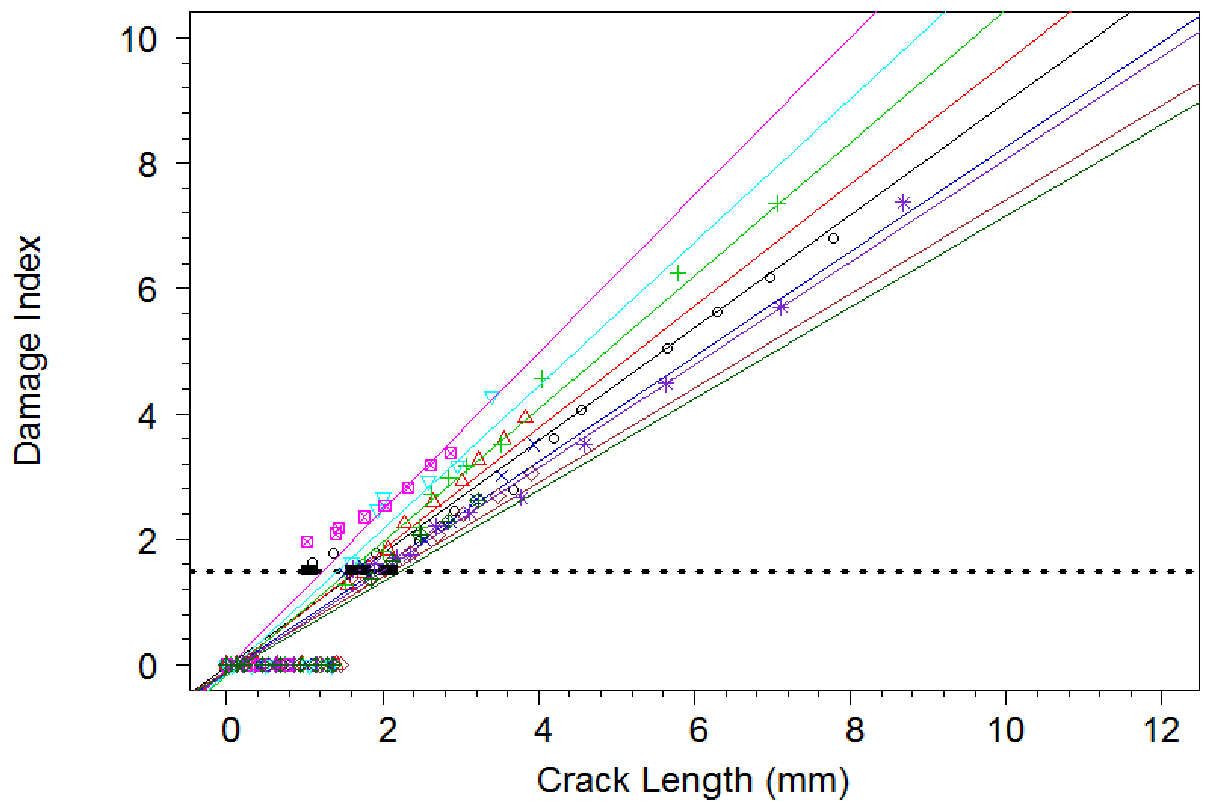
LaD is defined at the crack length just after detection (so the regression lines are not used)

