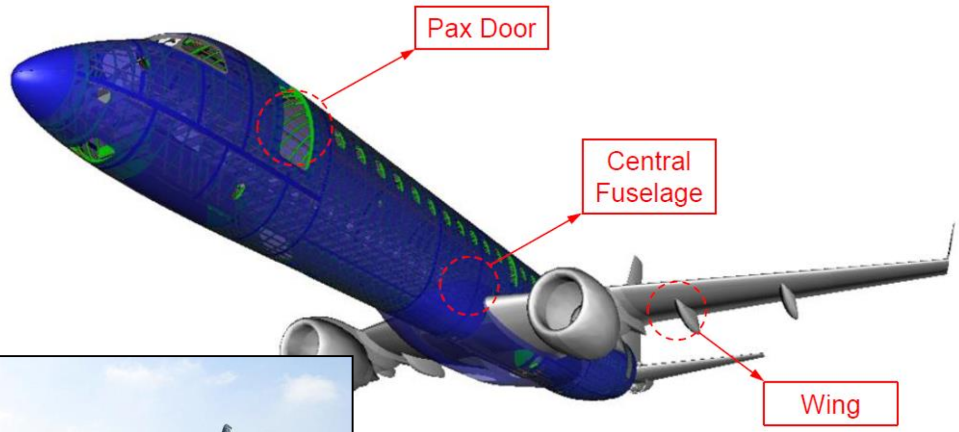
Adoption of SHM Systems to Address Families of Aircraft Integrity Checks

SAND2017-9998C



Dennis Roach
Tom Rice
FAA Airworthiness Assurance Center
Sandia National Labs

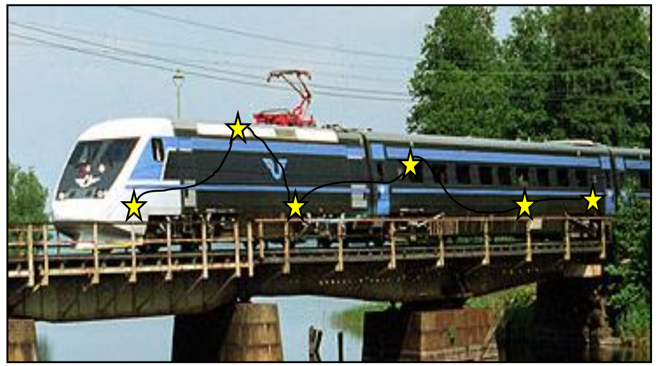
Ricardo Rulli
Fernando Dotta
Carlos Chaves
Embraer

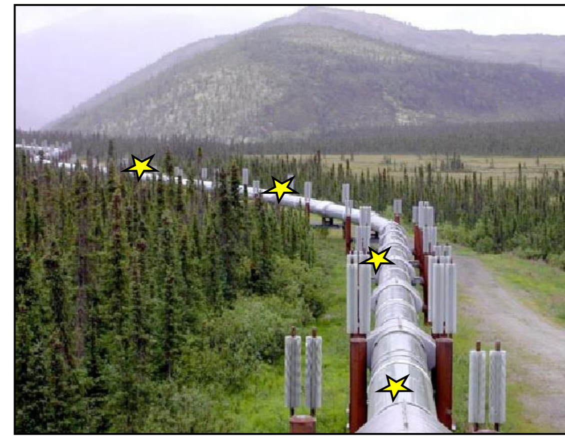
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

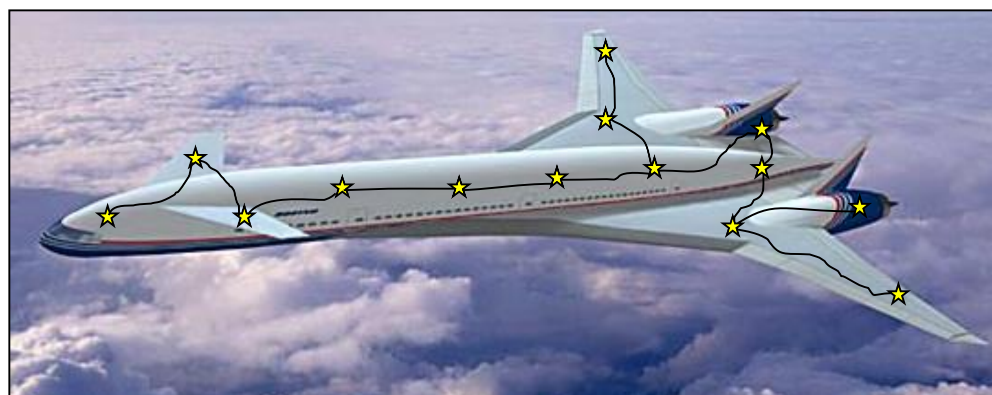
Distributed Sensor Networks for Structural Health Monitoring

Smart Structures: include in-situ distributed sensors for real- time health monitoring; ensure integrity with minimal need for human intervention

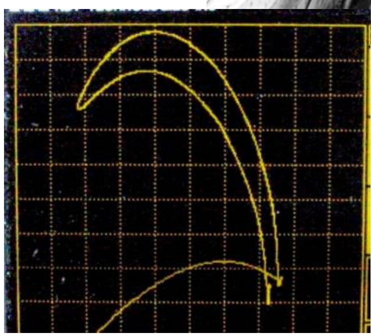
- **Remotely monitored sensors allow for condition-based maintenance**
- **Automatically process data, assess structural condition & signal need for maintenance actions**
- **SHM for:**
  - **Flaw detection**
  - **Flaw location**
  - **Flaw characterization**
  - **Condition Based Maintenance**



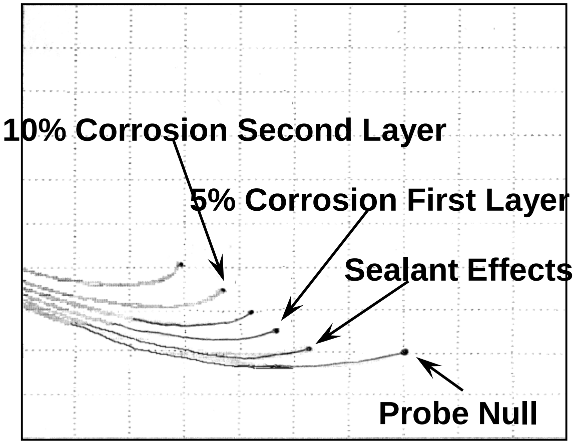




Typical A-Scan Signals Used for Flaw Detection with Hand-Held Devices

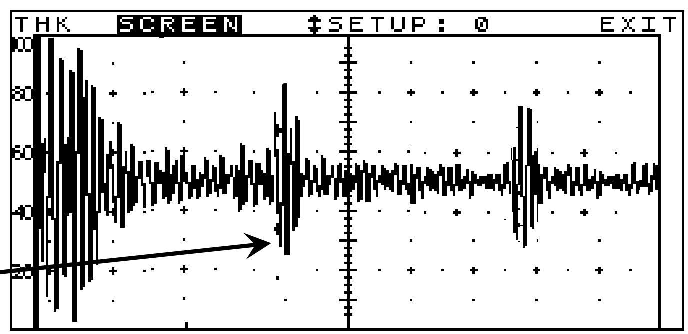


Eddy Current Signal at Crack Site



Corrosion Detection with Dual Frequency Eddy Current

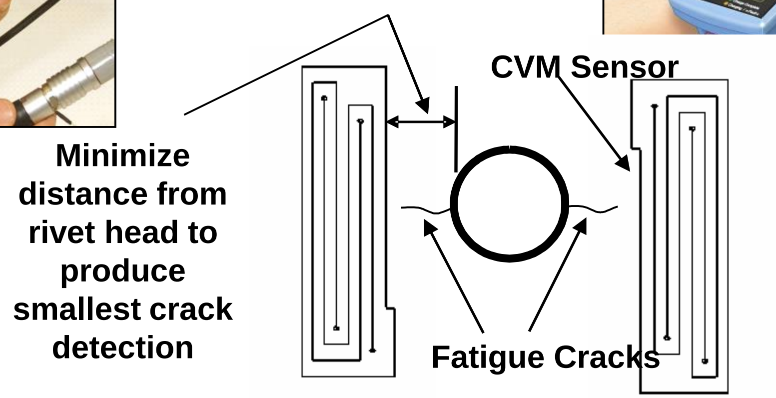
Intermediate Echo Caused by Delamination



Ultrasonic Pitch-Catch UT Signals Comparing Flawed and Unflawed Signatures

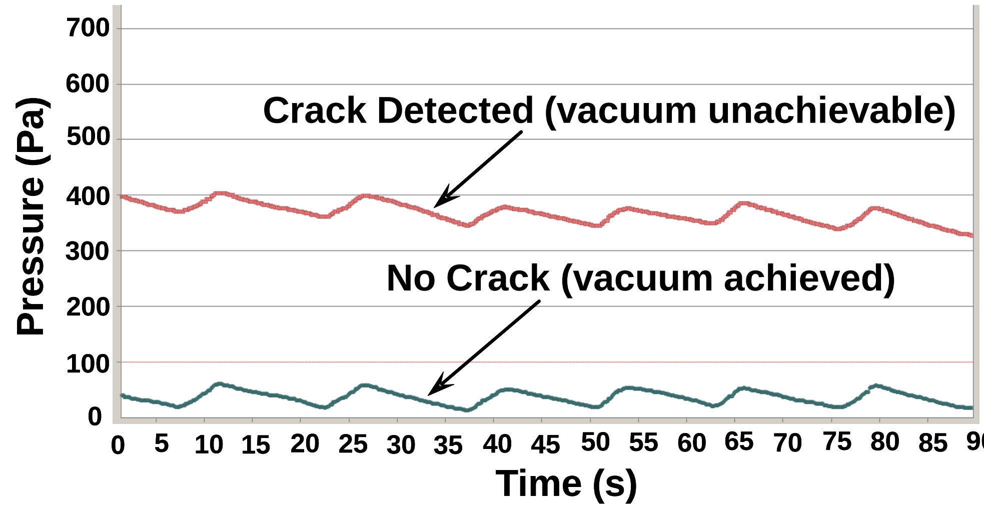
Drivers for Application of CVM Technology

- Overcome accessibility problems; sensors ducted to convenient access point
- Improve crack detection (easier & more often)
- Real-time information or more frequent, remote interrogation
- Initial focus – monitor known fatigue prone areas
- Long term possibilities – distributed systems; remotely monitored sensors allow for condition-based maintenance

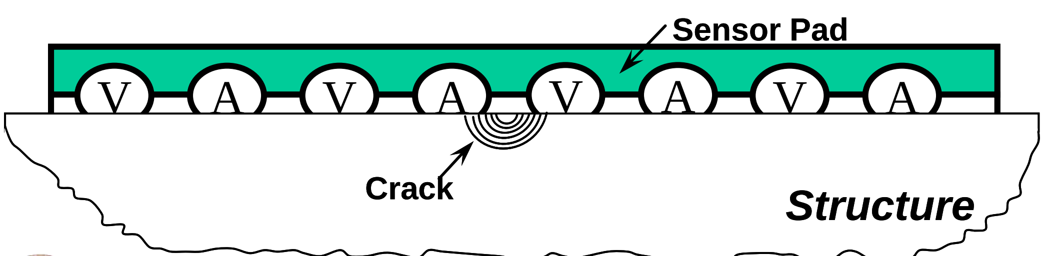


Comparative Vacuum Monitoring System

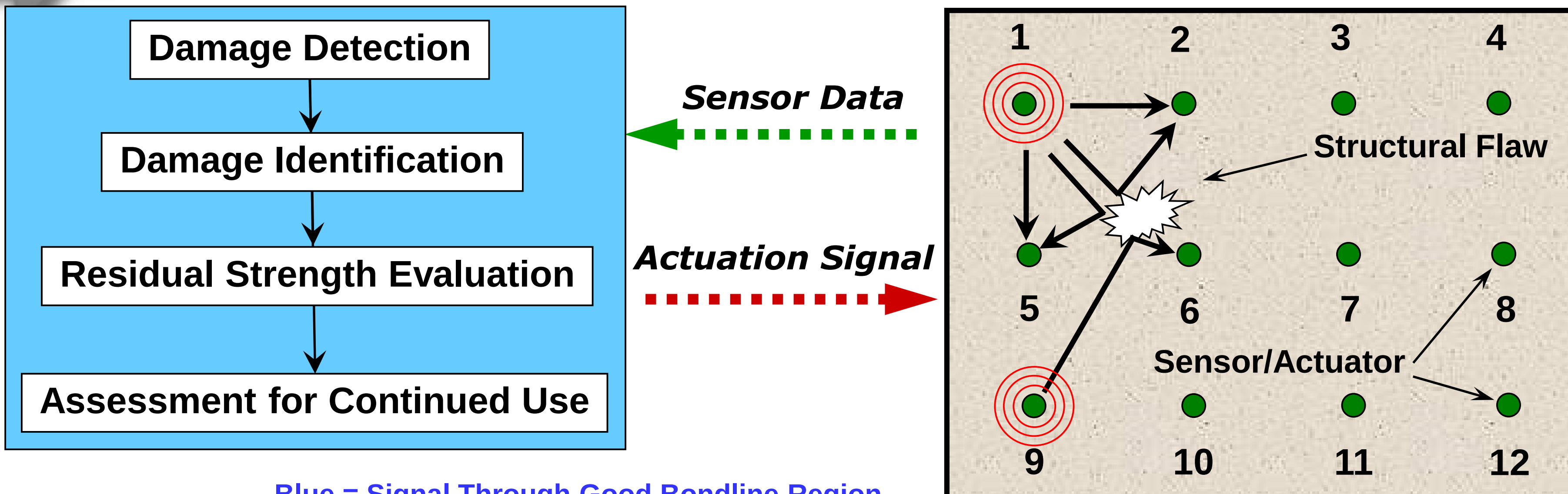
- Sensors contain fine channels - vacuum is applied to embedded galleries
- Leakage path produces a measurable change in the vacuum level
- Doesn't require electrical excitation or couplant/contact



