FAA SHM RESEARCH PROGRAM

Federal Aviation Administration

Presented to: A4A NDT Forum

By: Danielle Stephens, Paul Swindell

Date: Sept 29, 2022

Outline

- **SHM Program Overview**
- **Past Work**
  - –Airframe Beam Structural Test (ABST)
  - –Probability Of Detection (POD) Sensitivity study
  - –Full-Scale Aircraft Structural Test Evaluation and Research (FASTER)
- **Current Work**
  - –FASTER
  - –Boeing 737 Aft Pressure Bulkhead
- **Future Work**
  - –Consortium: Model Assisted POD (MAPOD)
- **Summary**

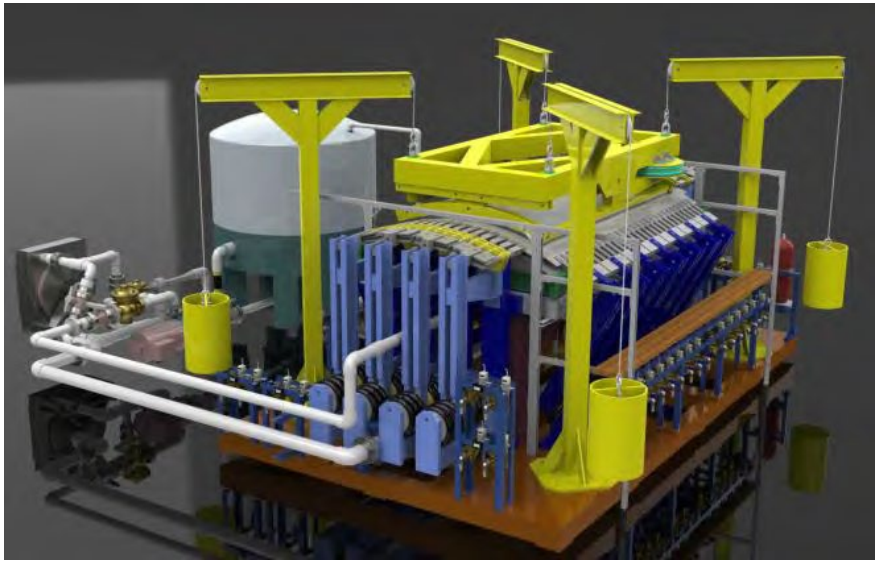
PROGRAM OVERVIEW: PURPOSE

- 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

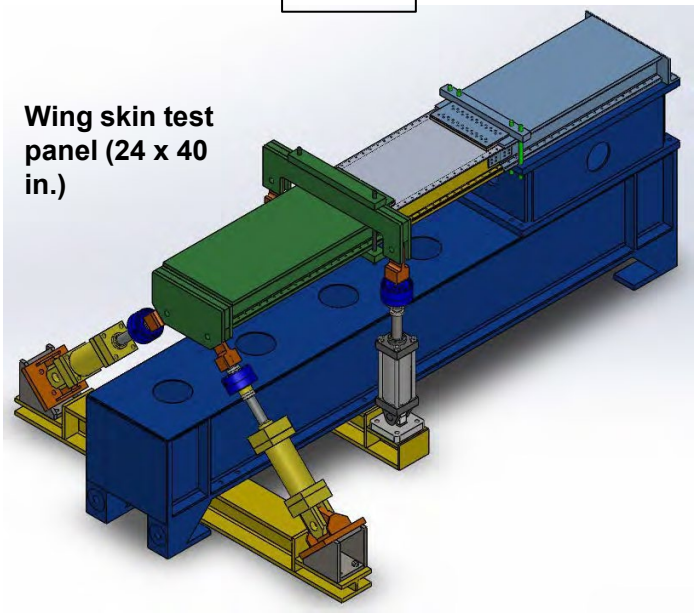
SHM on FAA Emerging Technologies Research

- **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

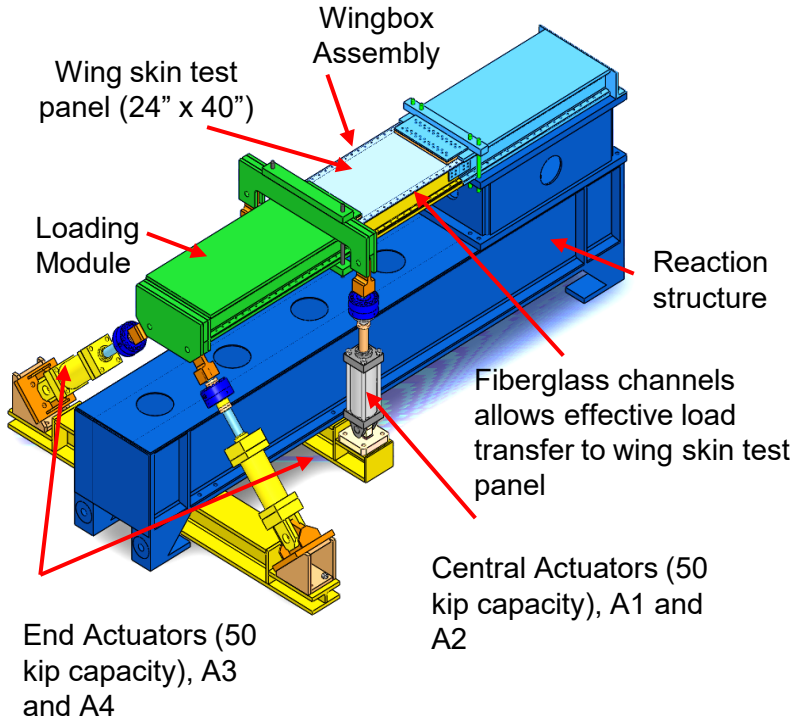


PAST PROGRAMS

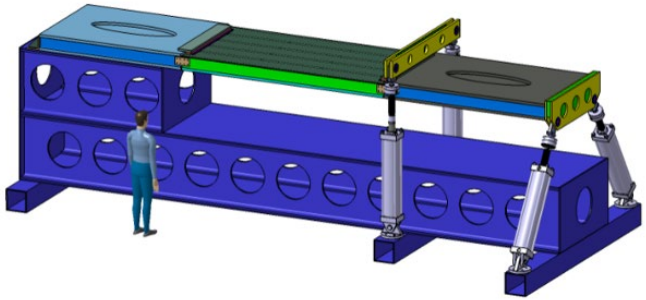
- **ABST: 18 Ply solid laminate**
- **POD/Sensitivity Assessment: Al-Li test pieces**
- **FASTER Test: Aluminum Lithium skin structure**

Airframe Beam Structural Test (ABST)

- **18 ply solid laminate composite**
- **Partner:** BOEING
- **Panels: 6 panels completed**
- **Honeycomb composite (current test program)**
  - **Fatigue/Residual strength tests**



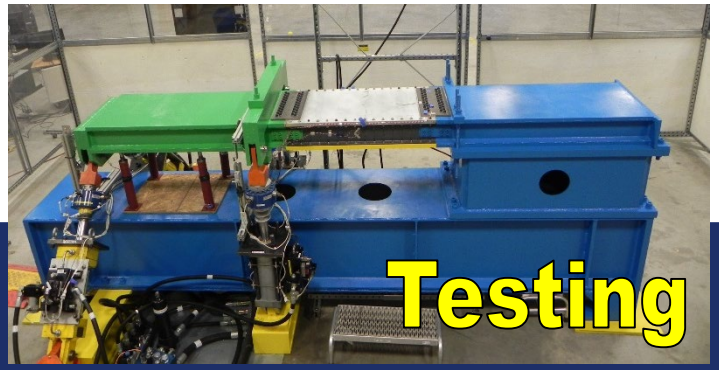
Future - Large Wingbox Test Fixture

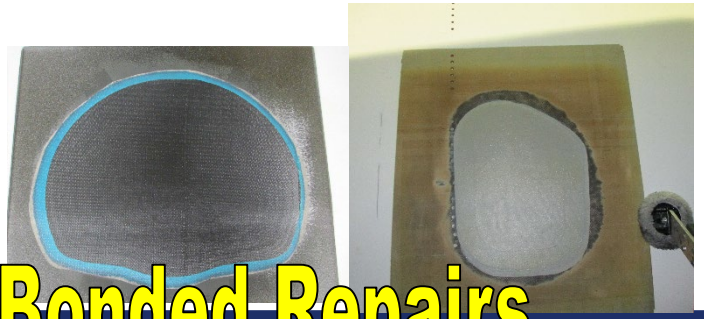


Static and Fatigue loading capability for composite wing panel damage tolerance studies.