PZT PC – POD samples



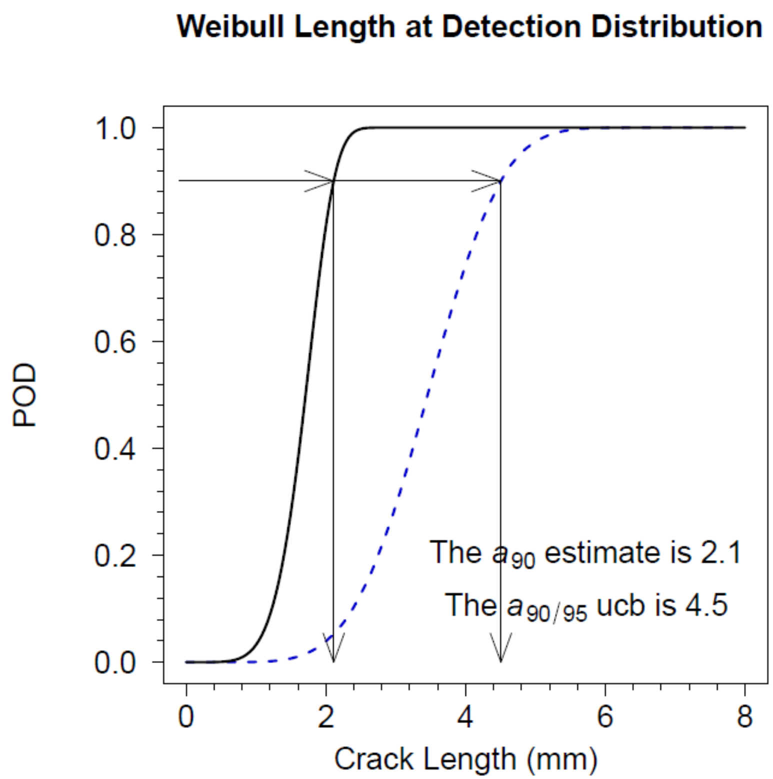


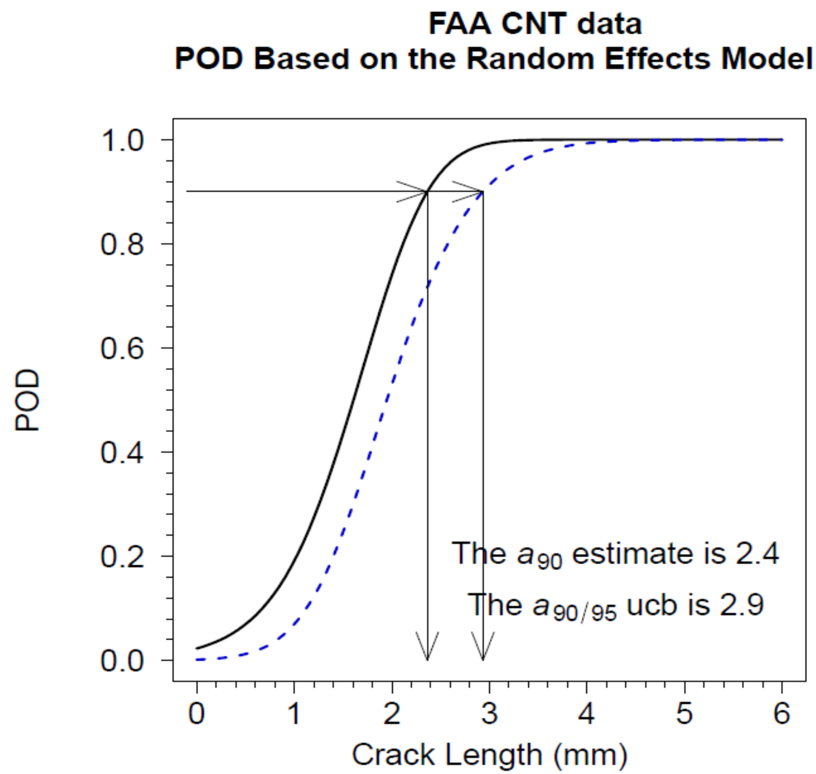
CNT – Length at Detection Plot



LaD is defined at the crack length just after detection (so the regression lines are not used)

CNT – POD samples





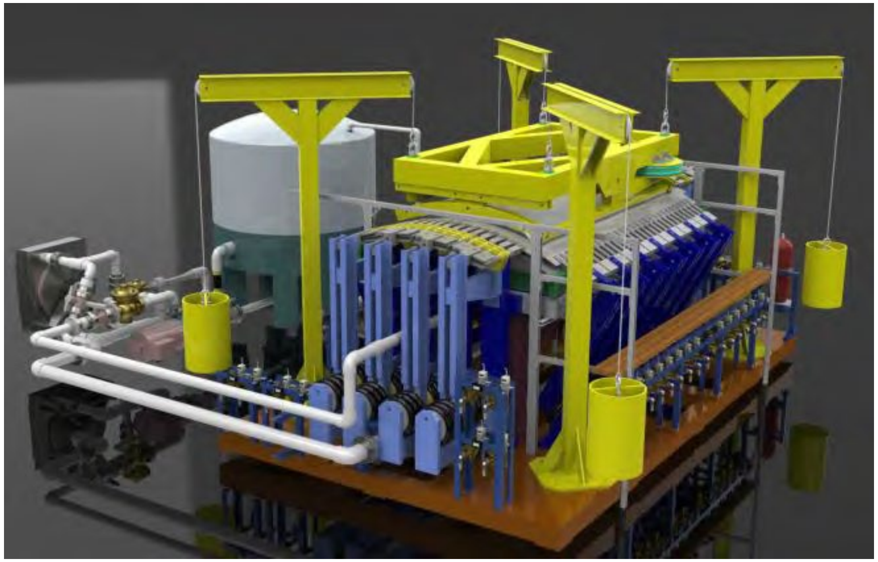
Outline

- SHM Program Overview
- Coupon Level – Sensitivity Assessment
  - Test Set Up
  - SHM Systems
- Full-Scale Level – SHM Support
- Applications – Present & Future
- Summary

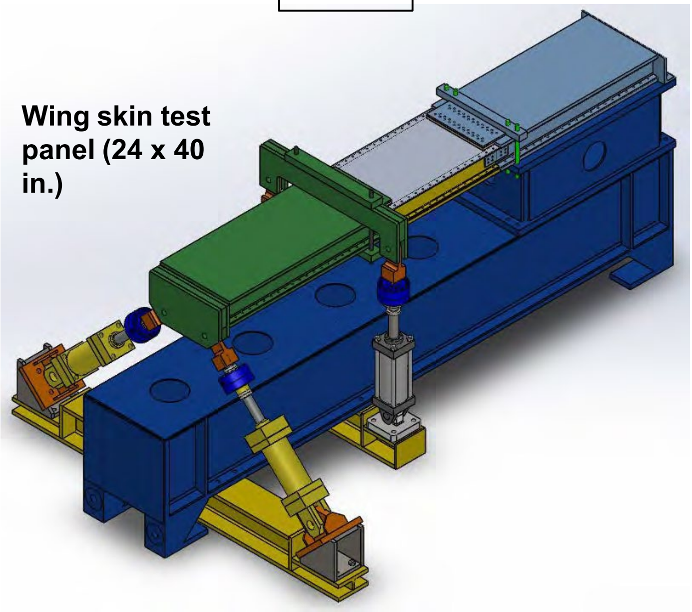
SHM on FAA Emerging Technologies Research