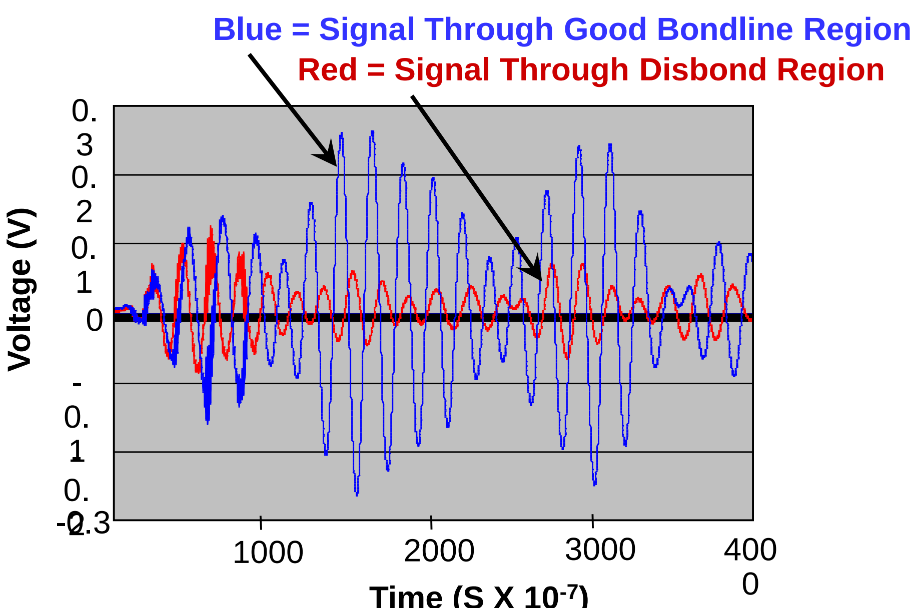
CVM Sensor Adjacent to Crack Initiation Site



Damage Detection & Growth Monitoring with Piezoelectric Sensors



Piezoelectric Sensor Network



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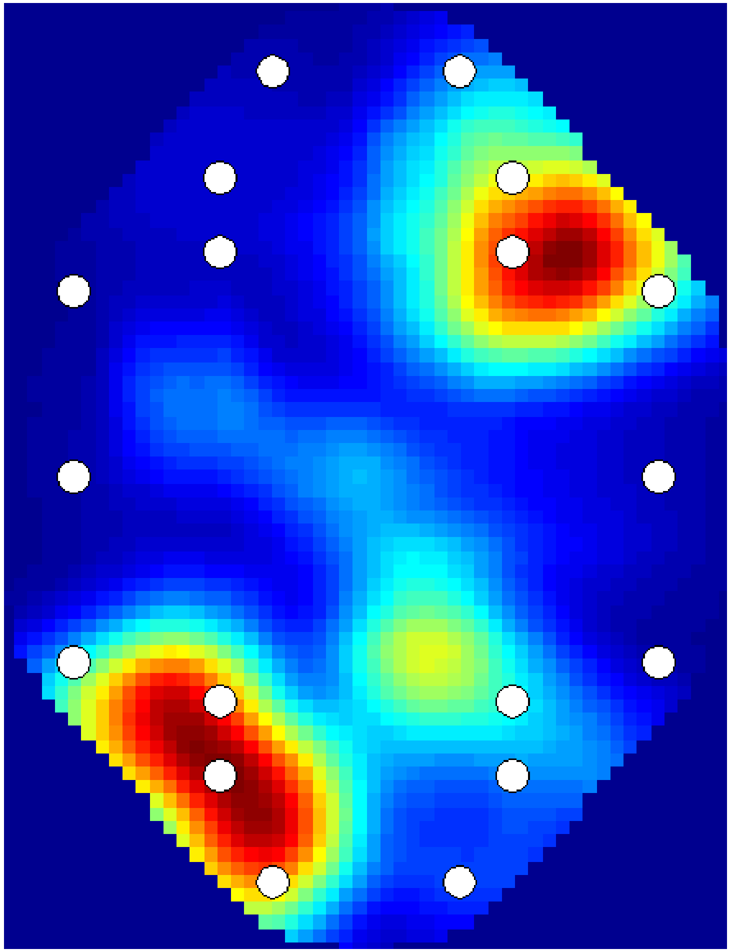
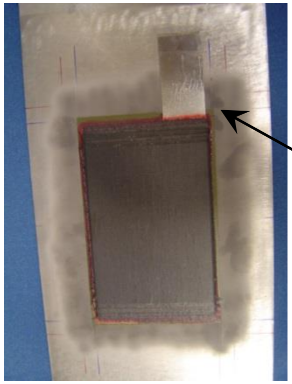
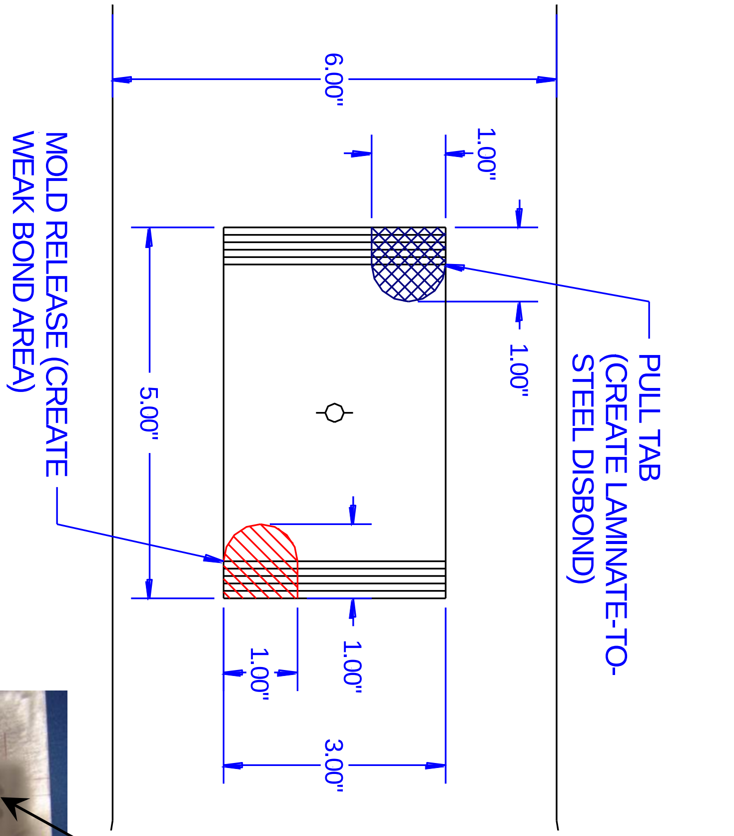
Disbond Detection & Growth Monitoring with Piezoelectric Sensors



After mold release flaw growth (50 KHz inspection)



Pull tab flaw



CVM for Structural Health Monitoring – Integration into Routine Maintenance

Program Participants

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Federal Aviation Administration — Paul Swindell, Dave Galella, Ian Won, Mark Freisthler

Delta TechOps — David Piotrowski, Alex Melton, John Bohler, Joe Reeves, Chris Coleman, John Hays

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Sikorsky — Mark Davis, Andrew Brookhart, Preston Bates, Ray Beale

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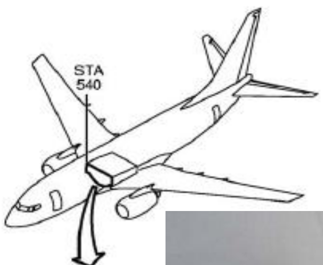
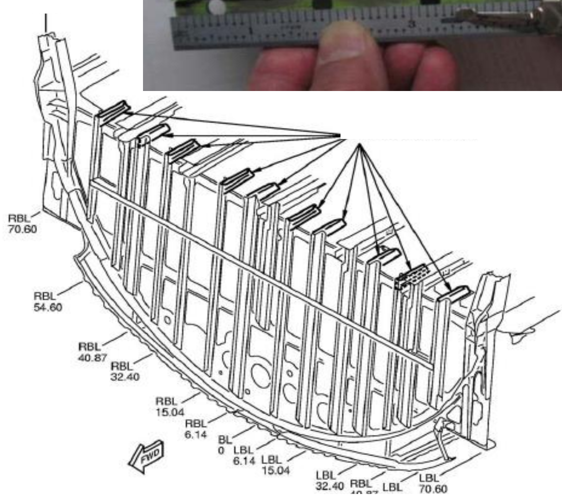
CVM Sensor Network Applied to 737 Wing Box Fittings

SHM Certification Program - 737NG Center Wing Box, Shear Fitting

- **Cracking between 21K-36K cycles**
- **Visual/eddy current inspection for crack detection**
- **Mod requires fuel tank entry; inspection does not**



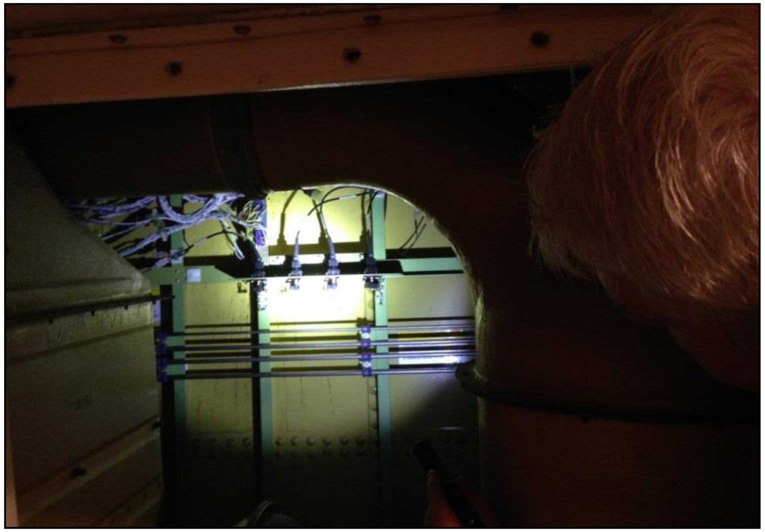



CVM Sensor on Wing Box Fitting

737NG Center Wing Box – Accumulating Successful Flight History

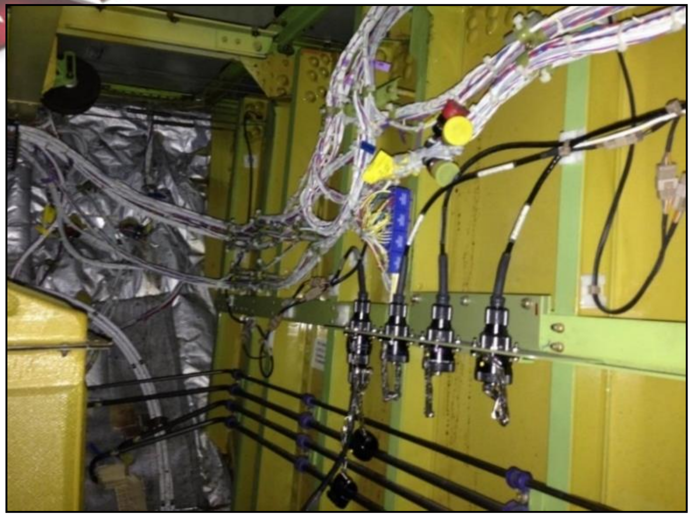
Aircraft Parked at Gate After Final Flight of the Day