ABST

- Panels: Test (1 month)
  - Fatigue and residual strength tests
  - Delaminations common
  - 5k cycle: Inspection includes NDI/SHM
  - Once delam of sufficient size, residual strength test to failure
- Solid Laminate complete, Honeycomb panel currently testing





Partial-Depth Scarf Panel

SHM Sensors Layout

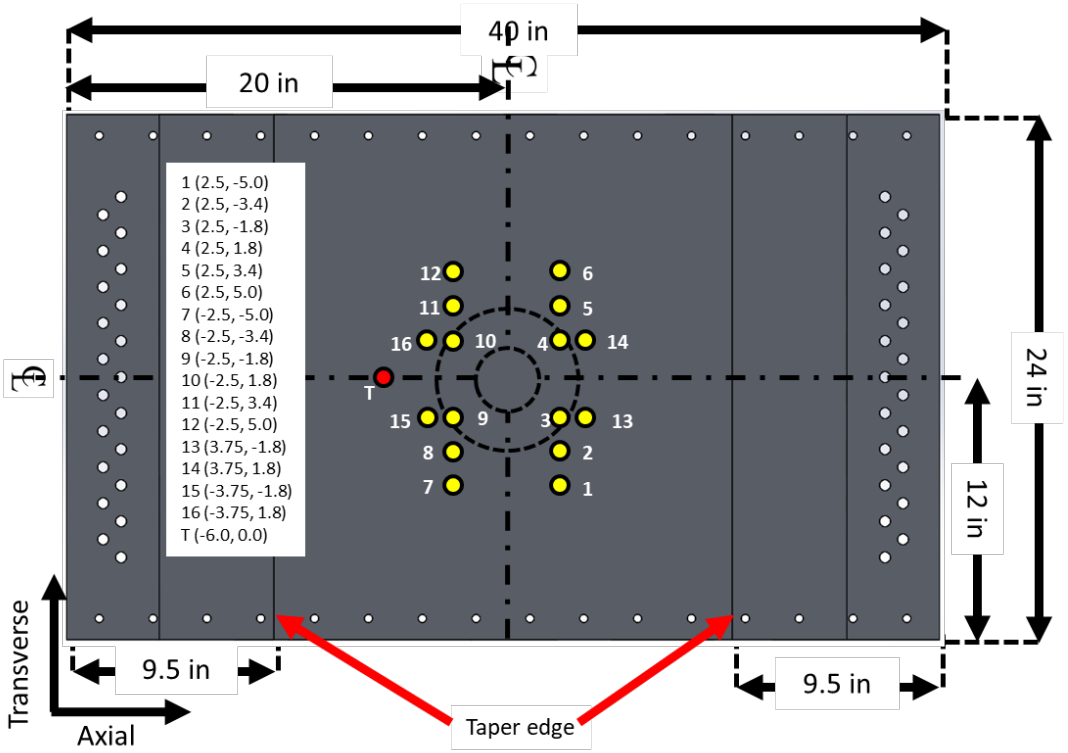
- SHM Sensor
- Temperature Sensor

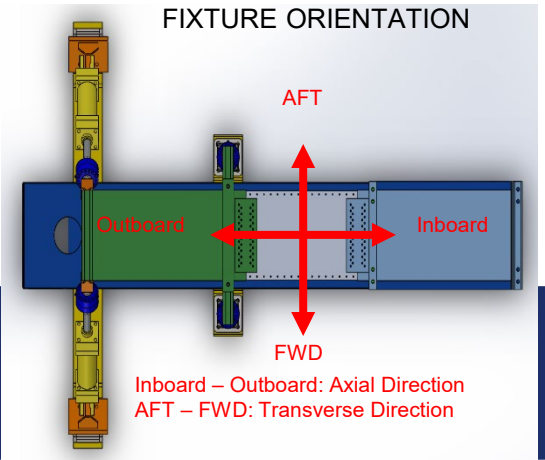
All the SHM sensors are on the internal surface of the panel

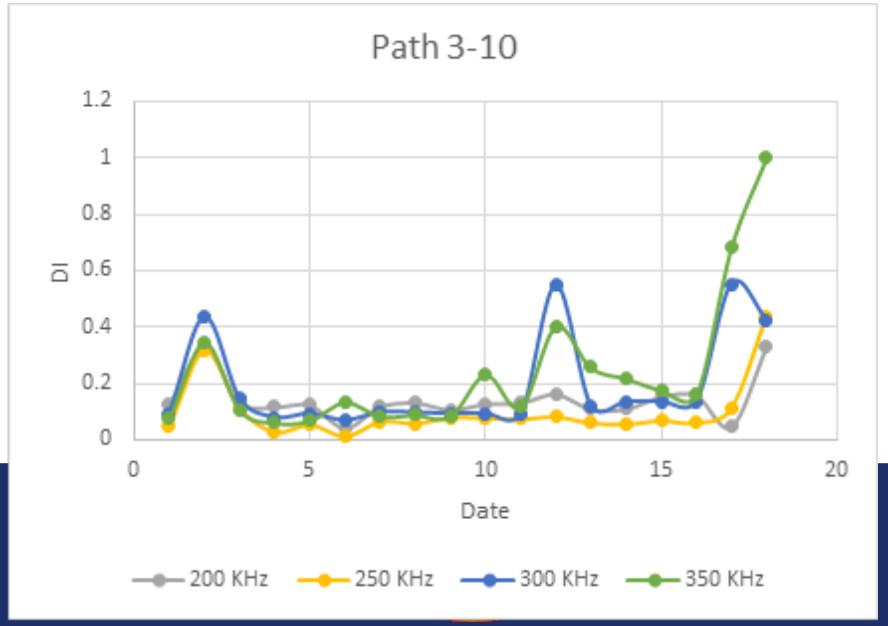
Origin (0,0) is Center of the Clean-up damage

Clean-up Damage Diameter = 3″

Scarf Diameter = 6.7”







POD/Sensitivity Assessment Tests

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
- Iowa State University
  - Bill Meeker
- Sandia National Laboratories
  - Dennis Roach