- **In order to assess SHM capabilities (detect/monitor damage growth) and collect data, SHM sensors were installed on two FAA Emerging Technologies Programs:**
  - Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) Test: Advanced fuselage panels
  - Airframe Beam Structural Test (ABST): 18 Ply solid laminate composite Wing Panels

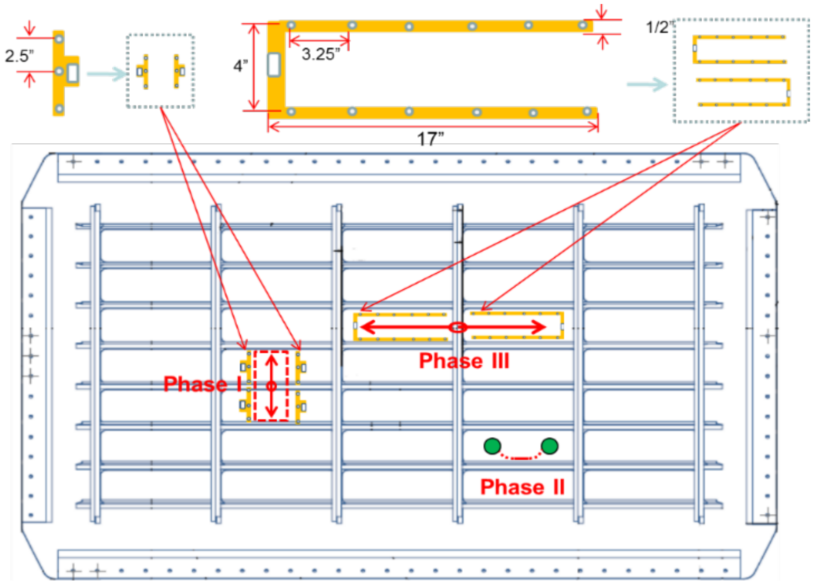
FASTER

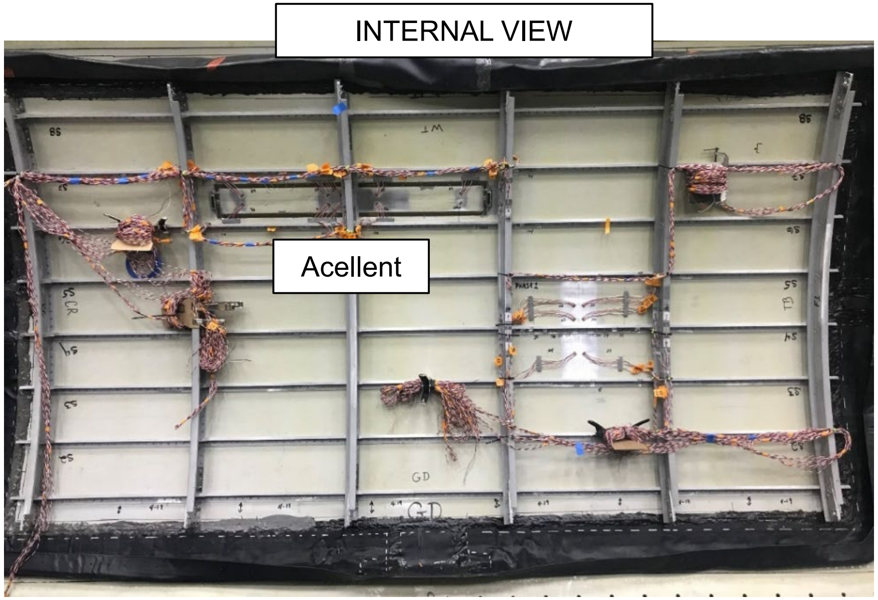


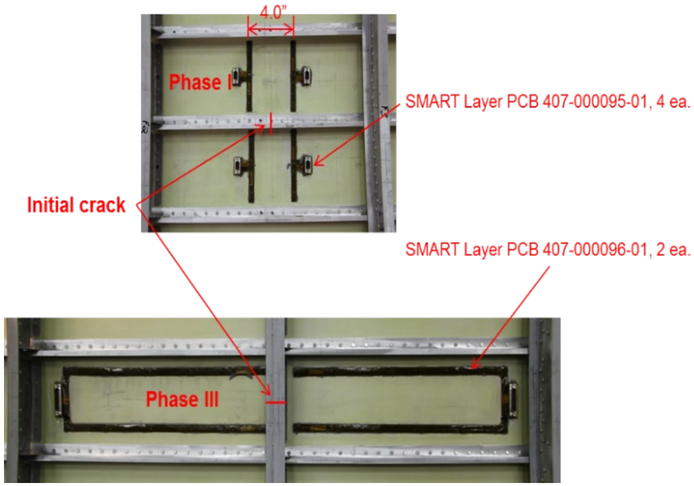
ABST

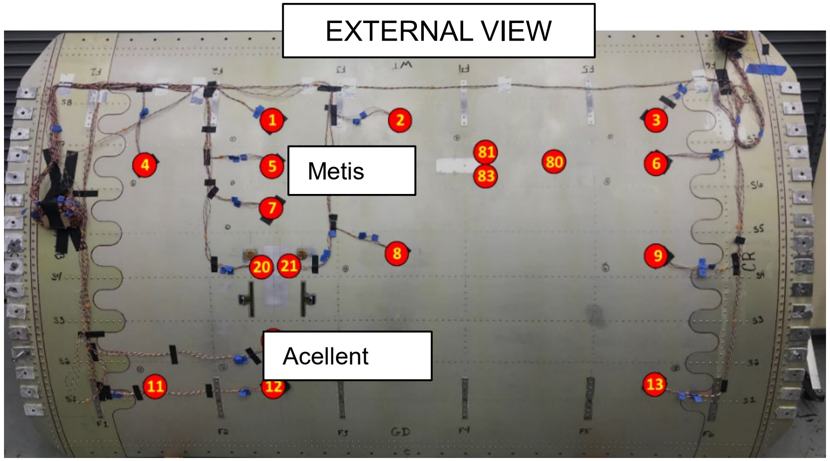


FASTER Panel Instrumented with SHM









FASTER

- Test emerging technologies
  - Al-Li skins/frames/stringers
  - Friction stir weld lap splice
  - Bonded stiffeners
  - Multisite damage