Access to SLS Connectors Through Forward Baggage Compartment



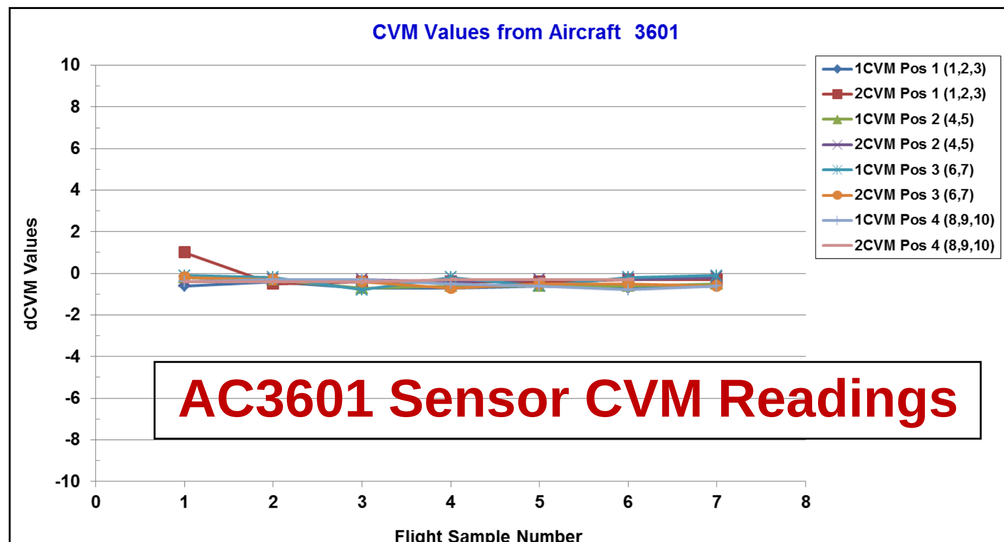
Removal of Baggage Liner to Access 4 SLS Connectors Mounted to Bulkhead

737NG Center Wing Box – CVM Sensor Monitoring



Connecting SLS Leads and Running PM-200 to Monitoring Device to Check Sensor Network

Logging Inspection Completion at Aircraft Gate



737 NDT Manual - New SHM Chapter Published (Nov 2015)

Building Block to Approval for Routine Use of SHM

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737 Non-Destructive Testing Manual

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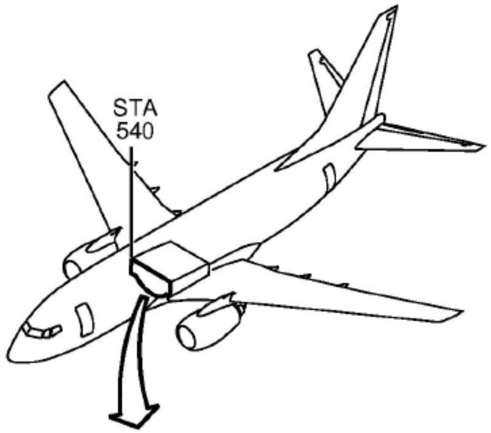
- ☑ FRONT MATTER
- ☑ PART 01 - GENERAL
- ☑ PART 02 - X-RAY
- ☑ PART 04 - ULTRASONIC
- ☑ PART 05 - COMPARATIVE VACUUM MONITORING
- ☑ PART 06 - EDDY CURRENT
- ☑ PART 09 - THERMOGRAPHY
- ☑ PART 10 - VISUAL/OPTICAL

Changed to

PART 05 – STRUCTURAL HEALTH MONITORING

Boeing Service Bulletin – Modification to Allow for Routine Use of SHM Solution (June 2016)



DO A DETAILED INSPECTION OR COMPARATIVE VACUUM MONITORING (CVM) INSPECTION OF THE CENTER WING BOX FRONT SPAR SHEAR FITTINGS FOR ANY CRACKS. IF ANY CRACK IS FOUND, REMOVE THE DAMAGED SHEAR FITTING, MAKE SURE THERE IS NO CRACKING IN THE UPPER PANEL AND INSTALL A NEW SHEAR FITTING AS GIVEN IN THIS SERVICE BULLETIN.

AT EACH SHEAR FITTING, IF NO CRACKING IS FOUND IT IS OPTIONAL TO ACCOMPLISH THE PREVENTIVE MODIFICATION BY REPLACING THE SHEAR FITTINGS.

BOEING SERVICE BULLETIN 737-57-1309

BOEING Commercial Airplanes

737
Service Bulletin

Number: **737-57-1309**
Original Issue: January 28, 2011
Revision 1: June 27, 2016
ATA System: 5714

Revision Transmittal Sheet

SUBJECT: WINGS - Center Wing Box - Front Spar Shear Fitting - Inspection, Repair and Preventive Modification

This revision includes all pages of the service bulletin.

COMPLIANCE INFORMATION RELATED TO THIS REVISION

Effects of this Revision on airplanes on which Original Issue was previously done:

None.

REASON FOR REVISION

This revision is sent to add a Comparative Vacuum Monitoring (CVM) inspection as an alternative inspection method for the front spar shear fitting. In addition, illustrations in figures are changed to show correct views, footnotes are added in fastener tables for clarification and footnotes in figures are changed to clarify sealing instructions.

Embraer Family of SHM Applications

Goal: **quantify the sensitivity, reliability and repeatability of crack detection using PZT and CVM sensors.**

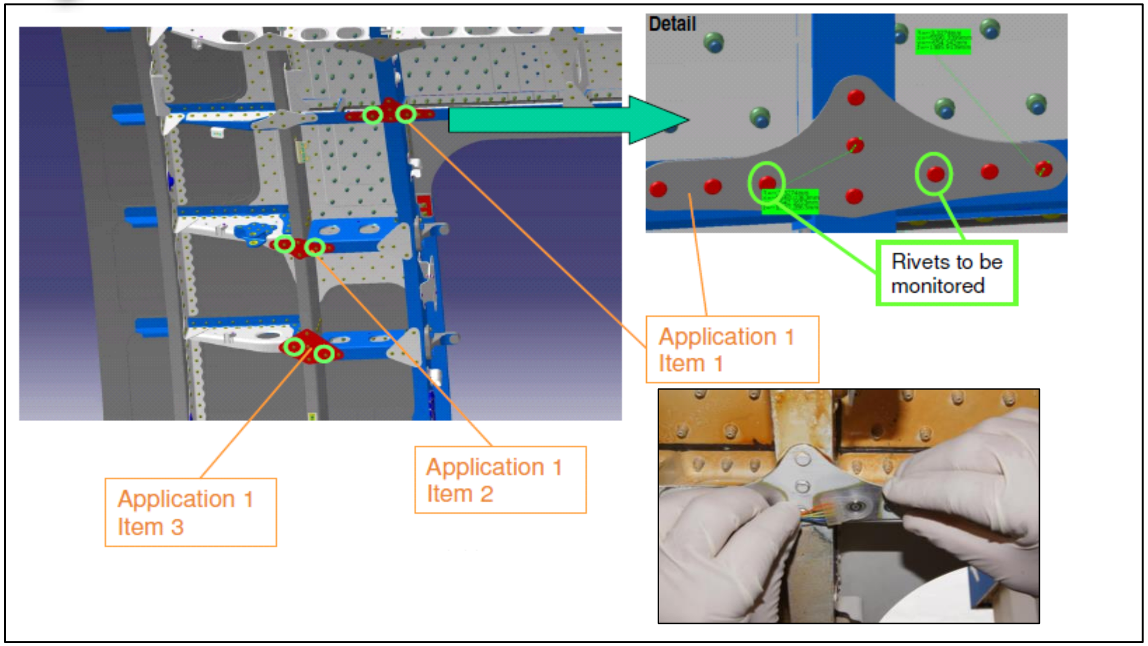
Approach:

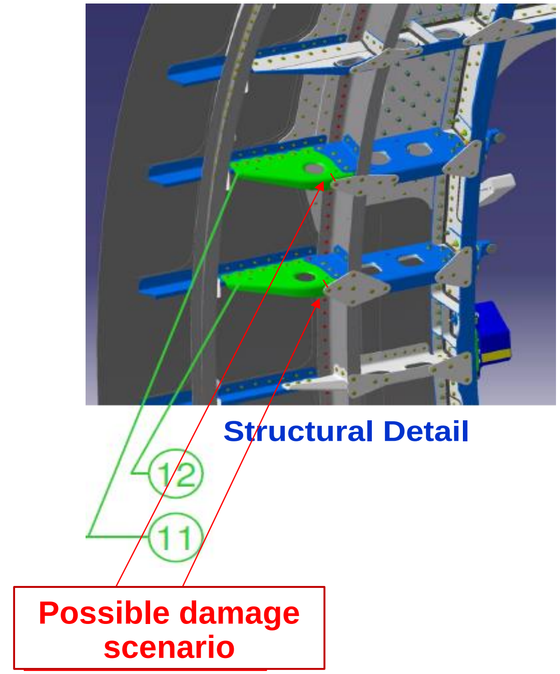
- **Design test configurations using representative structures & geometry on aircraft**
- **Evaluate sensor performance using Probability of Detection (POD) analyses**

Application Number	SHM Type	Description	Rank
1	CVM	Fwd Fuselage PAX Door - Bracket	1
2	PZT	Fwd Fuselage PAX Door - Stringer	2
11	CVM	Central Fuselage II Side Fittings	8
15	PZT	Central Fuselage II Side Fittings	8
4	PZT	Center Fuselage End Fittings	5
5	CVM	Wing (Left/Right) FTE Upper Skin	3-4, 7
8	CVM	Wing (Left/Right) Main Box, Rib	6
8R	CVM	Wing (Left/Right) Main Box - Reinforced	6

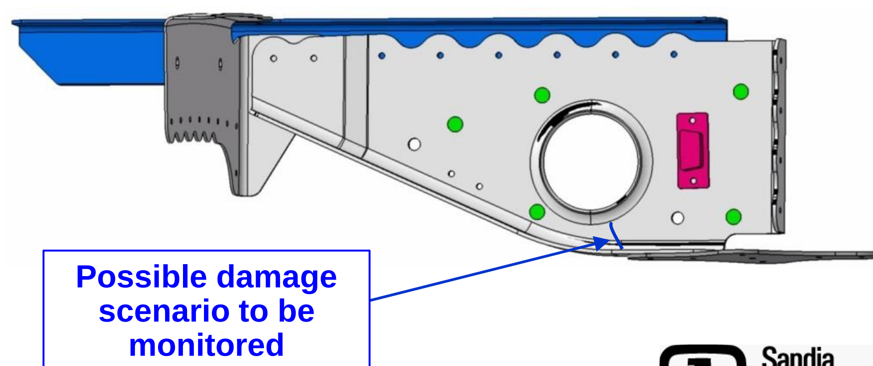
Embraer Damage Detection Applications

Application 1 – CVM on Forward Fuselage PAX Door Bracket





Application 2 – PZT on Forward Fuselage PAX Door Stringer



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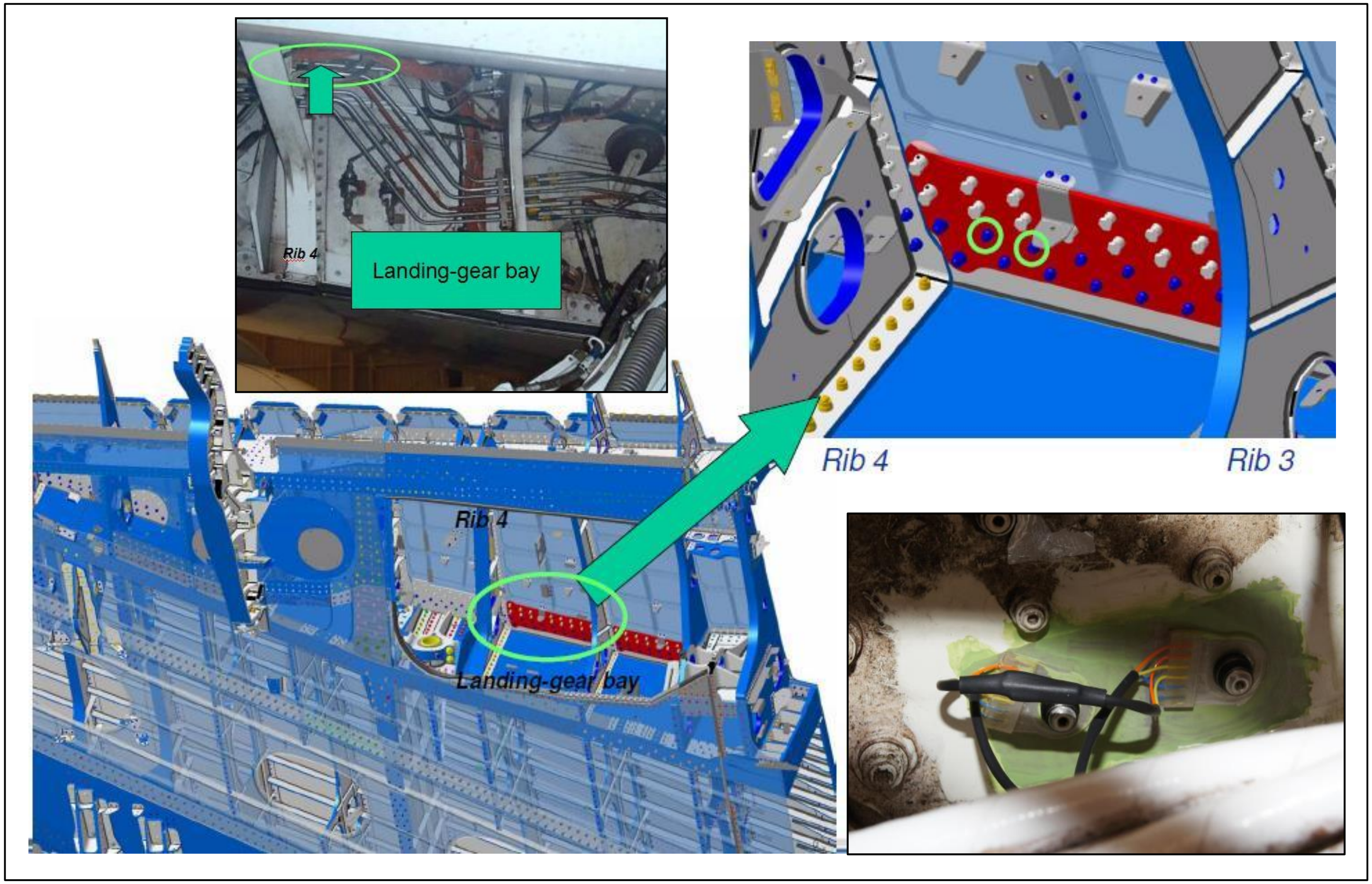
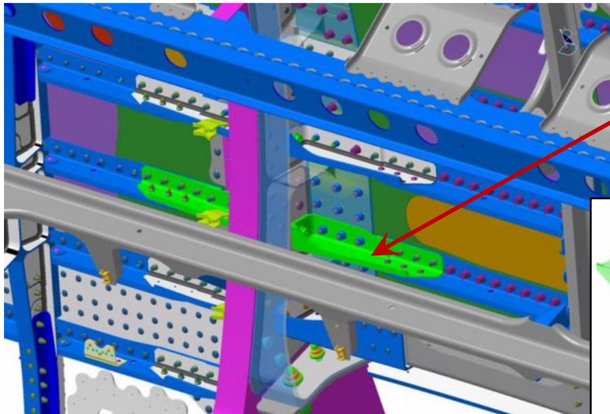
Embraer Damage Detection Applications