Drexel UNIVERSITY

ACELLENT® technologies, inc

metis design

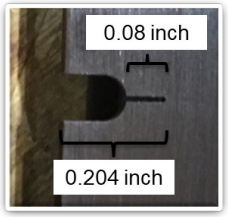
STRUCTURAL MONITORING SYSTEMS plc

Sandia National Laboratories

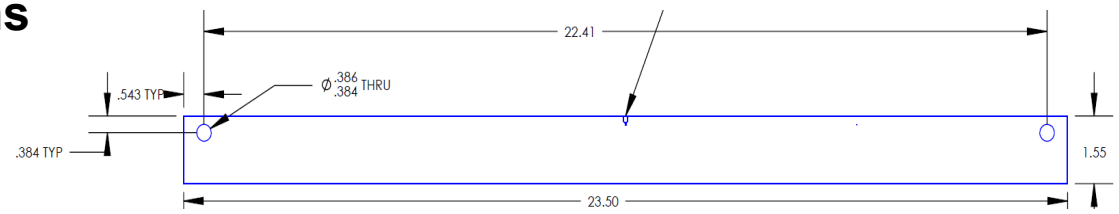
IOWA STATE UNIVERSITY
Center for Nondestructive Evaluation

Project results herein are the product of a collaborative effort

POD/Sensitivity Assessment Tests



- **Fixed sensors placed on notched 23”L x 1.5”W x 0.13”T Al-Li test specimens**

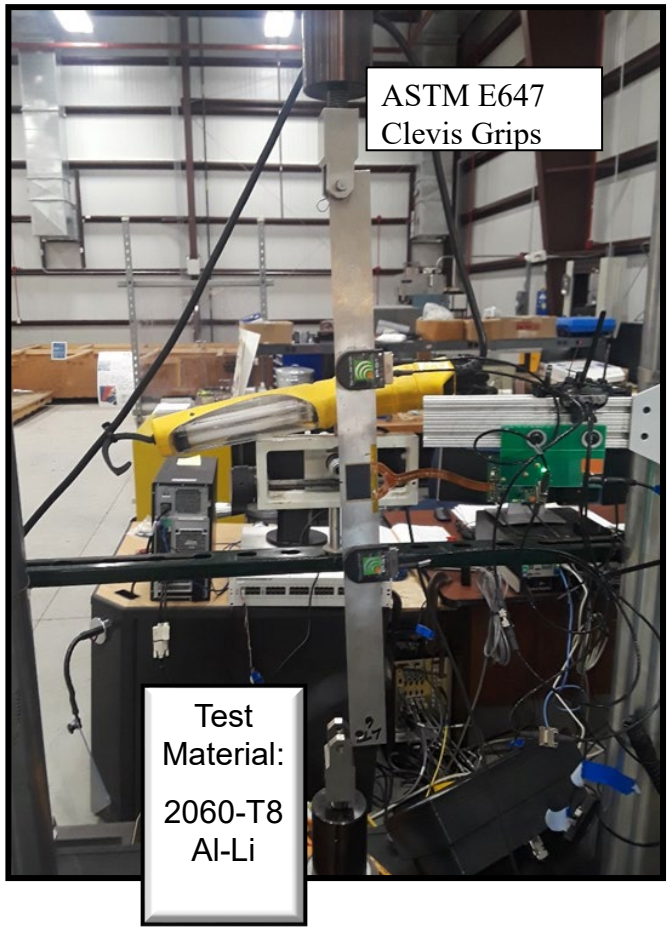


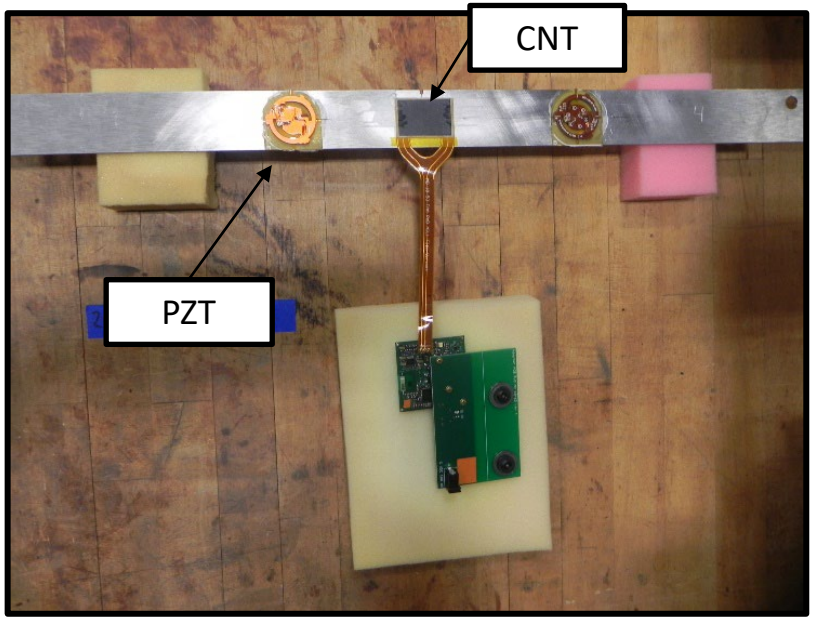
- **24 Test Specimens: MTS testing to grow fatigue cracks**
  - **12 with Piezoelectric Transducers (PZT) and Carbon Nanotube (CNT) Sensors**
  - **12 with PZT and Comparative Vacuum Monitoring (CVM) Sensors**

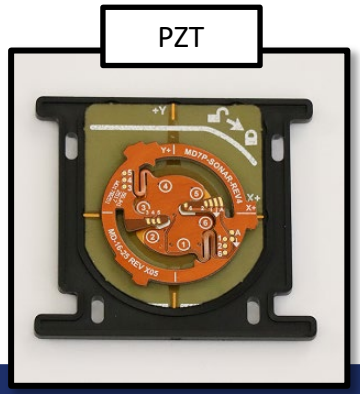
- **Test Parameters: Develop data to run through POD SHM methodologies**
  - **A minimum of three data points needed before and after crack formation observation**
  - **Visual measurements were taken along with Eddy current inspections**
  - **Consistent, steady crack formation and extension that fits methodology**

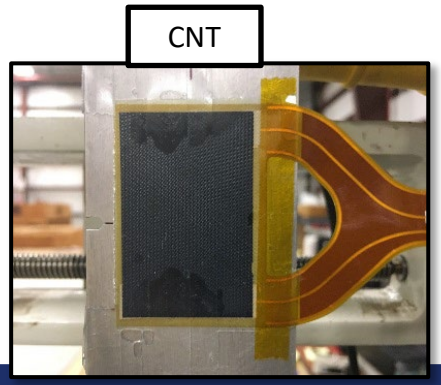
Test Fixture Set-Up - ASTM E647 ESE(T)