- Partners: Arconic/Embraer

- Test 5 panels: Well characterized cracks with NDI/SHM

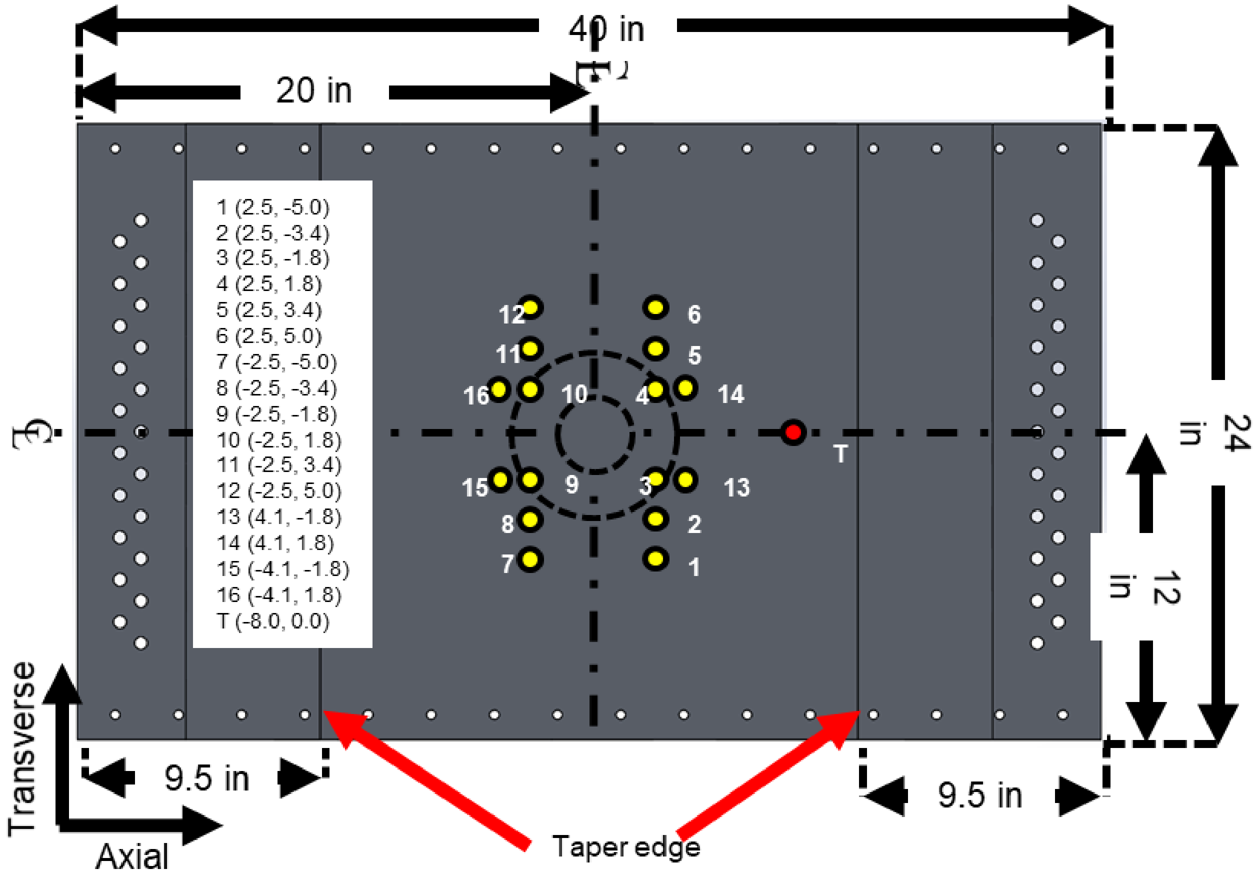
ABST Wing Panel Instrumented with SHM

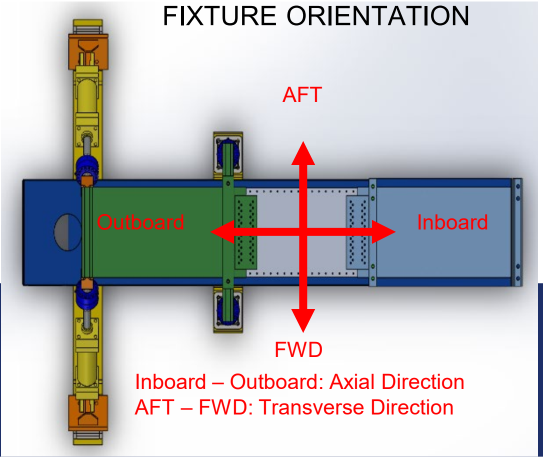
Partial-Depth Scarf Panel

SHM Sensors Layout

- SHM Sensor
- Temperature Sensor

All the SHM sensors are on the internal surface of the panel
Origin (0,0) is Center of the Clean-up damage
Clean-up Damage Diameter = 3″
Scarf Diameter = 6.7”





ABST

- 18 ply solid laminate
  Sizing repair limits