Application 5 – CVM on Wing (Left/Right) FTE Upper Skin at Rib 4

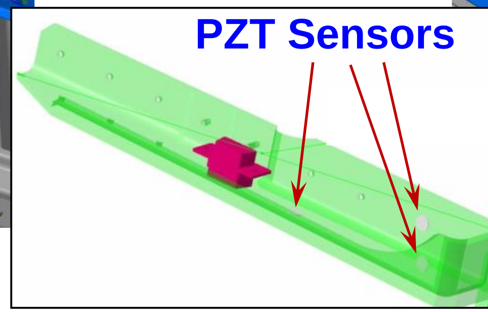


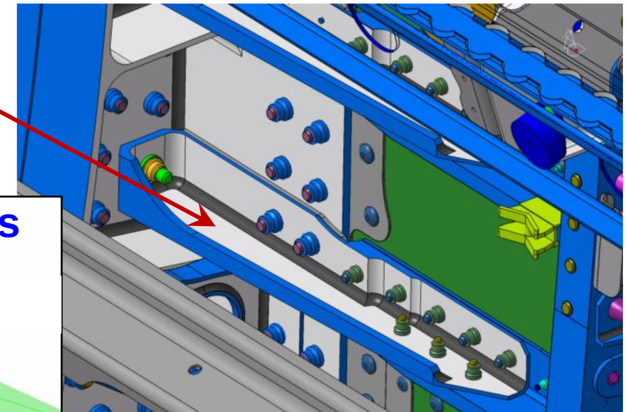
Embraer Damage Detection Applications

Application 15 – PZT on Center Fuselage (Left/Right) Side Fittings

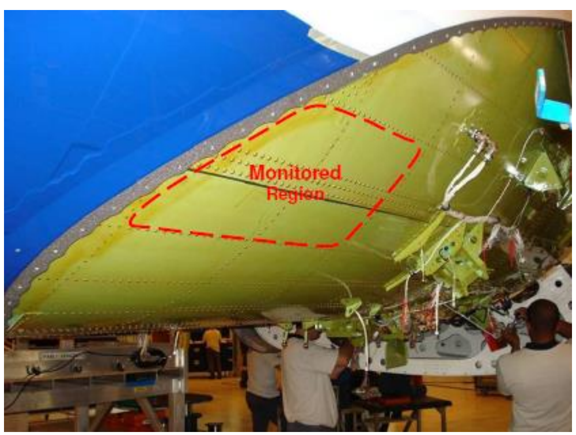


Structure to be Monitored

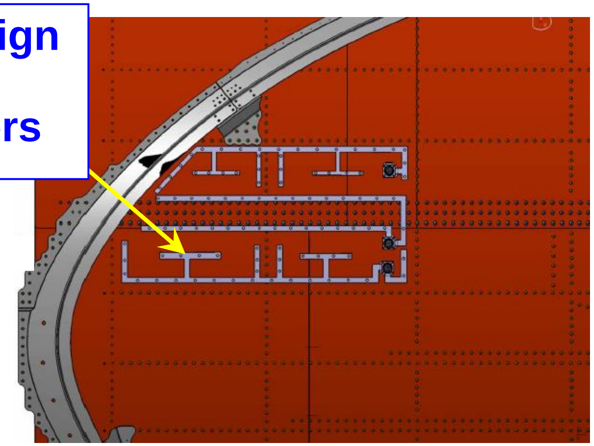




Application 14 – PZT on Fuselage (Left/Right) Fastener Region Under Fairings

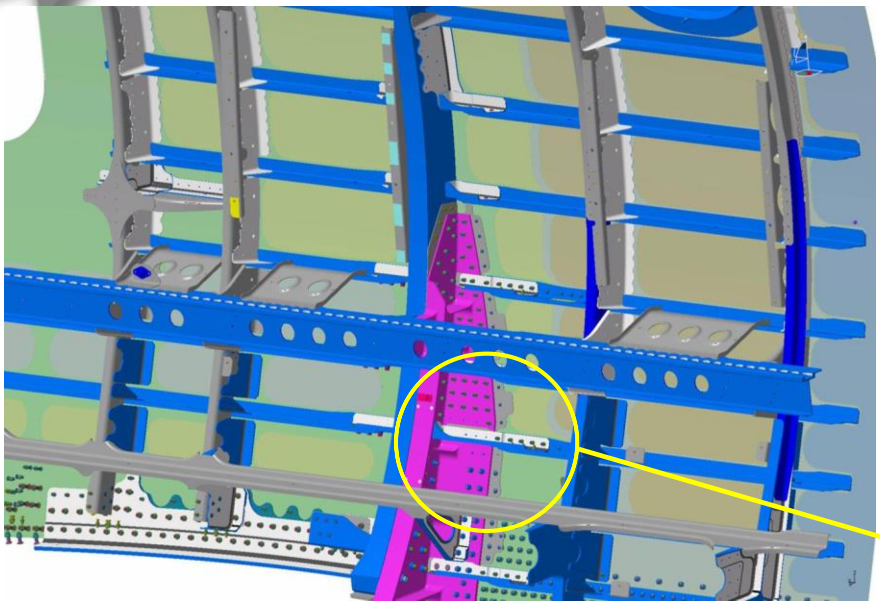


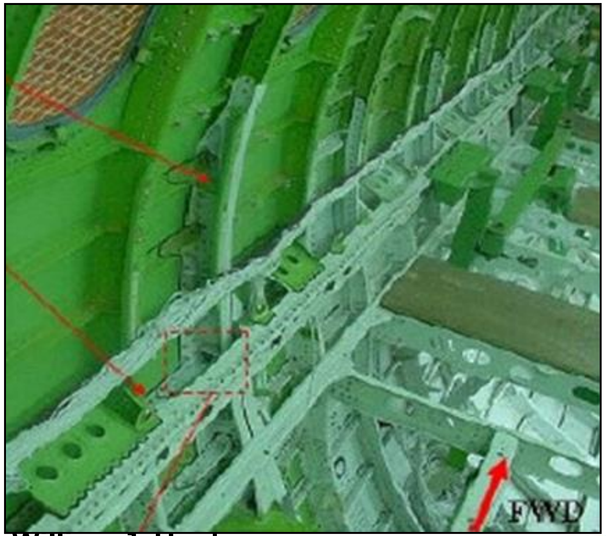
Smart Patch Design to Monitor All Needed Fasteners

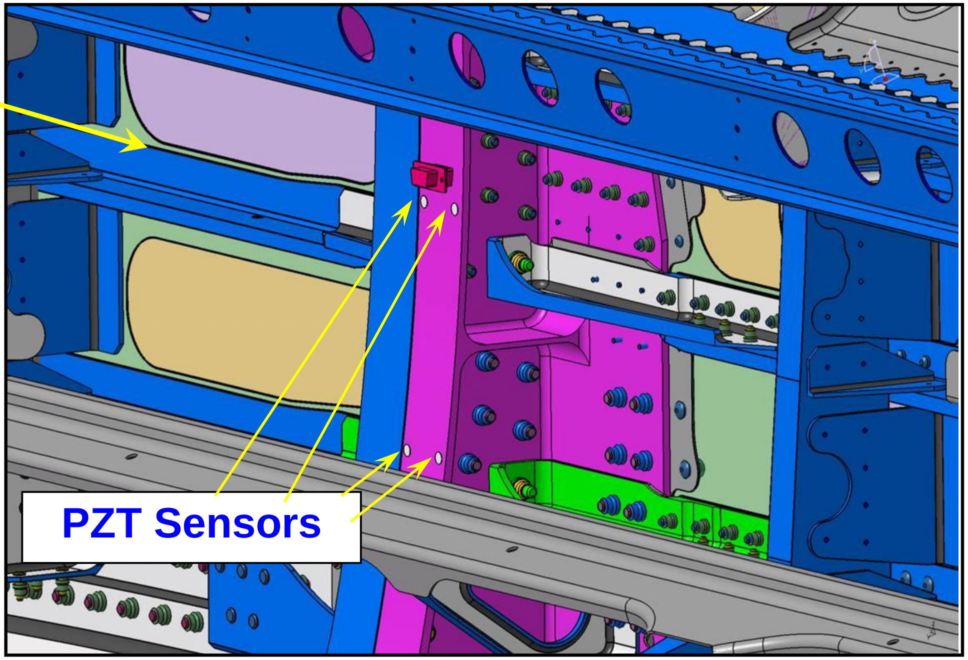


Embraer Damage Detection Applications

Application 4 – PZT on Center Fuselage (Left/Right) End Fittings







Embraer Service Bulletins Supporting the Use of SHM Solutions

DATE: 07/May/2013 SB No.: 190-00-0027

EMBRAER

SERVICE BULLETIN

GENERAL - STRUCTURAL HEALTH MONITORING SYSTEM (BASED ON CVM TECHNOLOGY) INSTALLATION IN THE WING STRUCTURE

DATE: 10/Jun/2013 SB No.: 190-00-0028

EMBRAER

SERVICE BULLETIN

GENERAL - STRUCTURAL HEALTH MONITORING SYSTEM (BASED ON CVM AND LW TECHNOLOGY) INSTALLATION IN THE FORWARD FUSELAGE STRUCTURE

DATE: 27/Jun/2013 SB No.: 190-00-0029

EMBRAER

SERVICE BULLETIN

GENERAL - STRUCTURAL HEALTH MONITORING SYSTEM (BASED ON CVM AND LW TECHNOLOGY) INSTALLATION IN CENTRAL FUSELAGE II STRUCTURE

Produce certification data package to allow SHM solutions on Embraer aircraft

Fuselage Components – CVM Performance Tests

Completion of Specimen Conformity Checks and Test Witness

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POD Assessment Using One-Sided Tolerance Interval

- **Interval to cover a specified proportion of a population distributed with a given confidence – related to measures of process capability**
- **One-sided Tolerance Interval – estimates the upper bound which should contain a certain percentage of all measurements in the population with a specified confidence**
- **Since it is based on a sample of the entire population (n data points), confidence is less than 100%. Thus, it includes two proportions:**
  - ➢ **Percent coverage (90%)**
  - ➢ **Degree of confidence (95%)**
- **The reliability analysis becomes one of characterizing the distribution of flaw lengths and the cumulative distribution function is analogous to a Probability of Detection (POD) curve:**

$$TI = X \pm (K_{n,\gamma,\alpha})(S) \qquad \text{[log scale calculation]}$$

- **Interested in a 1-tailed interval (utilize "+" in equation); upper limit of TI. Uncertainty in knowing the true mean and population variance requires that the estimate of the range of values encompassing a given percentage of the population must increase to compensate.**

$\overline{X}$

CVM Validation – Data Analysis Using One-Sided Tolerance Intervals

- **Crack detection based on PM-200 “Green Light” – “Red Light” results**
- **Data captured is the crack length at the time when CVM provided permanent (unloaded) detection**
- **Reliability analysis – cumulative distribution function provides maximum likelihood estimation (POD)**
- **One-sided tolerance bound for various flaw sizes:**

$$POD_{95\%\ Confidence} = \overline{X} + (K_{n,\ 0.95,\ \alpha})\ (S)$$

X = Mean of detection lengths

K = Probability factor (~ sample size, confidence level)

S = Standard deviation of detection lengths

n = Sample size

α = Detection level

γ = Confidence level

POD Calculations - One-Sided Tolerance Interval

POD Determined from CVM Response Data

CVM Crack Detection Data (0.040" th)