Sample in MTS: PZT & CNT



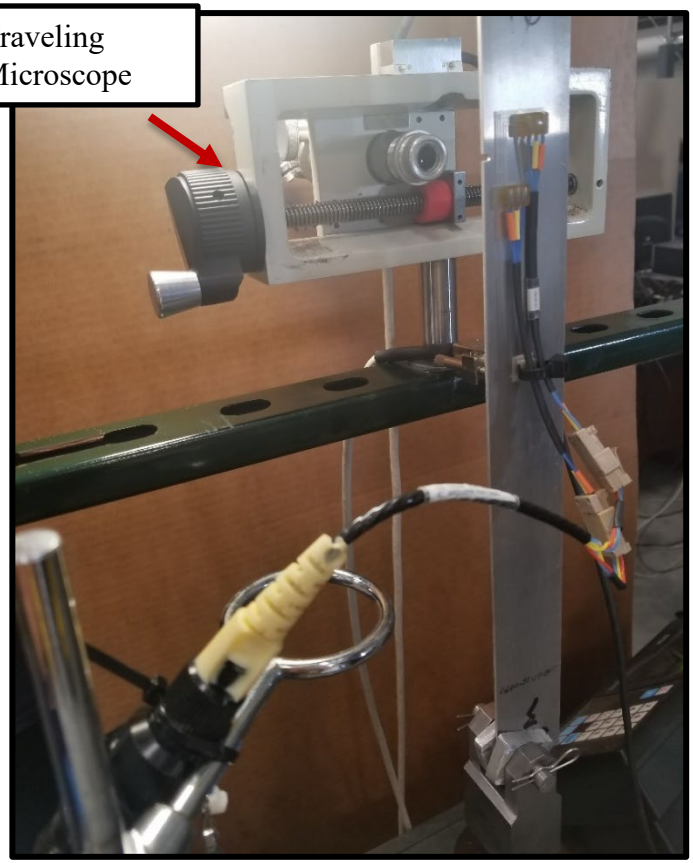


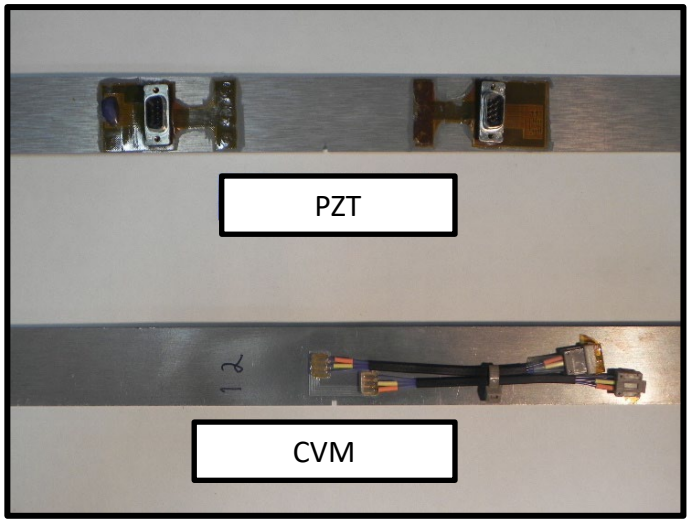


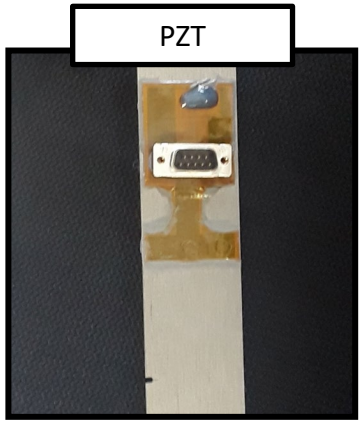


Test Fixture Set-Up

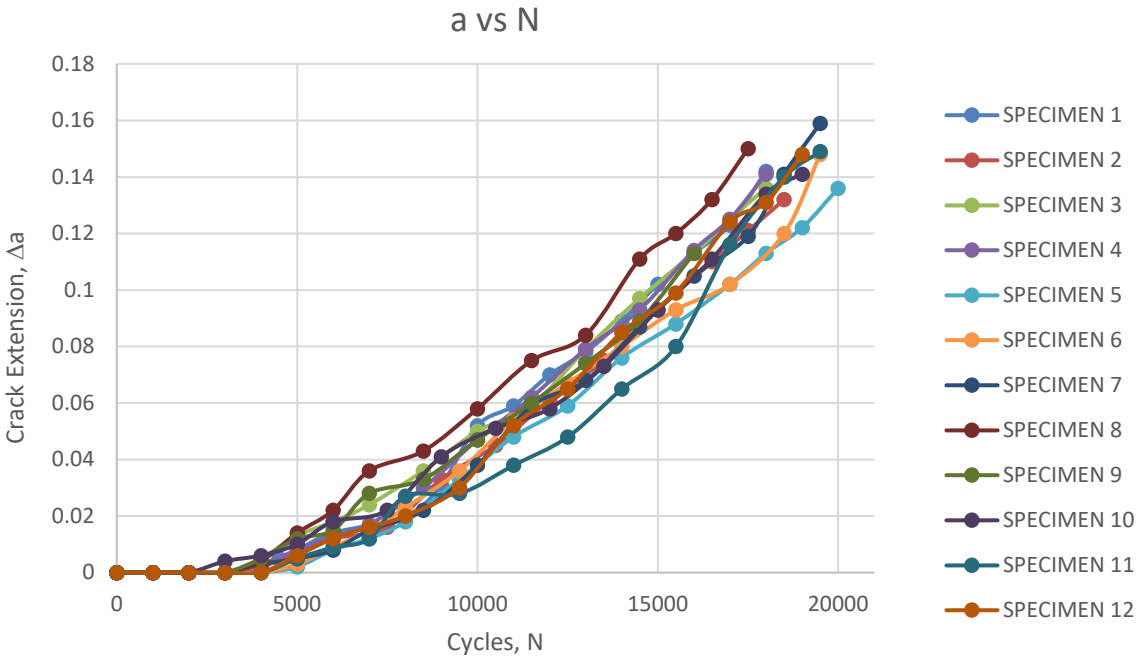
Sample in MTS: PZT & CVM



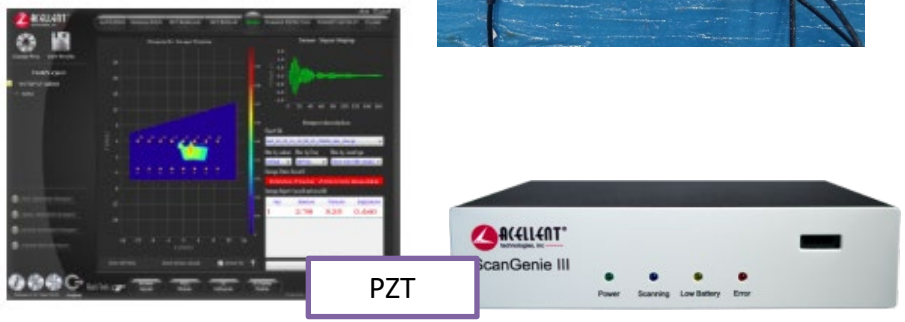




Truth Data vs Sensor Data



- **Data was collected using visual and NDI methods**
  - Visual: Traveling microscope with linear digital micrometer
  - NDI: High Frequency Eddy current