- Partners: Boeing

- Test 7 panels: Delamination detection with NDI/SHM

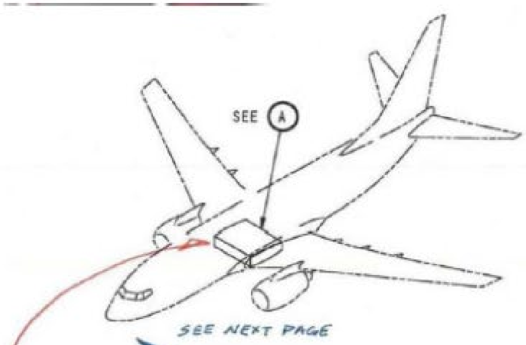
- Future: Honeycomb and Wing structure

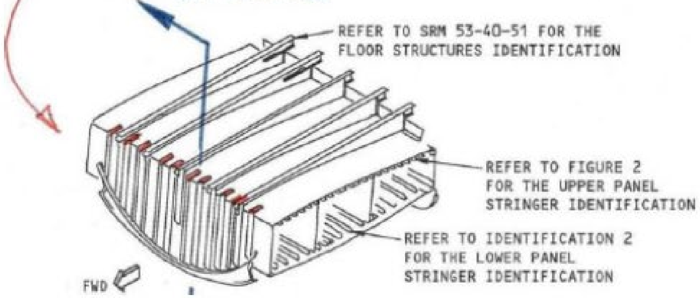
Outline

- SHM Program Overview
- Coupon Level – Sensitivity Assessment
  - Test Set Up
  - SHM Systems
- Full-Scale Level – SHM Support
- Applications – Present & Future
- Summary

Present

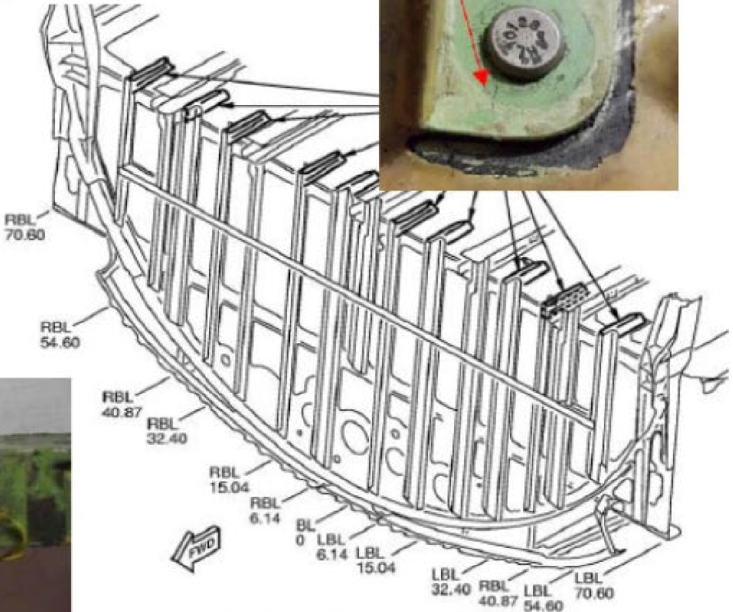
737NG Center Wing Box, Shear Fitting





Boeing 737 SB:

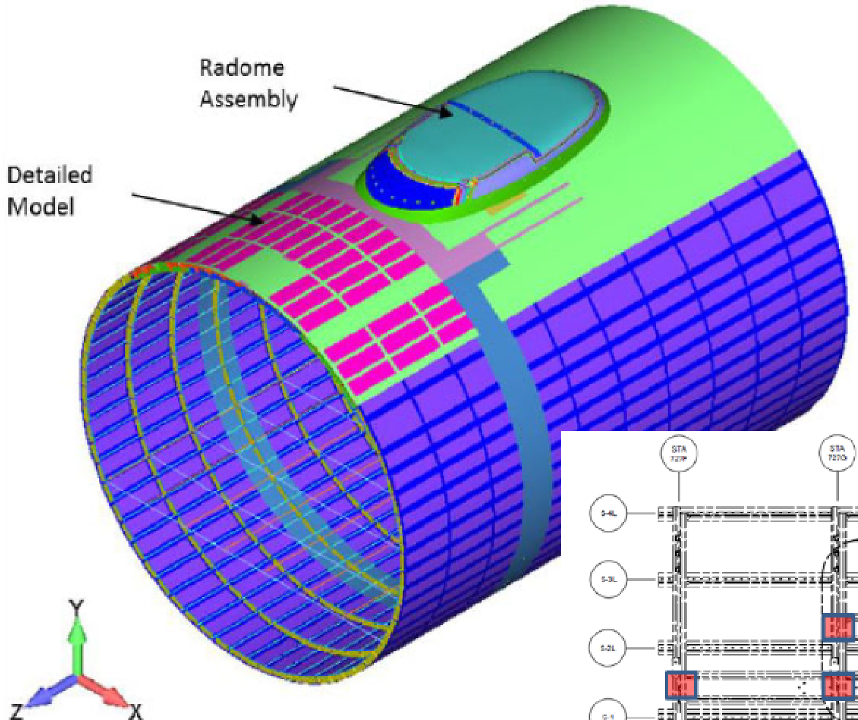
- Cracking between 21K-36K cycles
- Visual/eddy current inspection for crack detection



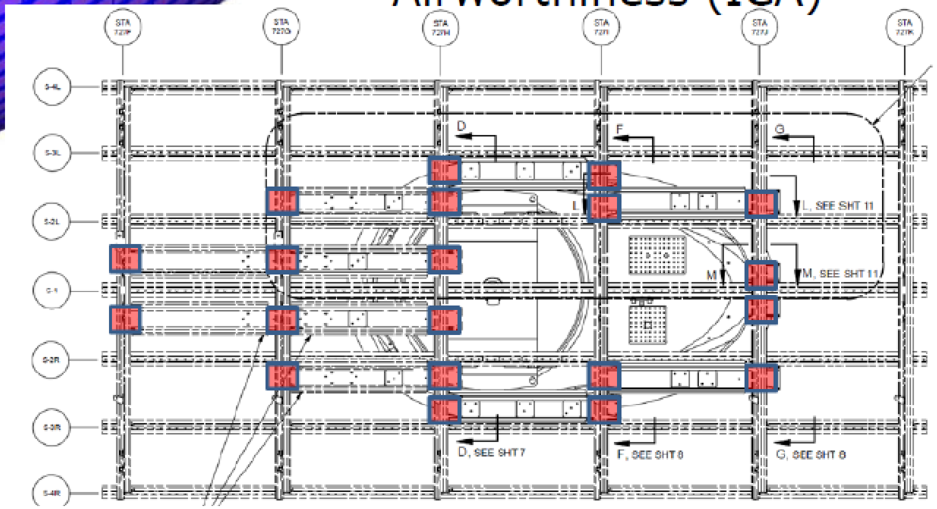
FRONT SPAR AND WING CENTER SECTION

Present

STC applications found!



- Wifi/SAT TV structural modifications
  - Panasonic
  - Gogo
  - Viasat
- Different approval path
- Instructions for continued Airworthiness (ICA)

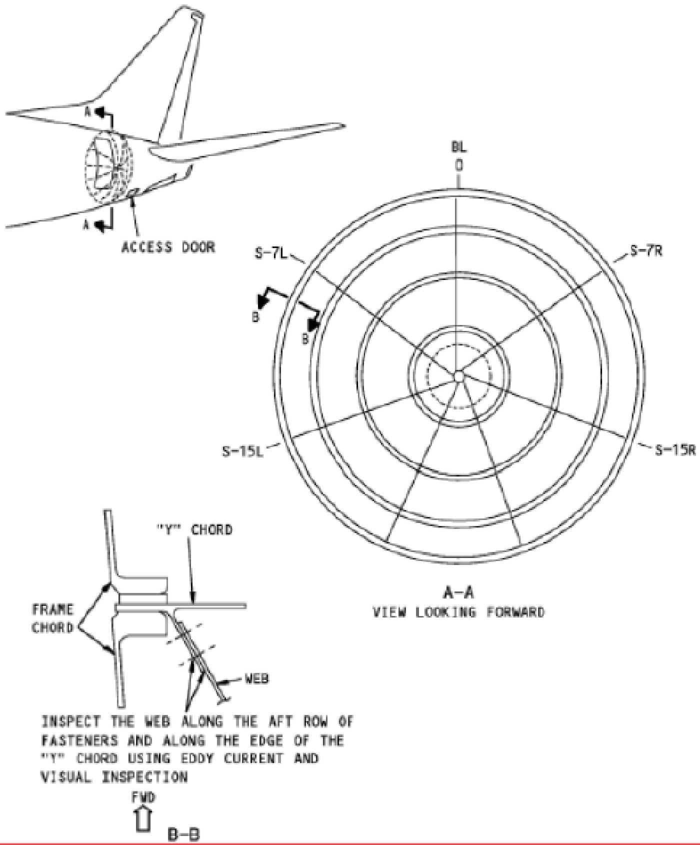


Future

Boeing B737 application - APB

737 Fus Aft Pressure Bulkhead

- SB 737-53A1248
  - Threshold 25,000 FC
  - Repeat Intervals
    - LFEC 1,200 FC
    - HFEC 3,800 FC
- Airworthiness Directive AD 2016-18-15
- Airplane Models: 737-600, 737-700, 737-700C, 737-800, 737-900