Bare Metal		Over Primer	
Flaw size (inch)	Log (flaw size)	Flaw size (inch)	Log (flaw size)
0.003	-2.52	0.002	-2.70
0.007	-2.15	0.007	-2.15
0.002	-2.70	0.010	-2.00
0.030	-1.52	0.009	-2.05
0.009	-2.05	0.004	-2.40
0.005	-2.30	0.006	-2.22
0.004	-2.40	0.010	-2.00
0.002	-2.70	0.009	-2.05
0.014	-1.85	0.011	-1.96
0.005	-2.30	0.007	-2.15
0.013	-1.89		
0.032	-1.49		

Statistic Estimates on Log Scale

Statistic	Over Bare metal	Over Primer
Mean	-2.1566	-2.1679
Stnd deviation	0.40889	0.22809

POD Detection Levels
(ɣ = 95%, n = 12 for bare, n=10 for primer)

Detection level $(1-\alpha)$	$K_{n,0.95,\alpha}$		$\overline{X} + K_{n,0.95,\alpha} \cdot S$ (log scale)		Flaw size in inches	
	bare	primer	bare	primer	bare	primer
0.75	1.366	1.465	-1.598	-1.834	0.025	0.015
0.90	2.210	2.355	-1.253	-1.631	0.056	0.023
0.95	2.736	2.911	-1.038	-1.504	0.092	0.031
0.99	3.747	3.981	-0.624	-1.260	0.237	0.055
0.999	4.900	5.203	-0.153	-0.981	0.703	0.104

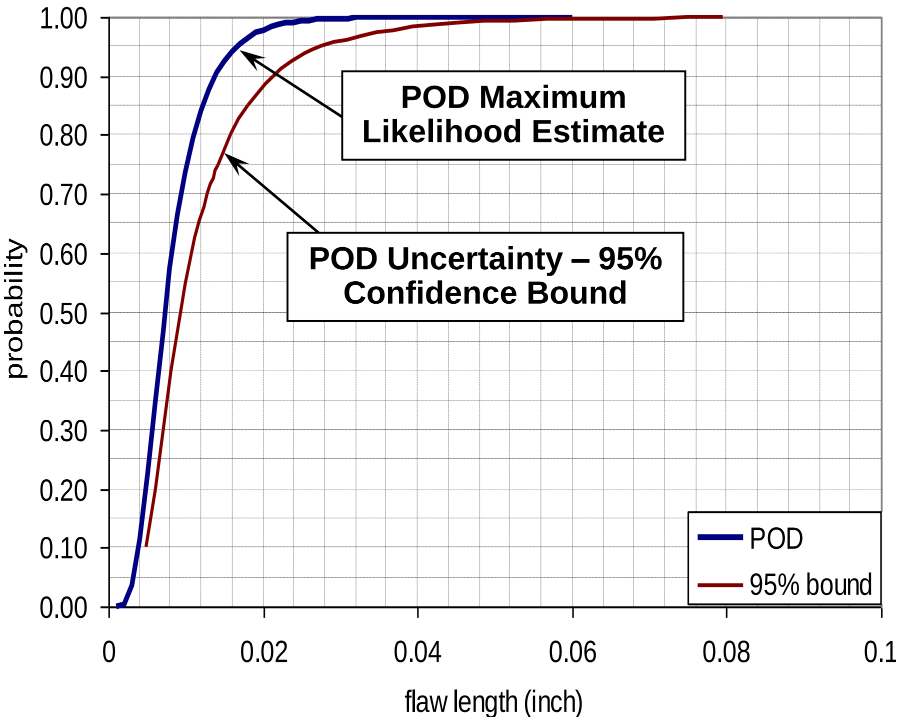
$$\text{POD}_{\text{(Max Likelihood Est)}} = \frac{1}{xS\sqrt{2\pi}} \, EXP \left(\frac{-(ln(x)-\overline{X})^2}{2S^2} \right)$$

It is possible to calculate a one sided tolerance bound for various percentile flaw sizes - find factors $K_{n,\gamma,\alpha}$ to determine the confidence ɣ such that at least a proportion (α) of the distribution will be less than *X* + ($K_{n,\gamma,\alpha}$)S where *X* and *S* are estimators of the mean and the standard deviation computed from a random sample of size *n*

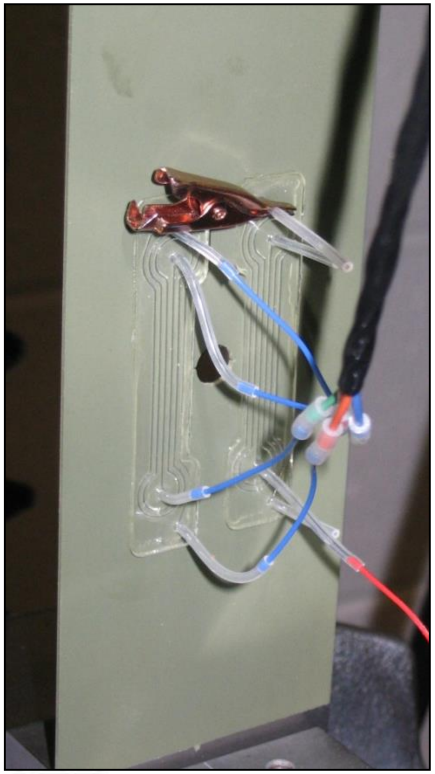
CVM - Quantified Probability of Crack Detection for a Range of Variables

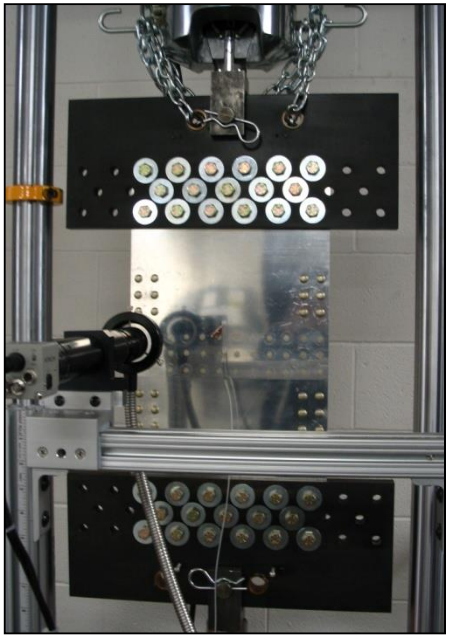
Test Scenarios:

Material	Thickness	Coating
2024-T3	0.040”	bare
2024-T3	0.040”	primer
2024-T3	0.071”	primer
2024-T3	0.100”	bare
2024-T3	0.100”	primer
7075-T6	0.040”	primer
7075-T6	0.071”	primer
7075-T6	0.100”	primer



Cumulative Distribution Function of Detectable Flaw Lengths (0.040” th. primer panels)





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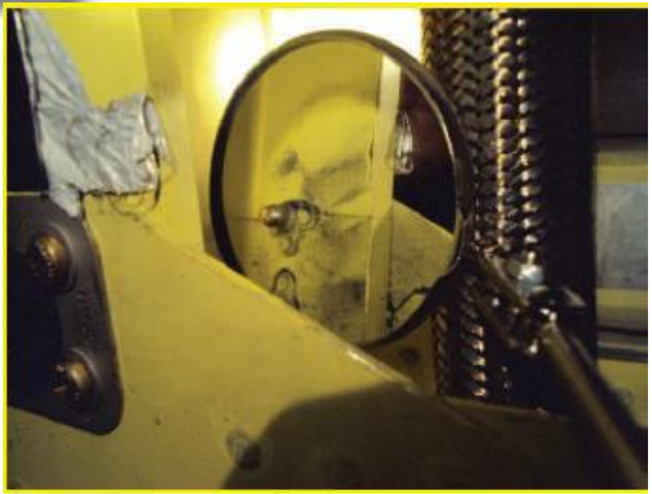
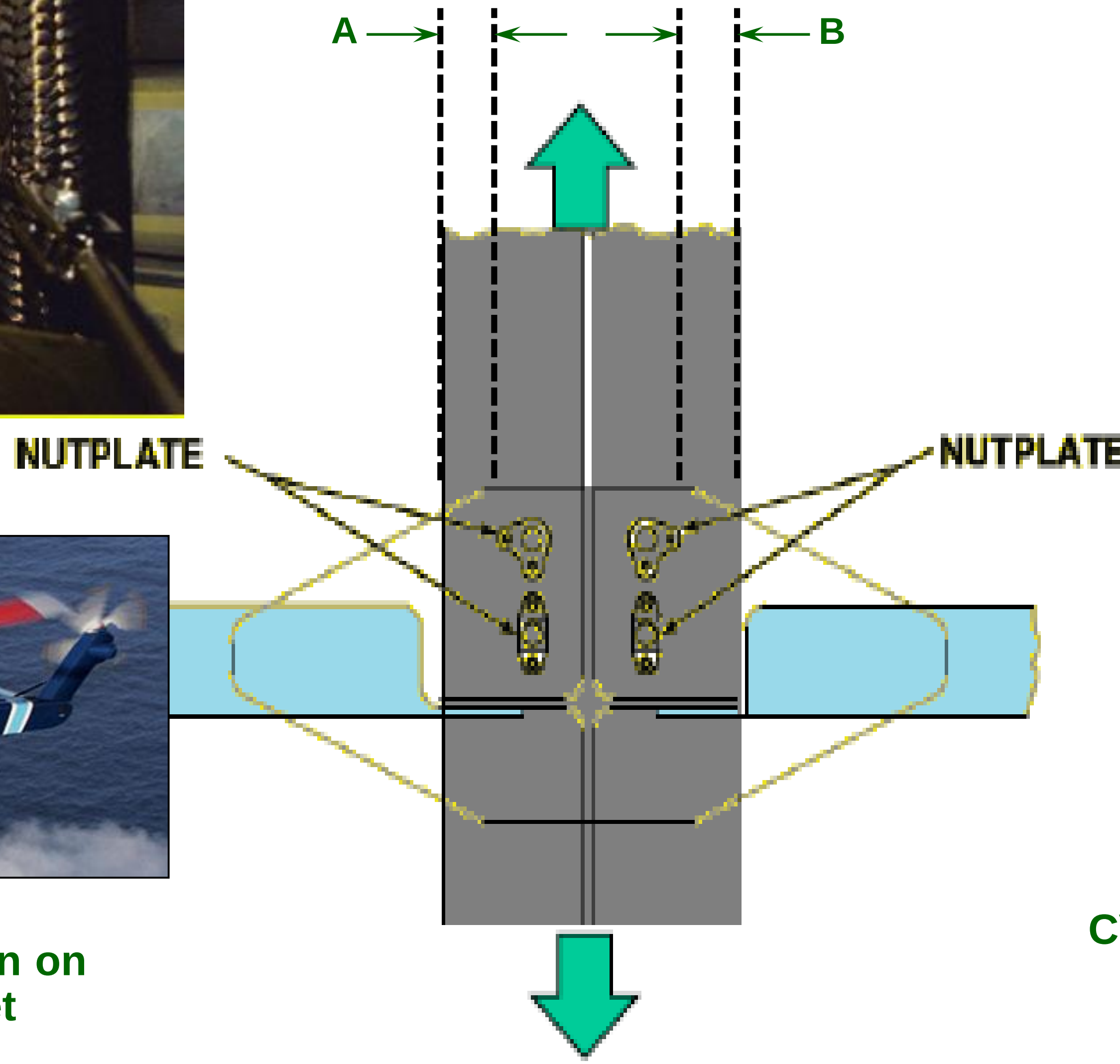
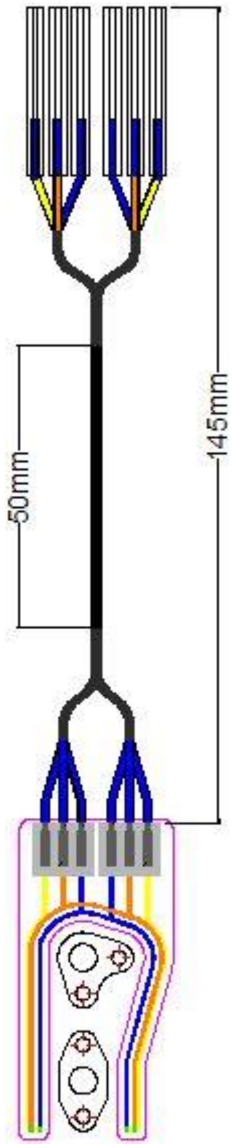
Comparative Vacuum Monitoring System - Local SHM of Cracks Emanating from Fastener and Nutplate Holes