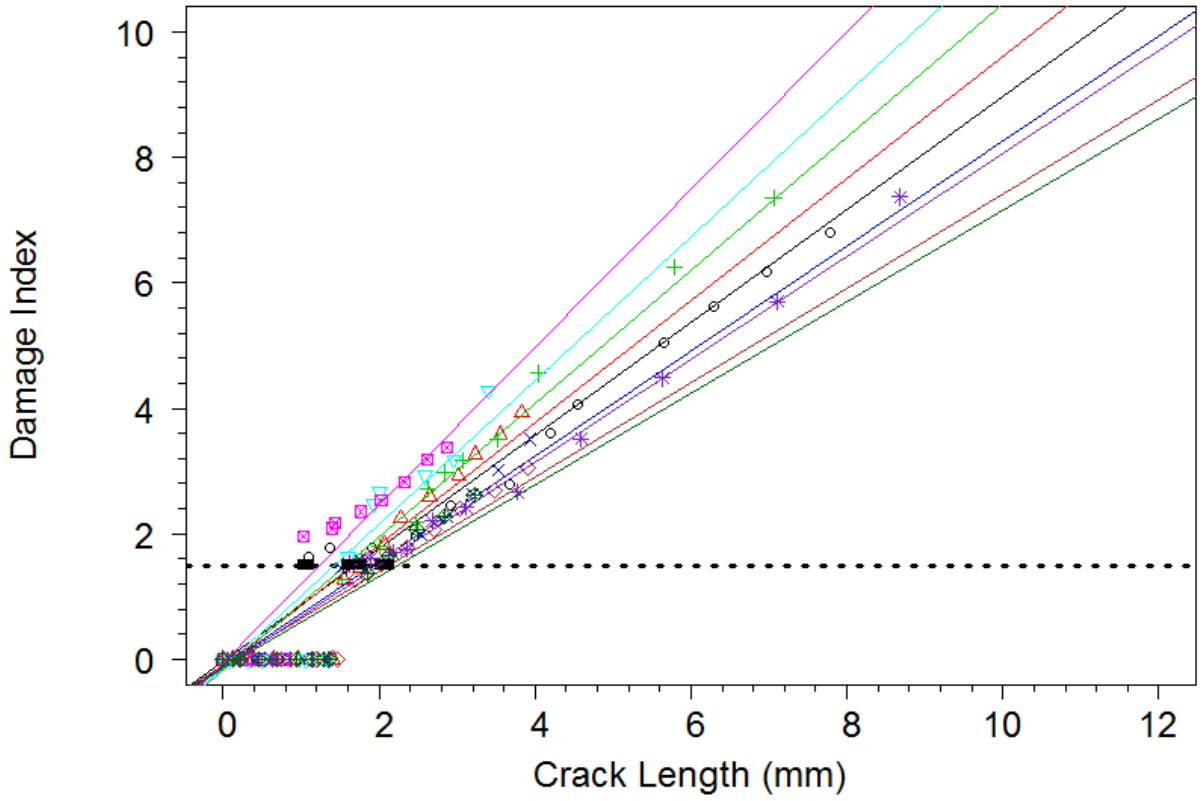
Correlating different sensor technologies with measured crack growth

POD/Sensitivity Assessment: Results

- Specimen Testing - completed 2019
- Meeker White Paper - “Statistical Methods for Probability of Detection in Structural Health Monitoring”
- FAA Draft report completed, Final report in editing

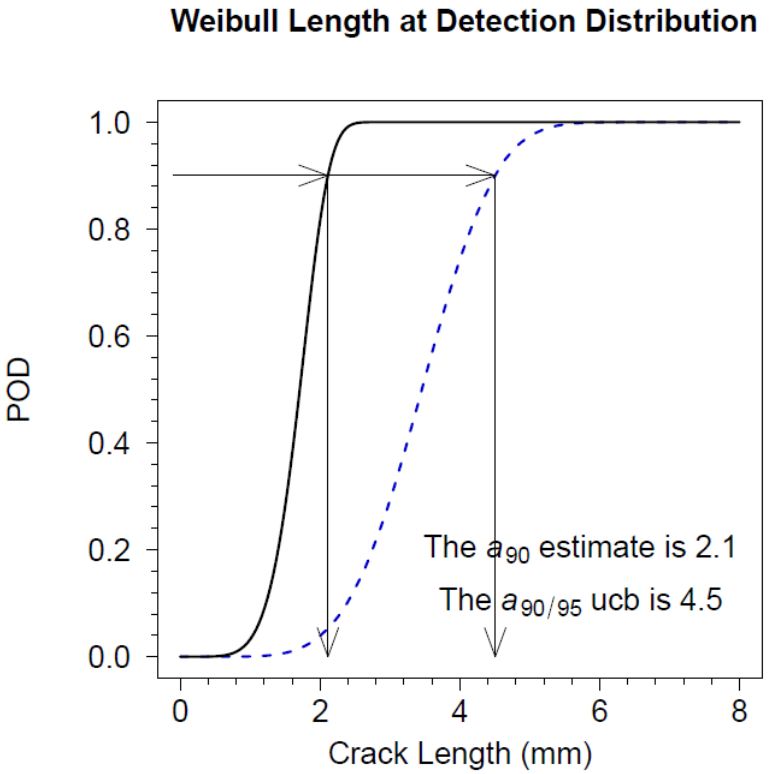
- Not an “apples” to “apples” comparison of results
- Ideally – need more samples

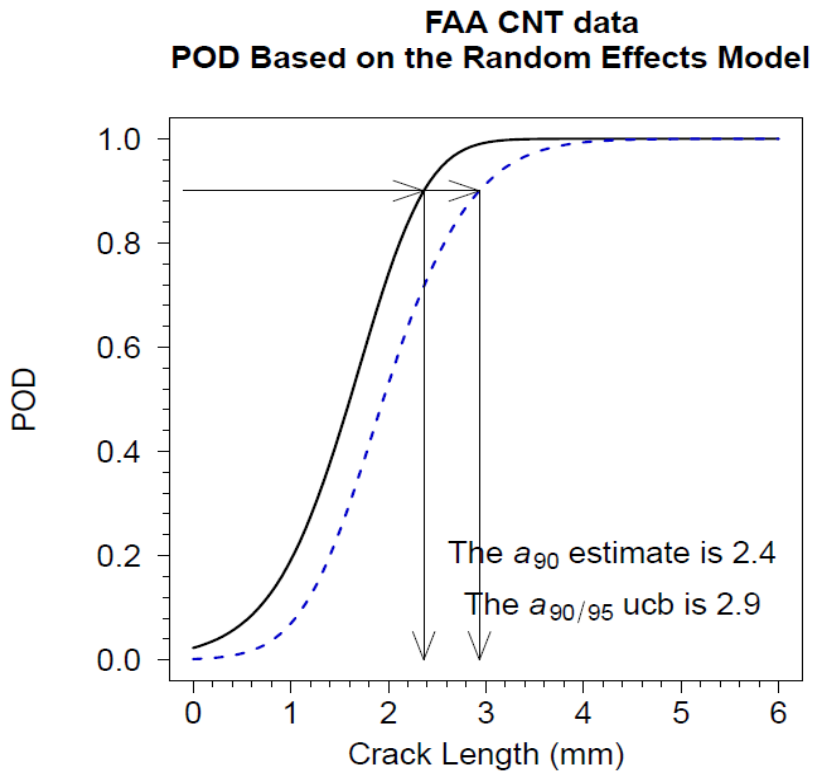
CNT – Length at Detection Plot



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

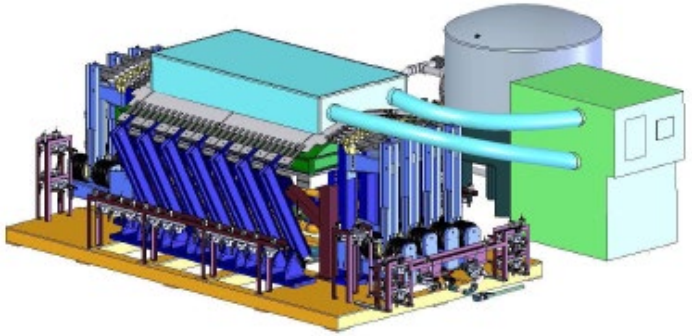
CNT – POD samples

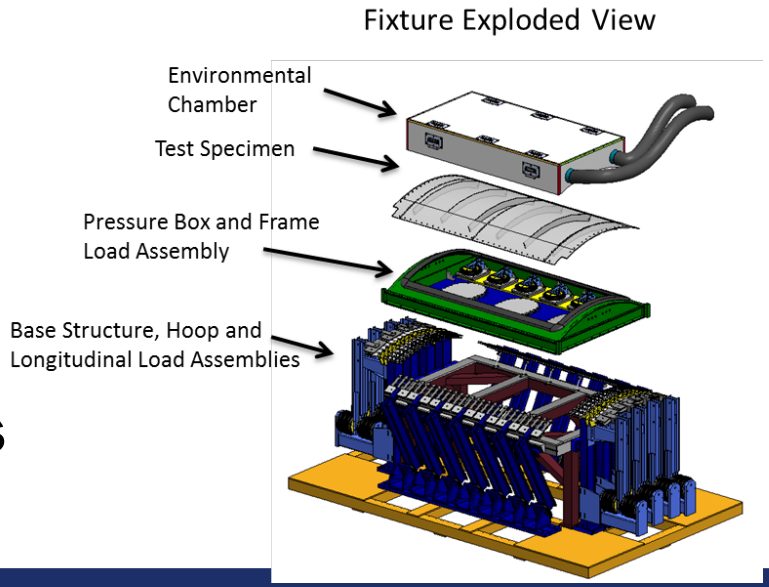




Full-Scale Aircraft Structural Test Evaluation and Research (FASTER)