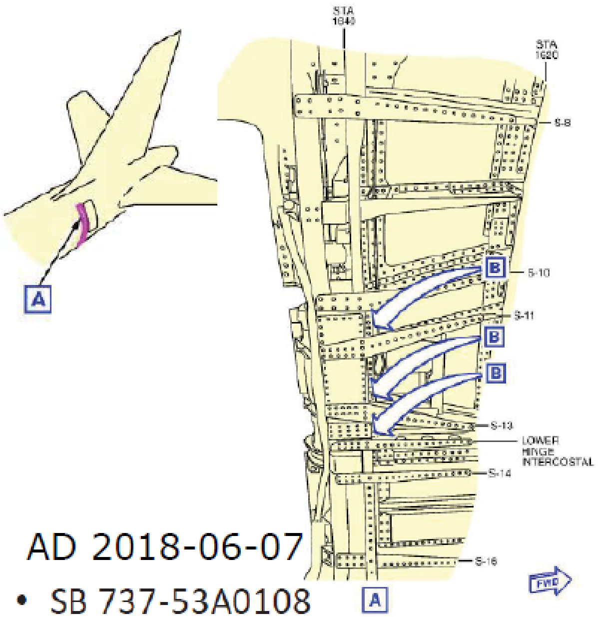


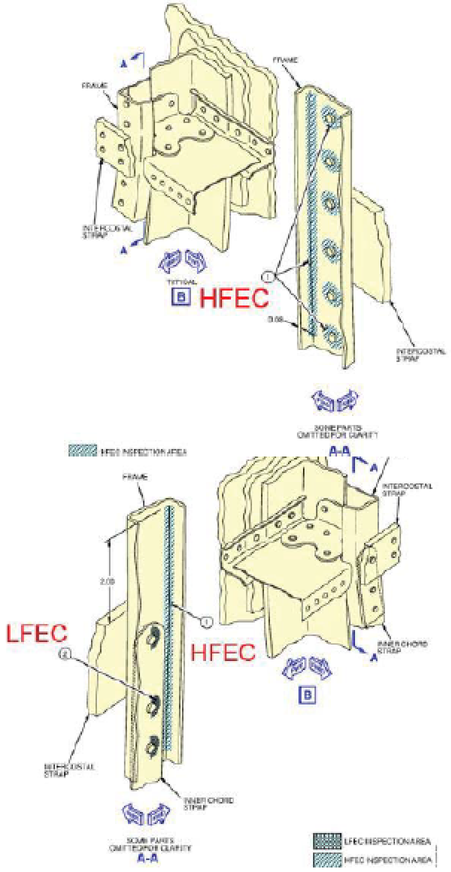
Aft Galley covering inspection area

Future

Boeing B757 application Frame 1640

757 Fus Section 46 - Body Station 1640 Frame Inspection





AD 2018-06-07

- SB 737-53A0108
  - Threshold: 20,000 flight cycles
  - Repeat Intervals 3,000 – 6,000 FC

CVM Installed on 3 aircraft

FAA Documents

- **Issue Paper being developed by FAA to address Wifi STC**
- **AC 43-218 draft**

Draft AC 43-218

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Operational Authorization of Integrated Aircraft Health Management Systems

Date: DRAFT
Initiated by: AFS-300

AC No: 43-218
Change:

1 **PURPOSE OF THIS ADVISORY CIRCULAR (AC).** Automated health monitoring in aircraft maintenance uses onboard sensors, data transmission, and data analysis to provide information regarding aircraft system performance. The result is then used to make aircraft airworthiness determinations that enhance operational safety and provide economic efficiencies. This end-to-end process is known as Integrated Aircraft Health Management (IAHM). This AC provides guidance for developing an operator's IAHM Program. This AC describes an acceptable means, but not the only means, to comply with Title 14 of the Code of Federal Regulations (14 CFR). However, if you use the means described in this AC to show compliance, you must follow it in all important respects.