Inner Cap

Local CVM Crack Monitoring Application on S-92 Frame Gusset





CVM Sensor Design

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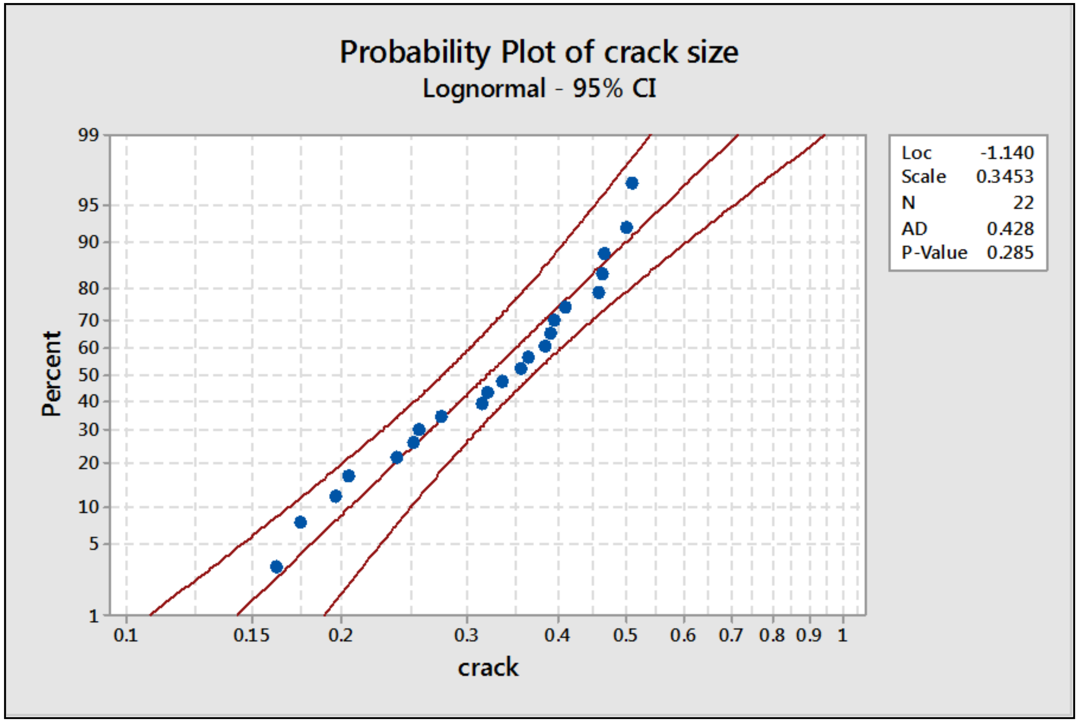
POD Assessment Using One-Sided Tolerance Interval

- **Assume that the distribution of flaws is such that the logarithm of the lengths (strictly positive sizes) has a Gaussian distribution (log-normal distribution)**
- **Validity depends on distribution on the flaw lengths at which detection is first made – lognormal distribution plots on straight line with data clustered near 50th percentile**
- **Anderson-Darling test requires P-value > 0.05**

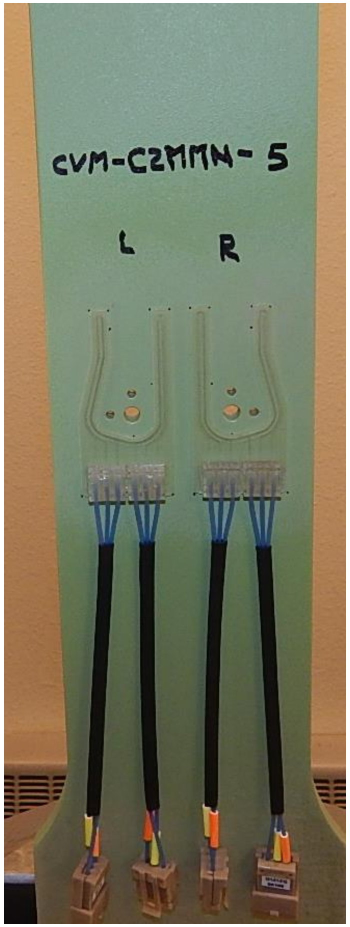


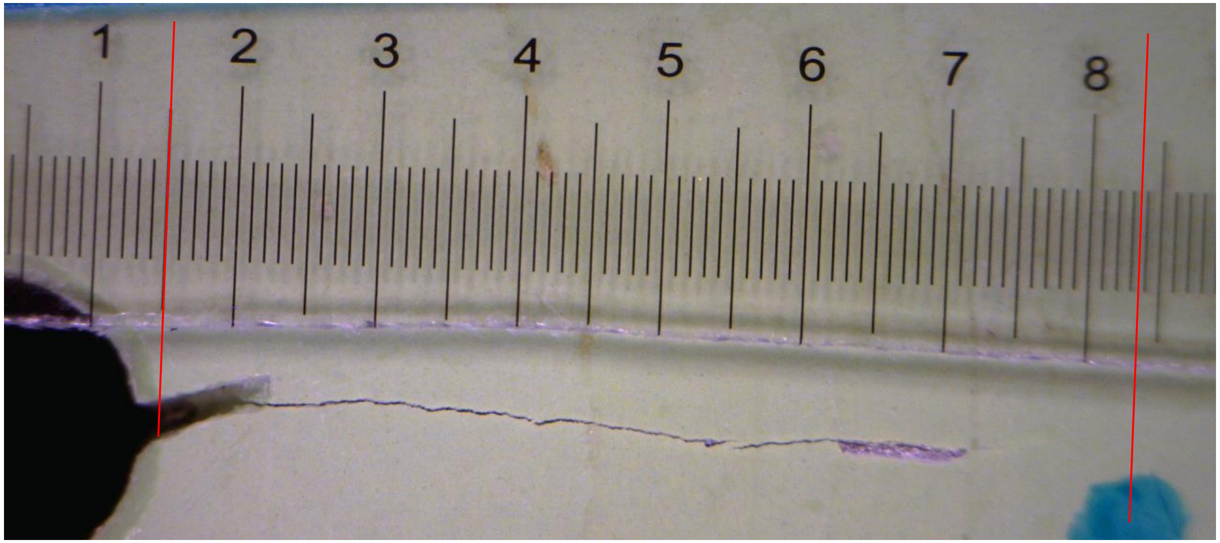
Lognormal Distribution

CVM Performance Testing – Mickey Mouse Nut Plate

Sample Data Recorded for Each Test Specimen

Crack Length = 6.85 mm = 0.270 in
1dCVM = Gallery 1 = 4.2
2dCVM = Gallery 2 = 1.1
SIM2 = 16,250 Pa
Cycles = 20,278





Specimen CVM-C2MMN-5, Right Sensor – Crack Measurements

CVM Performance Testing Results – MM Plate
OSTI Probability of Detection Calculation

CVM Crack Detection Data

Distance from Hole to Sensor Edge	Total Crack Length a (in)	Crack Length Under Sensor at CVM Detection a (in)	Log of Crack Length at CVM Detection a (In)
0.13	0.268	0.138	-0.860120914
0.106	0.217	0.111	-0.954677021
0.119	0.299	0.180	-0.744727495
0.123	0.248	0.125	-0.903089987
0.113	0.248	0.135	-0.869666232
0.14	0.382	0.242	-0.616184634
0.096	0.374	0.278	-0.555955204
0.101	0.321	0.220	-0.657577319
0.124	0.270	0.146	-0.835647144
0.097	0.226	0.129	-0.88941029
0.106	0.287	0.181	-0.742321425
0.100	0.321	0.221	-0.655607726
0.110	0.279	0.169	-0.772113295
0.112	0.280	0.168	-0.774690718
0.095	0.409	0.314	-0.503070352
0.127	0.325	0.198	-0.70333481
0.114	0.333	0.219	-0.659555885
0.134	0.327	0.193	-0.714442691
0.081	0.258	0.177	-0.752026734

Average Crack Length at CVM Detection =	0.187
Standard Deviation of CVM Detection =	0.053
Average Dist From CVM Edge to Hole Edge =	0.112

Statistic Estimates on Log Scale

Statistic	Value (in.)	Value in Linear Scale
Mean (X)	-0.745	0.187
Stnd Deviation (S)	0.121325291	0.05348766

POD Detection Levels
(ɣ = 95%, n = 19)

Flaw Size: POD = X + K(S) =	0.310

Overall POD (with sensor offset) = 0.422”

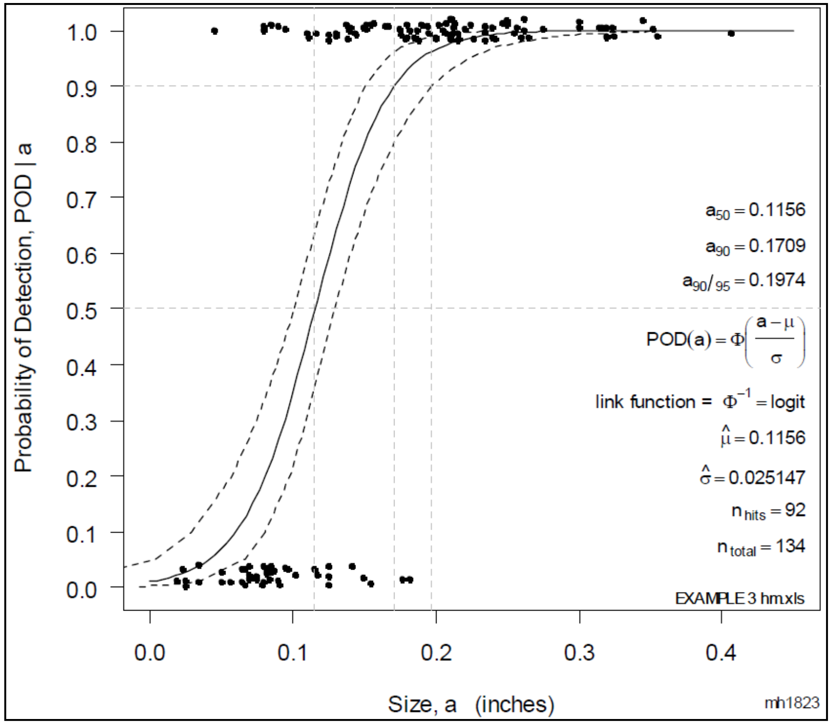
POD Analysis Using Standard Hit-Miss Methodology (Mil-HDBK-1823)

- An efficient use of the binary (***hit/miss***) data is to produce an underlying mathematical relationship between POD and size
- Logistic Regression ***Hit/Miss* POD model** is used to analyze binary (detect/no detect) data

$$\ln[POD(a)/(1 - POD(a))] = \alpha + \beta[\ln(a)]$$

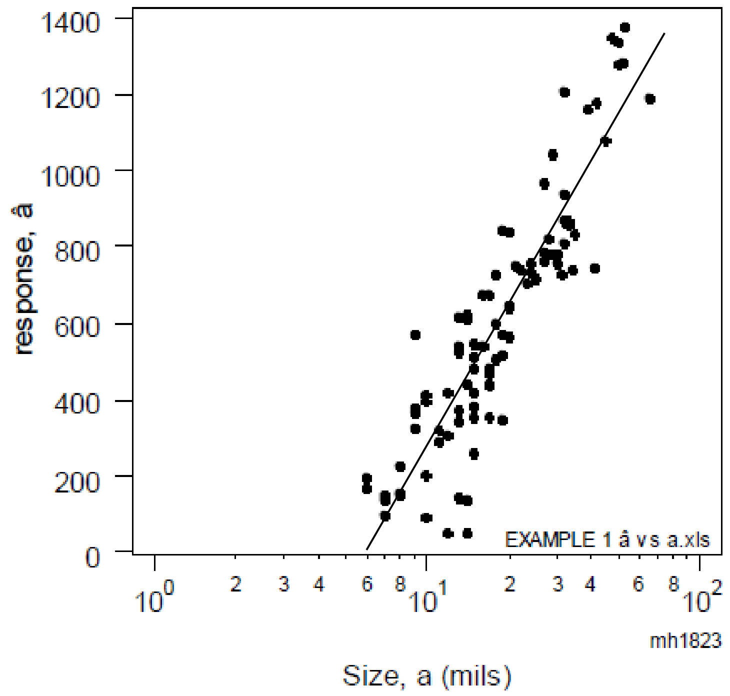
Where "a" is the flaw size and α and β are estimated by maximum likelihood estimates

- Assumption is for no variation in equipment or procedures
- Assumption is all critical factors are controlled in the testing so no need for additional φ·f to describe other factors on the RHS of log regression formula
- Each flaw is either detected or not detected – best estimate for POD(a) is either 0 or 1; use a range of flaws to determine the α and β that maximize the likelihood of the particular sequence of 0's (misses) and 1's (detects) that were observed.