- Test emerging technologies
  - Al-Li skins/frames/stringers
  - Friction stir weld lap splice
  - Bonded stiffeners
  - Multisite damage
- Partners: Arconic/Embraer
- Panels 1 and 2 complete, testing 3 now
- Panels 4 and 5 will be last panels

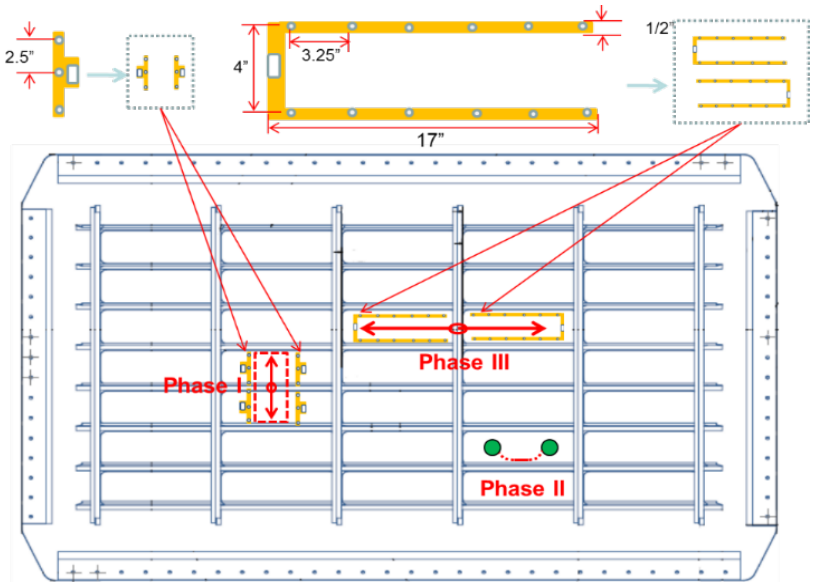




FASTER

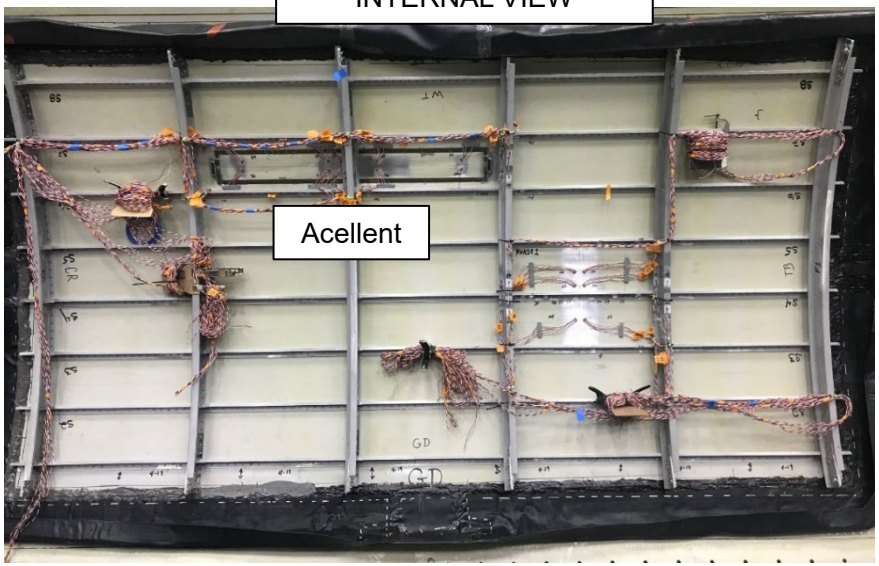
- Phase 1-3: Serial tests (approx. 6 months)
  - Sawcut thru skin/stiffener
  - Grow fatigue cracks
  - 5k cycle: Inspection includes NDI/SHM
  - Crack thru bay, repair
- Phase 2 started on panel 3
- Well characterized cracks with NDI/SHM, frequent inspection opportunities
  - Strain gauges, Digital Imaging Correlation
  - NDI: EC and Detailed Visual Inspection (DVI)
  - SHM: PZT (Acellent and Metis)