Outline

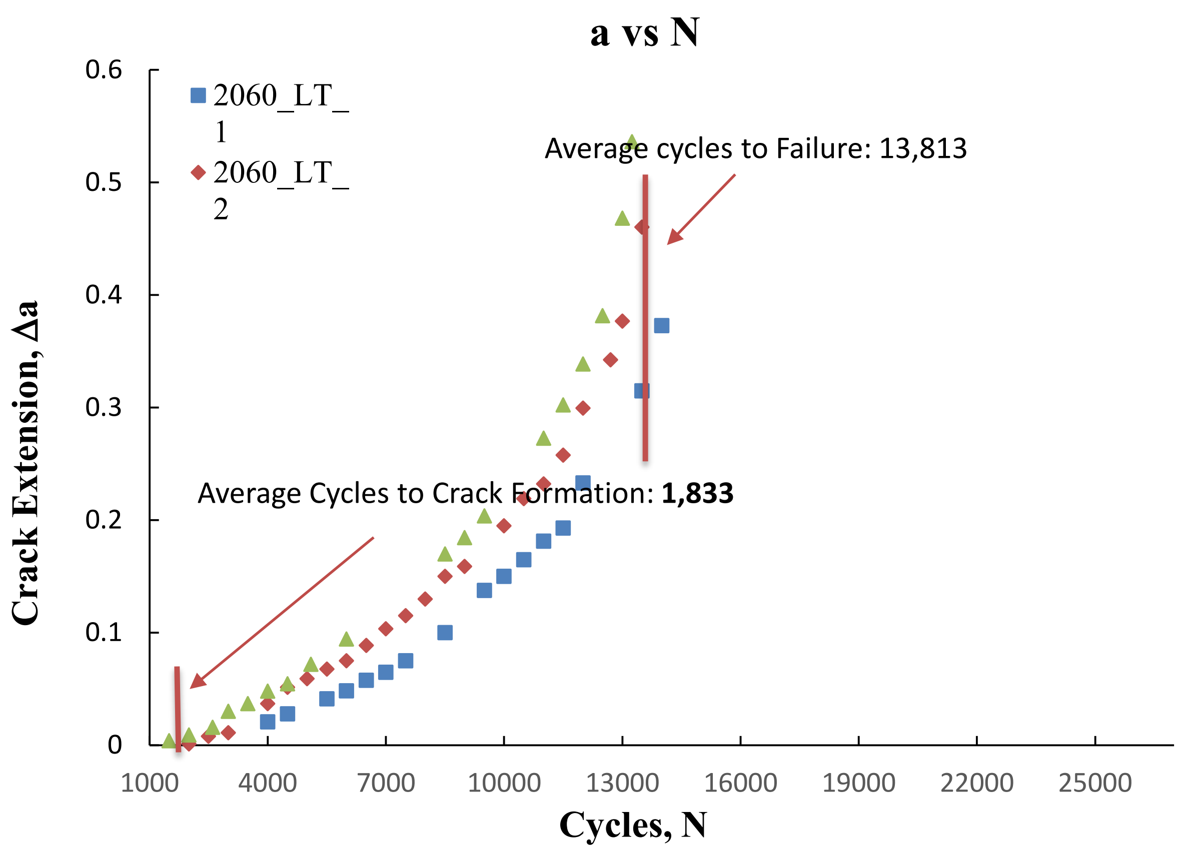
- SHM Program Overview
- Coupon Level – Sensitivity Assessment
  - Test Set Up
  - SHM Systems
- Full-Scale Level – SHM Support
- Applications
- **Summary**

Summary

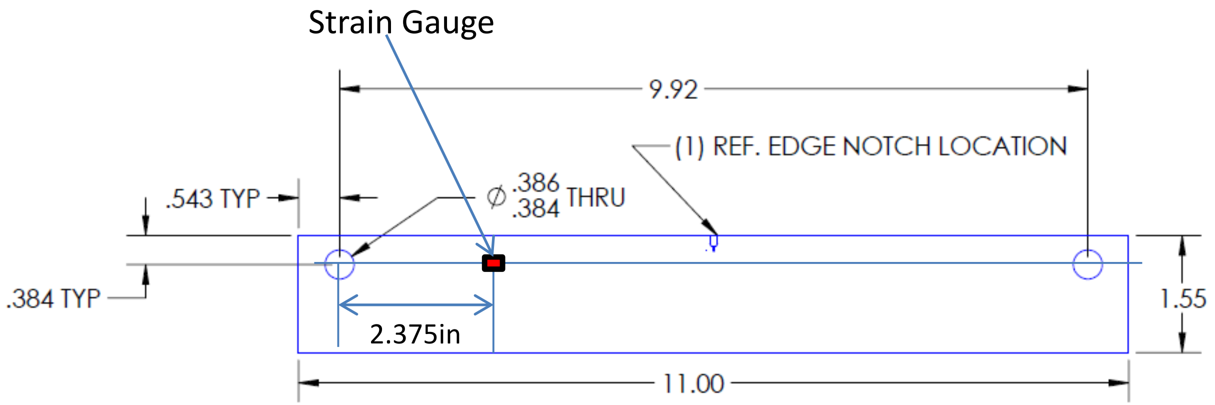
- **FAA SHM research program - very active**
  - Data development for certification, standardization, and public usage
- **NDI OEMS interested in participating in test program welcome**
- **SHM interest for use on civil aircraft is growing**
- **SAE AISC looking for operators to join**

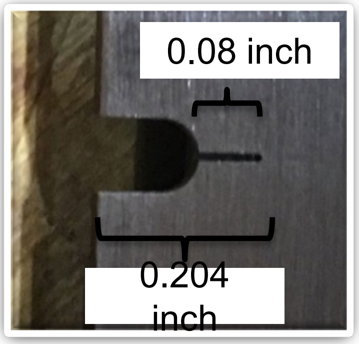
QUESTIONS?

Crack Length vs. Cycles Data From 1200με (800lb) Tests



Specimen Strain Measurement (Configuration Test Only)





Probability of False Alarms

Detection Threshold and Probability of a False Alarm

- **In any detection process, there will be a need to set a detection threshold to control the tradeoff between POD and the probability of a false alarm (PFA). In a simple situation where the SHM signal is a scalar, then, as in MIL-HDBK-1823A, the detection threshold is also a scalar. In NDE applications the threshold is generally set high enough that the probability of a PFA is acceptably low. Then POD can be evaluated to determine if it is acceptable or not. Detection capability of different inspection methods (i.e., POD) can be compared only if the corresponding PFA values are the same. PFA would be computed in exactly the same way as POD, except using the corresponding probability distribution of signals in the absence of a flaw.**