POD Analysis Using Standard a vs. â Methodology (Mil-HDBK-1823)

- The SHM system must produce output for damage detection that can be reduced to a quantitative signal, ***â***
- Use of a critical SHM system response can contain more information, and the amplitude, ***â***, of the output makes it possible to extract other POD(a) estimates that could have narrower confidence bounds; ***â*** is the system output and ***a*** is the size of the damage (***â vs a*** POD Model)
- POD(a) depends on a reasonable ***â vs a*** model - data plot of *â vs log(a)* should reveal a linear relationship. Describes the expected response, ***â***, at any given size, a. Notice that it provides a reasonable summary of the data – the line is straight; the data are straight. The scatter is consistent and not wider at one end or the other.
- Must consider the S/N ratio which includes the scatter in the results (note similarity in OSTI)



Data Acquired for Hit-Miss and a vs. â POD Analyses

dCVM values vs fatigue crack lengths were acquired throughout testing - mechanical trends analysis to assess complete hit-miss & a vs. â profiles

Sikorsky Mickey Mouse Nut Plate CVM Sensor Performance Tests

Specimen	Eddy Current Crack Length at CVM (in)	Hit (1) or Miss (0)
CVM-C2MMN-1-L	0.138	1
CVM-C2MMN-1-R	0.111	1
CVM-C2MMN-2-L	0.180	1
CVM-C2MMN-2-R	0.125	1
CVM-C2MMN-3-L	0.135	1
CVM-C2MMN-3-R	0.242	1
CVM-C2MMN-4-L	0.278	1
CVM-C2MMN-5-L	0.220	1
CVM-C2MMN-5-R	0.146	1
CVM-C2MMN-6-L	0.129	1
CVM-C2MMN-6-R	0.181	1
CVM-C2MMN-7-L	0.081	0
CVM-C2MMN-7-L	0.120	0
CVM-C2MMN-7-L	0.152	0
CVM-C2MMN-7-L	0.183	0
CVM-C2MMN-7-L	0.195	0
CVM-C2MMN-7-L	0.195	0
CVM-C2MMN-7-L	0.221	0
CVM-C2MMN-7-L	0.243	0
CVM-C2MMN-7-L	0.272	1
CVM-C2MMN-7-L	0.306	1
CVM-C2MMN-7-R	0.059	0

Sikorsky Mickey Mouse Nut Plate CVM Sensor Performance Tests

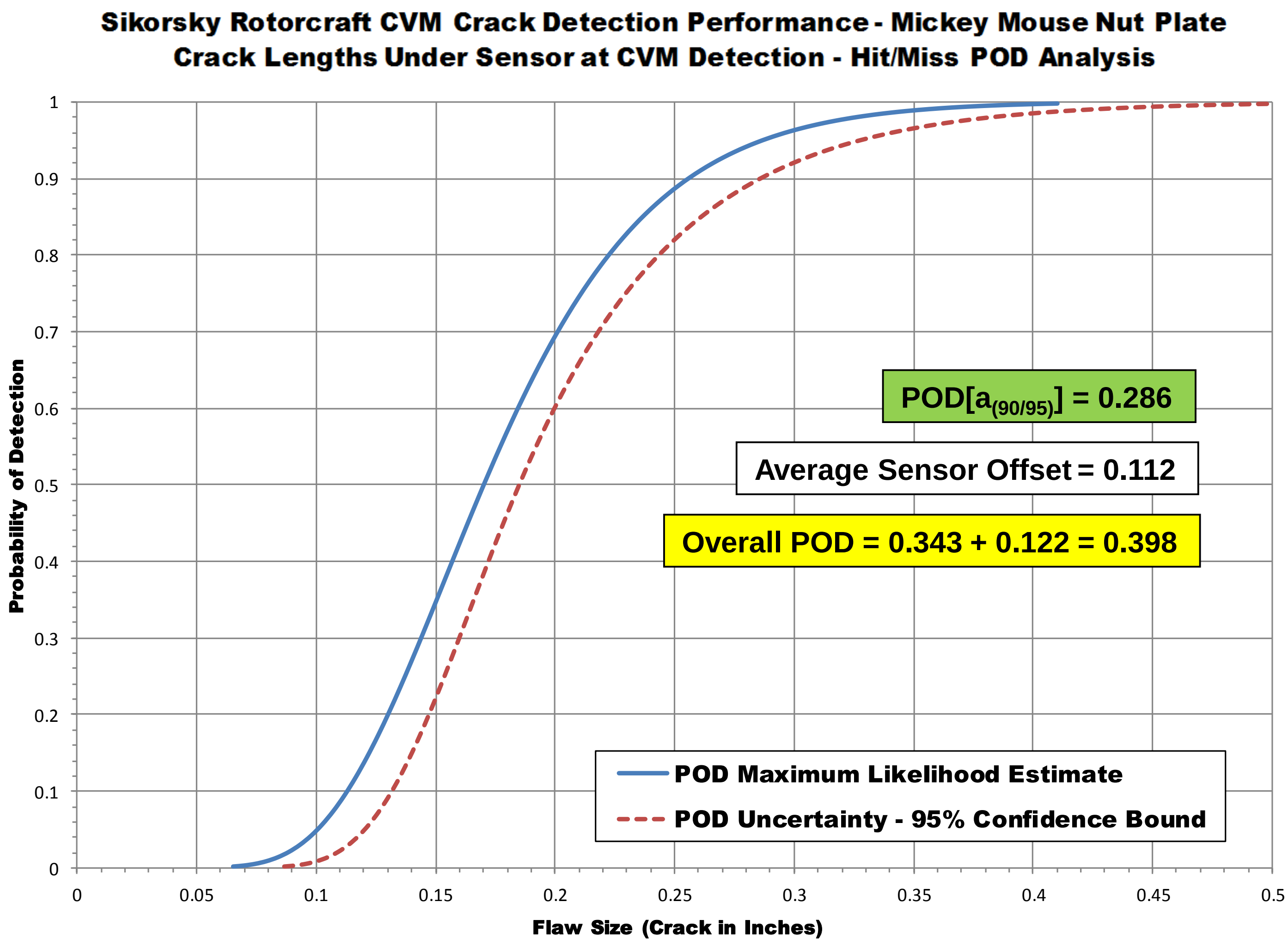
Specimen	Eddy Current Crack Length at CVM (in)	Hit (1) or Miss (0)
CVM-C2MMN-7-R	0.103	0
CVM-C2MMN-7-R	0.130	0
CVM-C2MMN-7-R	0.134	0
CVM-C2MMN-7-R	0.169	1
CVM-C2MMN-7-R	0.181	1
CVM-C2MMN-7-R	0.189	1
CVM-C2MMN-7-R	0.217	1
CVM-C2MMN-7-R	0.244	1
CVM-C2MMN-7-R	0.276	1
CVM-C2MMN-8-L	0.112	0
CVM-C2MMN-8-L	0.136	0
CVM-C2MMN-8-L	0.164	0
CVM-C2MMN-8-L	0.168	1
CVM-C2MMN-8-L	0.207	1
CVM-C2MMN-8-L	0.242	1
CVM-C2MMN-8-L	0.262	1
CVM-C2MMN-8-R	0.157	0
CVM-C2MMN-8-R	0.179	0
CVM-C2MMN-8-R	0.210	0
CVM-C2MMN-8-R	0.222	0
CVM-C2MMN-8-R	0.246	0
CVM-C2MMN-8-R	0.275	0

Sikorsky Mickey Mouse Nut Plate CVM Sensor Performance Tests

Specimen	Eddy Current Crack Length at CVM (in)	Hit (1) or Miss (0)
CVM-C2MMN-8-R	0.314	1
CVM-C2MMN-9-L	0.111	0
CVM-C2MMN-9-L	0.131	0
CVM-C2MMN-9-L	0.149	0
CVM-C2MMN-9-L	0.182	0
CVM-C2MMN-9-L	0.186	0
CVM-C2MMN-9-L	0.198	1
CVM-C2MMN-9-L	0.233	1
CVM-C2MMN-9-L	0.273	1
CVM-C2MMN-9-L	0.310	1
CVM-C2MMN-9-R	0.114	0
CVM-C2MMN-9-R	0.142	0
CVM-C2MMN-9-R	0.166	0
CVM-C2MMN-9-R	0.205	0
CVM-C2MMN-9-R	0.219	1
CVM-C2MMN-9-R	0.232	1
CVM-C2MMN-9-R	0.256	1
CVM-C2MMN-9-R	0.290	1
CVM-C2MMN-9-R	0.325	1
CVM-C2MMN-10-L	0.193	1
CVM-C2MMN-10-R	0.177	1

(65 data points)

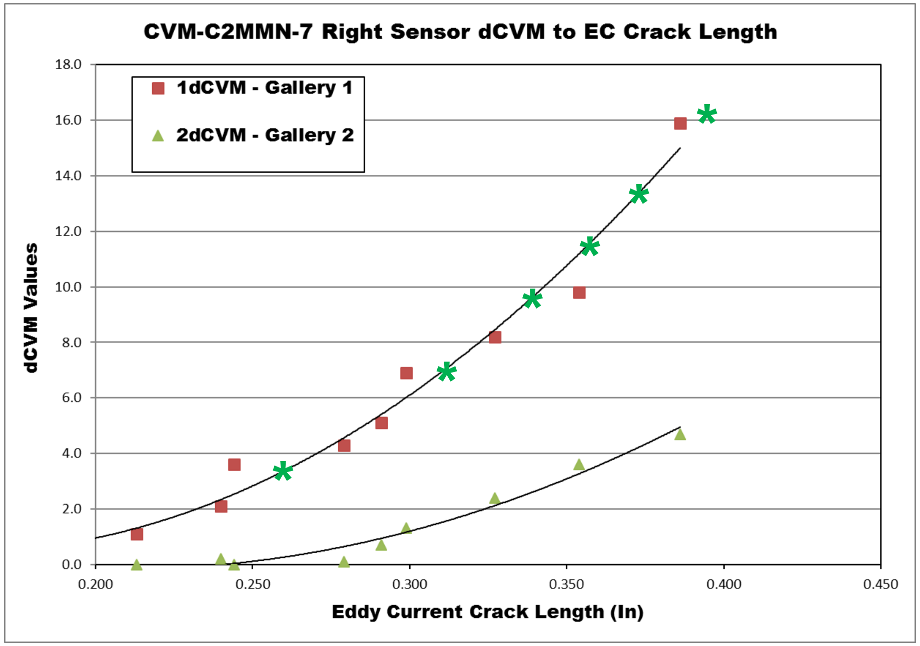
POD Analysis Using Standard Hit-Miss Methodology – MM Nutplate

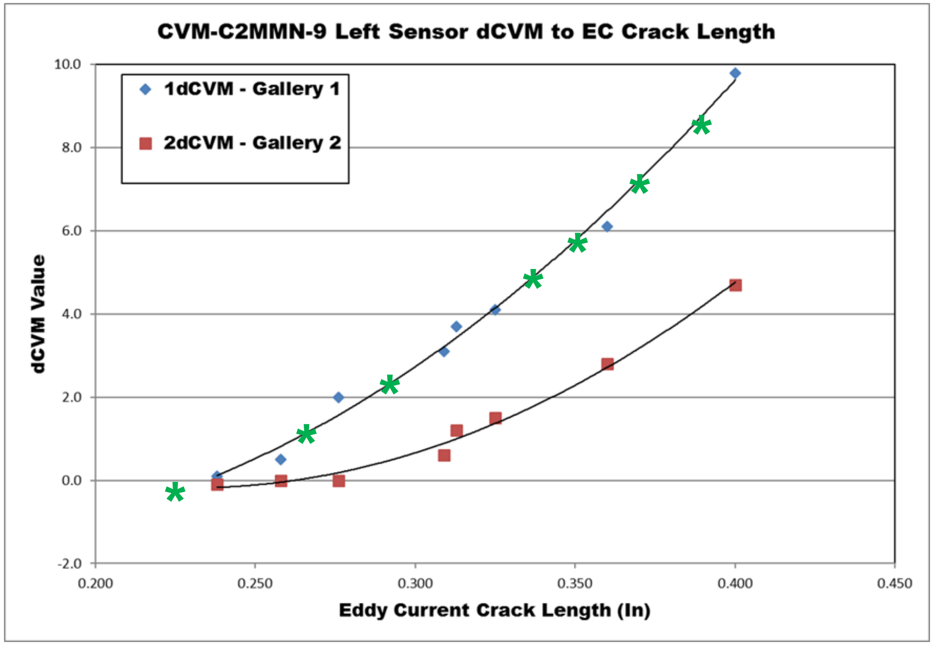


65 Acquired Hit/Miss Data Points Plus Extrapolated Hit/Miss Data Points on Either Side to Produce a Complete POD Curve Using Extreme Crack Lengths (High and Low)

POD Analysis Using Standard a vs. â Methodology (Mil-HDBK-1823)

- CVM system response data dCVM (*â*) vs. crack length (*a*) was acquired during testing that included measurements before, during and after SHM crack detection
- Convergence observed as additional data points were acquired by interpolating between the measured points in the dCVM vs Crack Length plots