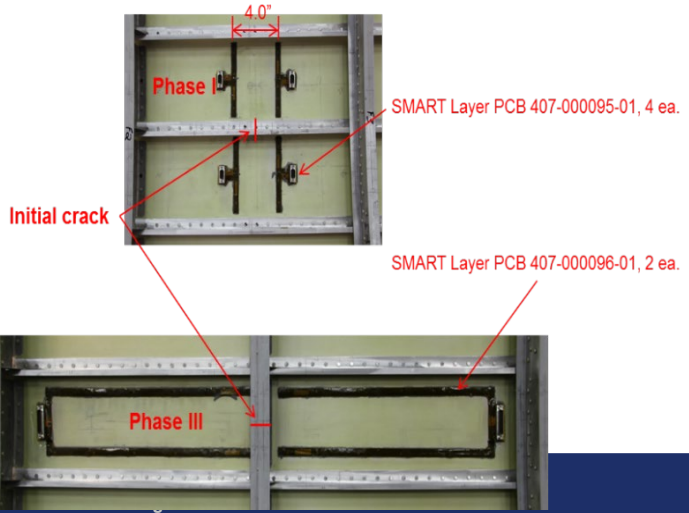
FASTER Panel Instrumented with SHM



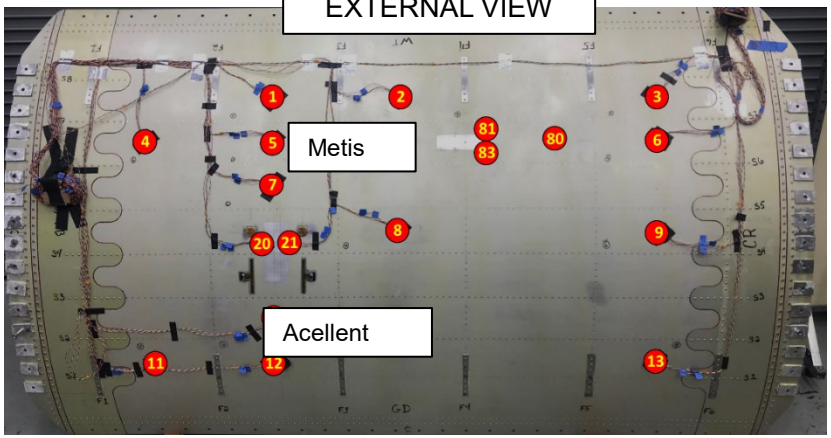
SHM ON PANEL 1

INTERNAL VIEW



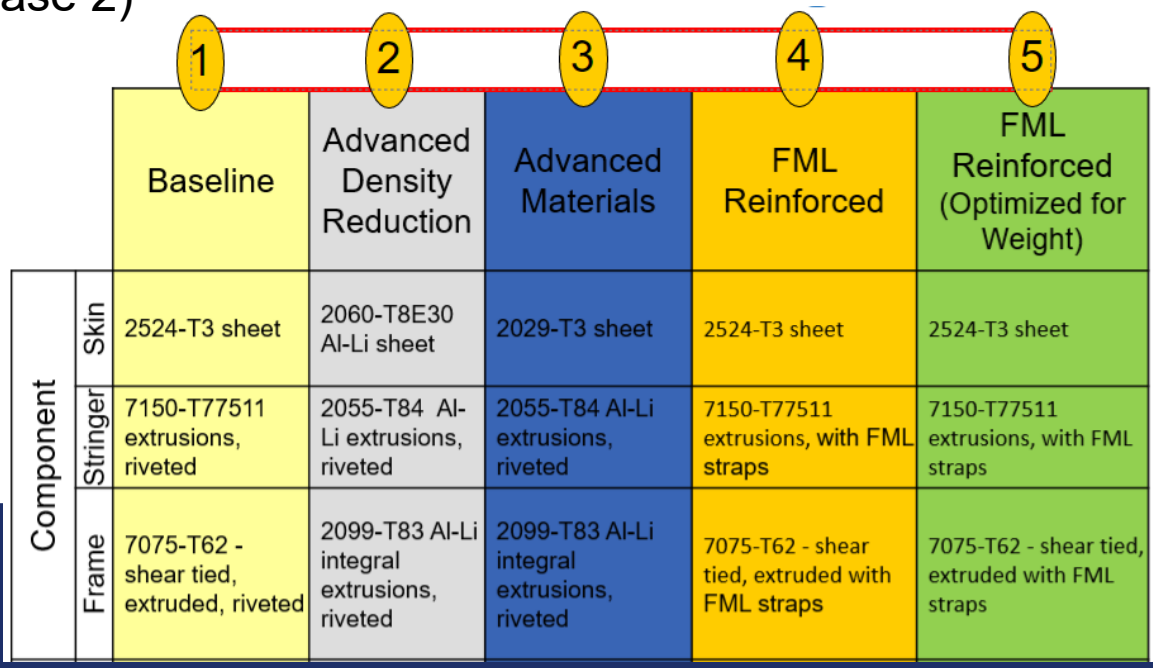


EXTERNAL VIEW



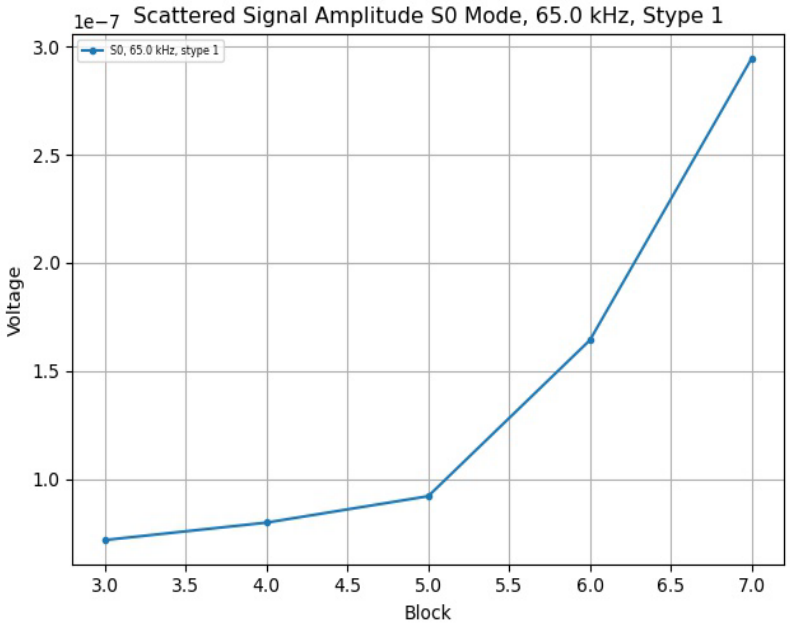
FASTER SHM

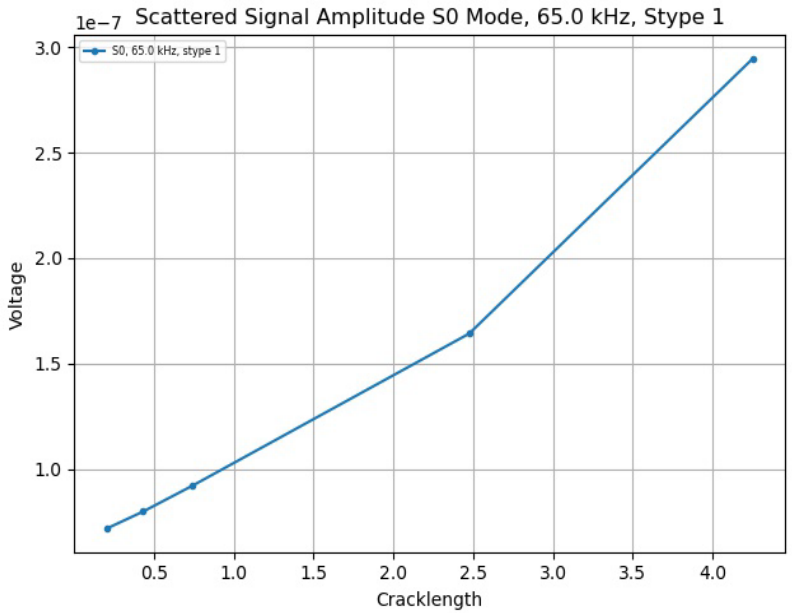
- Panel 1: Acellent smart sensors (Phase 1)
  Metis sensors (Phase 2)
  Acellent smart sensors (Phase 3)
- Panel 2: Acellent/Metis PZT sensors (Phase 1)
  Acellent sensors (Phase 2) (same as Phase 3 Panel 1)
  Metis CNT (Phase 2)
- Panel 3: Acellent/Metis PZT sensors (Phase 1)
  Current { Acellent sensors (Phase 2) (same as Phase 3 Panel 1)
  Metis CNT (Phase 2)
- Panel 4 and 5: TBD



Component		1 Baseline	2 Advanced Density Reduction	3 Advanced Materials	4 FML Reinforced	5 FML Reinforced (Optimized for Weight)
	Skin	2524-T3 sheet	2060-T8E30 Al-Li sheet	2029-T3 sheet	2524-T3 sheet	2524-T3 sheet
	Stringer	7150-T77511 extrusions, riveted	2055-T84 Al-Li extrusions, riveted	2055-T84 Al-Li extrusions, riveted	7150-T77511 extrusions, with FML straps	7150-T77511 extrusions, with FML straps
	Frame	7075-T62 - shear tied, extruded, riveted	2099-T83 Al-Li integral extrusions, riveted	2099-T83 Al-Li integral extrusions, riveted	7075-T62 - shear tied, extruded with FML straps	7075-T62 - shear tied, extruded with FML straps

FASTER Results Sample





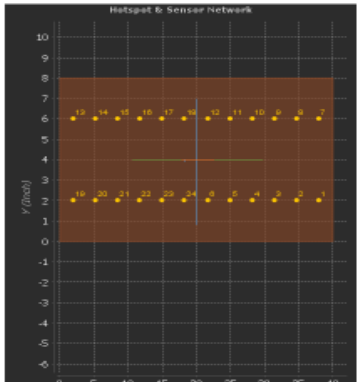
Each block represents an inspection point with a known crack length

Metis Sensors Panel 2, Phase 1

FASTER Results Sample

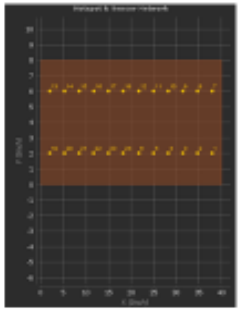
Panel 1 Phase 3 Daileon

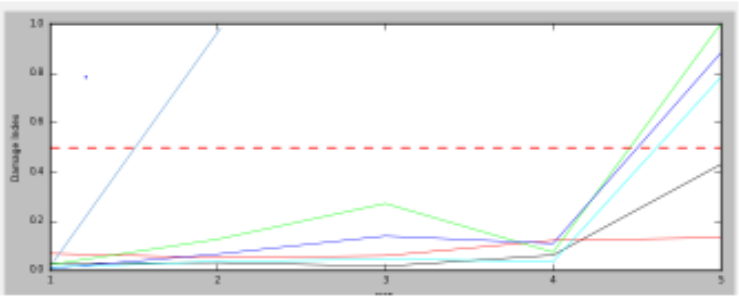
EMBRAER



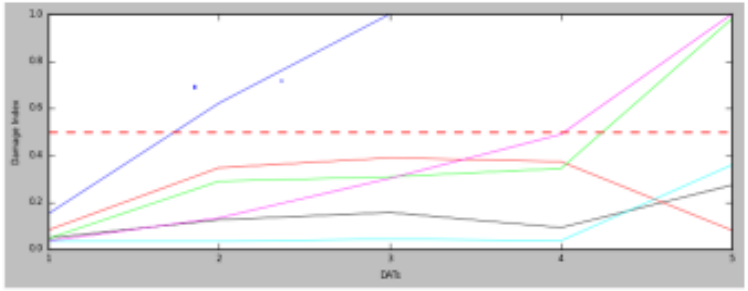
Panel 1: Phase 3	SHM File to Crack Size			
Filename		Cycle	Left Crack	Right Crack
Initial Notch 1.5"				
08_08_18_17_00_53	Baseline	0	0.75	0.75
08_09_18_07_30_53	Baseline			
08_20_18_16_15_41		1	3000	0.862	0.836
08_27_18_14_20_52		2			
Notch extended to 2"				
09_07_18_13_51_42		3	6000	1	1
09_14_18_11_21_09		4	9000	1.177	1.174
Notch extended to 3.25"				
09_18_18_11_57_48		5	12000	1.625	1.625
09_25_18_08_38_08		6	15000	1.704	1.723
10_11_18_08_58_02		7	24500	2.127	2.112
10_24_18_16_50_32		8	32500	2.698	2.671
10_31_18_13_21_48		9			
10_31_18_13_30_59		10	36500	3.103	3.086
11_16_18_08_21_42		11	43600	7.55	7.875

200 kHz
Threshold=0.5





Right Path 1-7, 2-8, 3-9, 4-10, 5-11 and 6-12



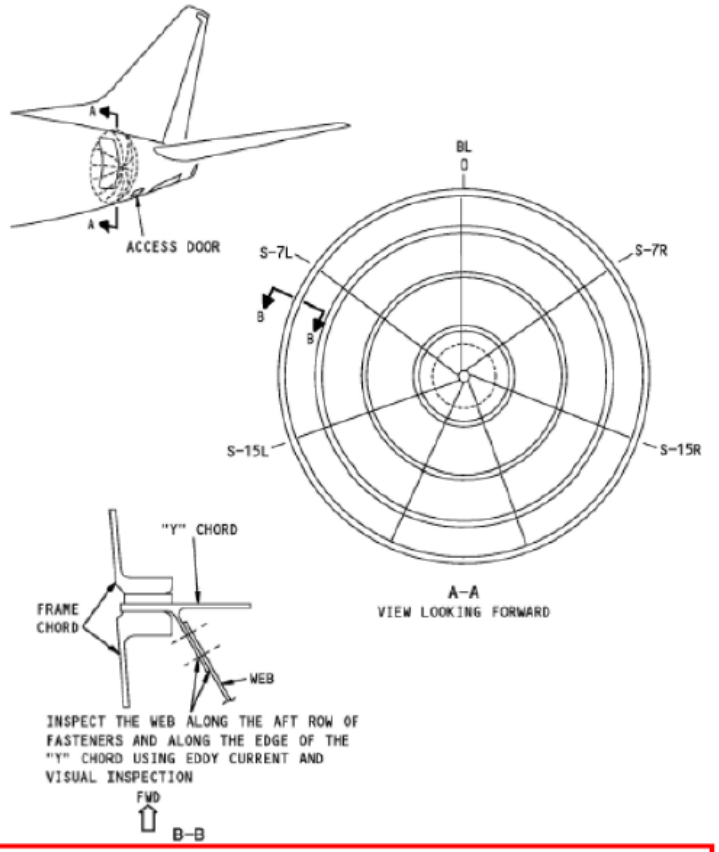
Left Path 13-19, 14-20, 15-21, 16-22, 17-23 and 18-24

Boeing 737 Aft Pressure Bulkhead

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

Boeing 737 Aft Pressure Bulkhead Testing
Environmental Chamber Testing

- **Boeing testing PZT sensors as an alternate means of compliance to Service Bulletin shown in previous slide (HFEC)**
- **Need POD curves**
- **FAA to test specimens at various temperatures via environmental chamber; take PZT sensor data**
- **Boeing statisticians to analyze data and generate POD curves**

FUTURE WORK

Industry Consortium: Model Assisted POD (MAPOD)

Purpose:

1) Establish a test program that can exercise any of the SHM POD methodologies and to use MAPOD.

2)To have a group of statisticians review the methodologies and data available to provide concurrence that statistics match the data.

Statistics Team

- Peter Parker: NASA Lead
- Dr. Meeker: ISU
- Elena-Beatriz Garcia: EASA
- Sabyasachi Basu: Boeing
- Nicolas Dominguez: Airbus
- Fernando Dotta: Embraer
- Rafik Hadjria: Safran
- Avinash Sarlashkar: Sikorsky
- David Forsyth
- Dennis Roach

Test Team: VISION

- Configuration chosen
- Define goals/purpose
- Exercise MAPOD
- DOE needs to be restarted
- Samples constructed (Embraer tentative)
- MAPOD Model to be developed (NASA Bill Schneck)
- Test Program (FAA tentative)
- Details

Summary

- **FAA SHM research program**
  - Lead to Boeing approving CVM as AMOC to HFEC on 737 fuel tank fitting (first commercial use of SHM)
  - Assisted in development of FAA Issue Paper for 737 wifi antenna application for SHM use to replace existing NDI Inspections (first FAA approved use of SHM)
  - Assisting Boeing in 737 APB potential application

Summary

- **FAA SHM research program - very active**
  - Data development for certification, standardization, and public usage
  - CRADA with Metis, Simmonds, Clarkson University, Acellent, Embraer, Mistras, and Boeing
  - Working agreement with NASA Langley
- **NDI OEMS interested in participating in test program welcome**
- **SHM interest for use on civil aircraft is growing**
- **SAE Aerospace Industry Steering Committee looking for operators to join**

QUESTIONS?

Danielle Stephens
danielle.stephens@faa.gov

Paul Swindell
Paul.E-CTR.Swindell@faa.gov