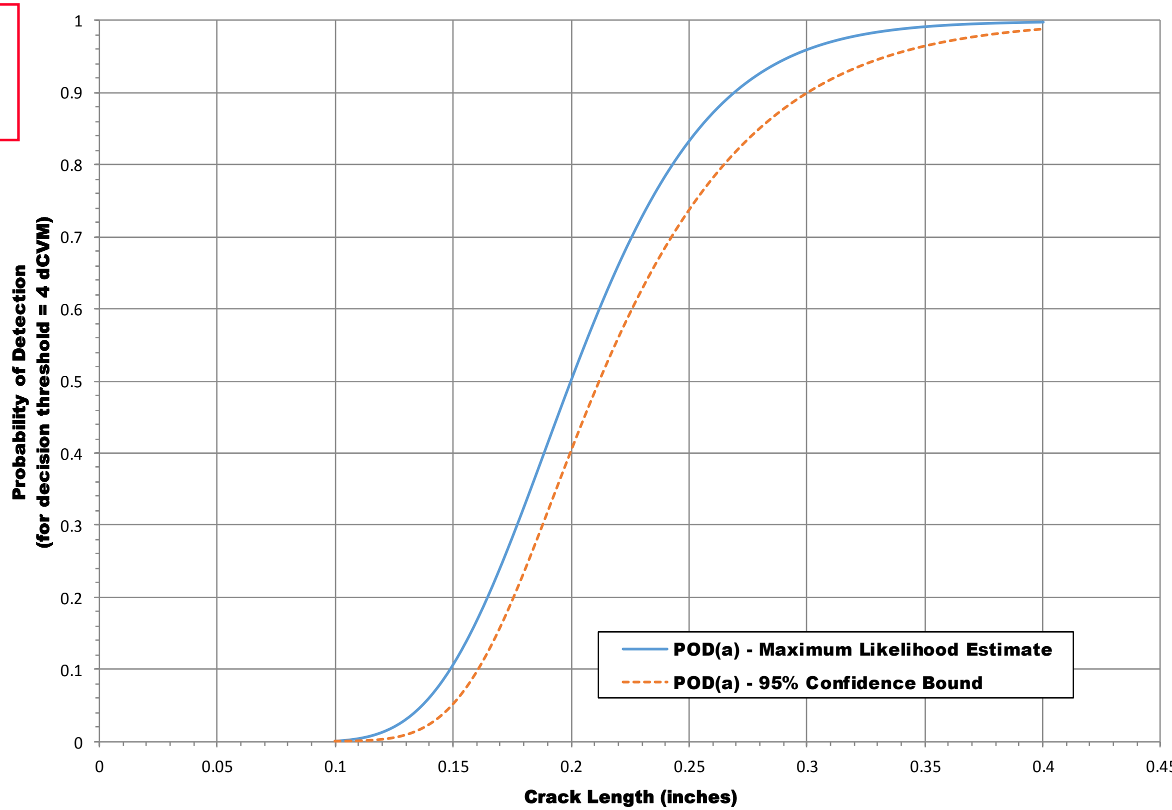
POD Analysis Using Standard a vs. â Methodology (Mil-HDBK-1823)

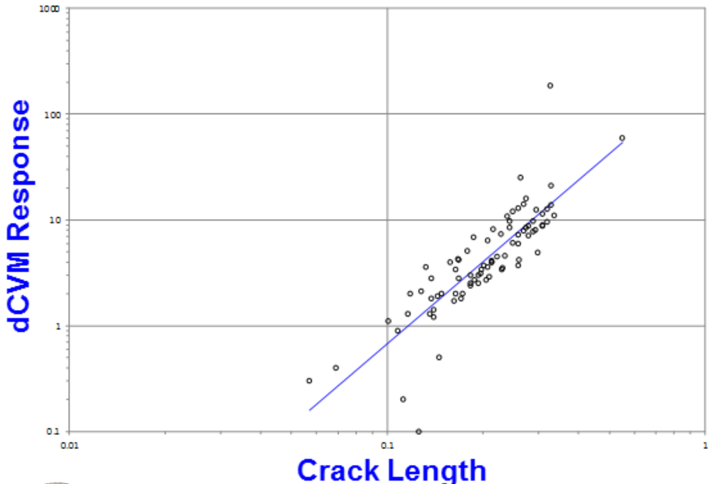
52 Acquired Data Points Plus 30 Extrapolated Data Points

$POD[a_{(90/95)}] = 0.300$

Average Sensor Offset = 0.112

Overall POD = 0.343 + 0.122 = 0.412

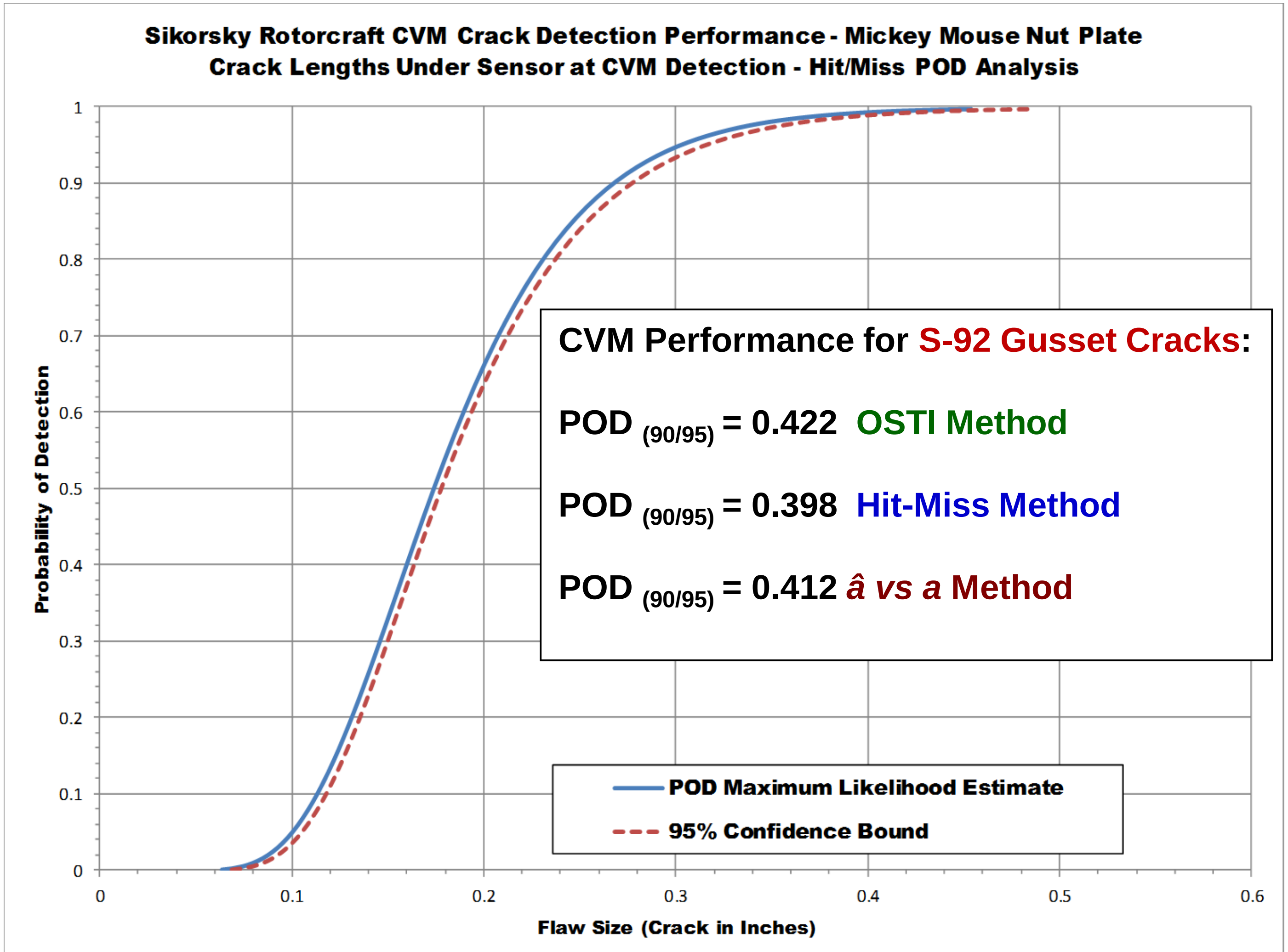




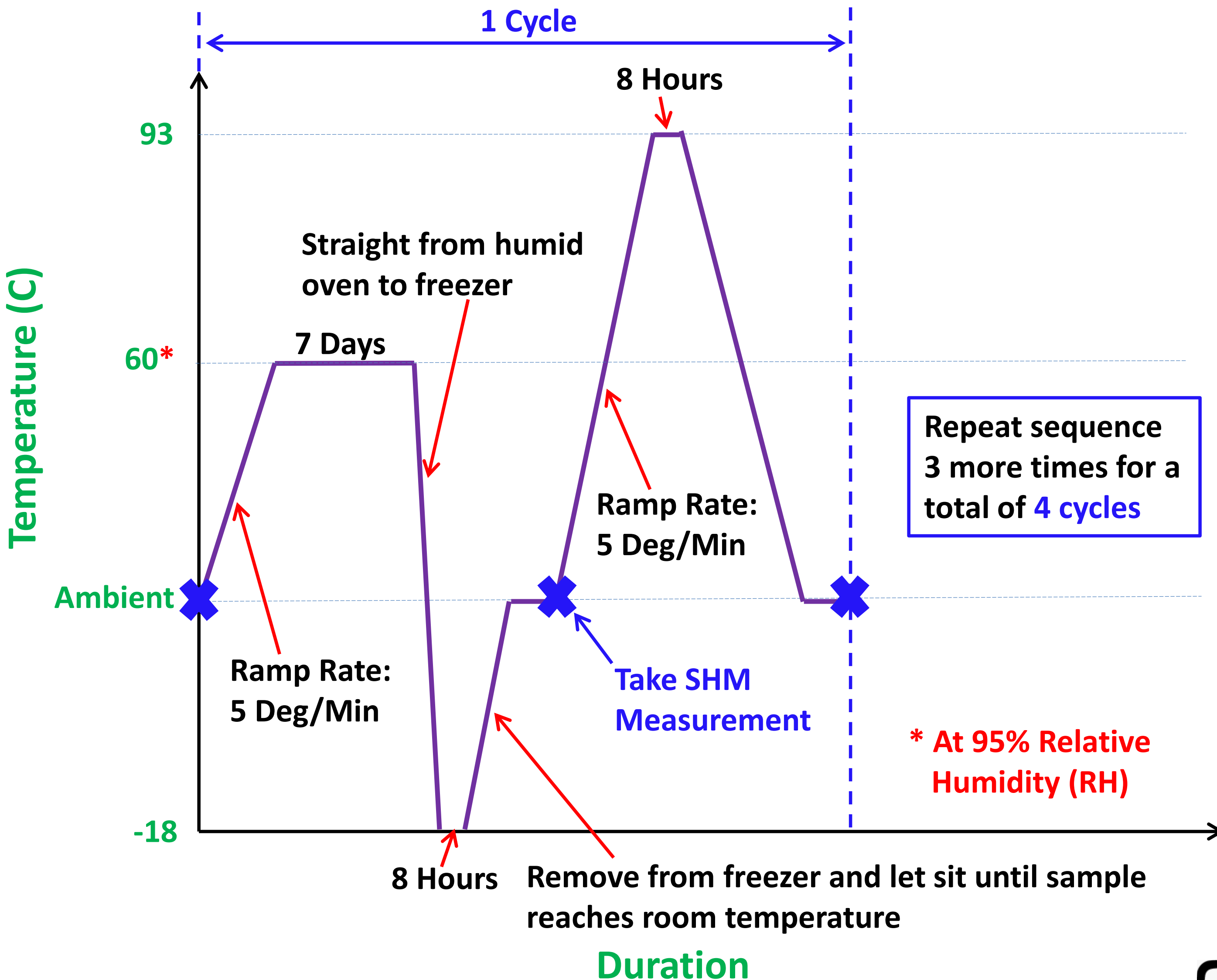
Data check – linear response on a log-log scale

Note: MM nutplate data

CVM Performance Testing Results –
Comparison of OSTI, Hit-Miss, and a vs. â Methodologies
MM Nutplate on S-92 Frame Gusset



Environmental Durability Performance Assessment for CVM and PZT Sensors



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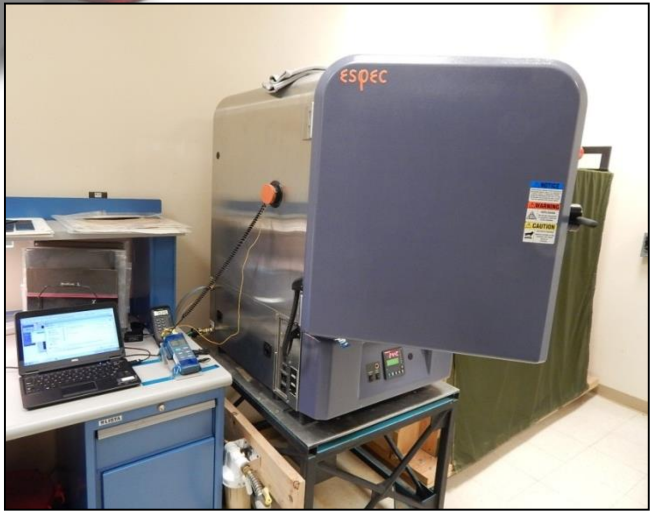
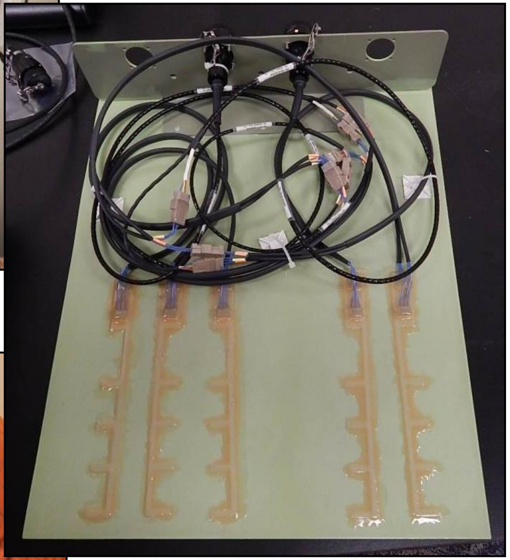
Environmental Tests – Hot-Wet-Freeze

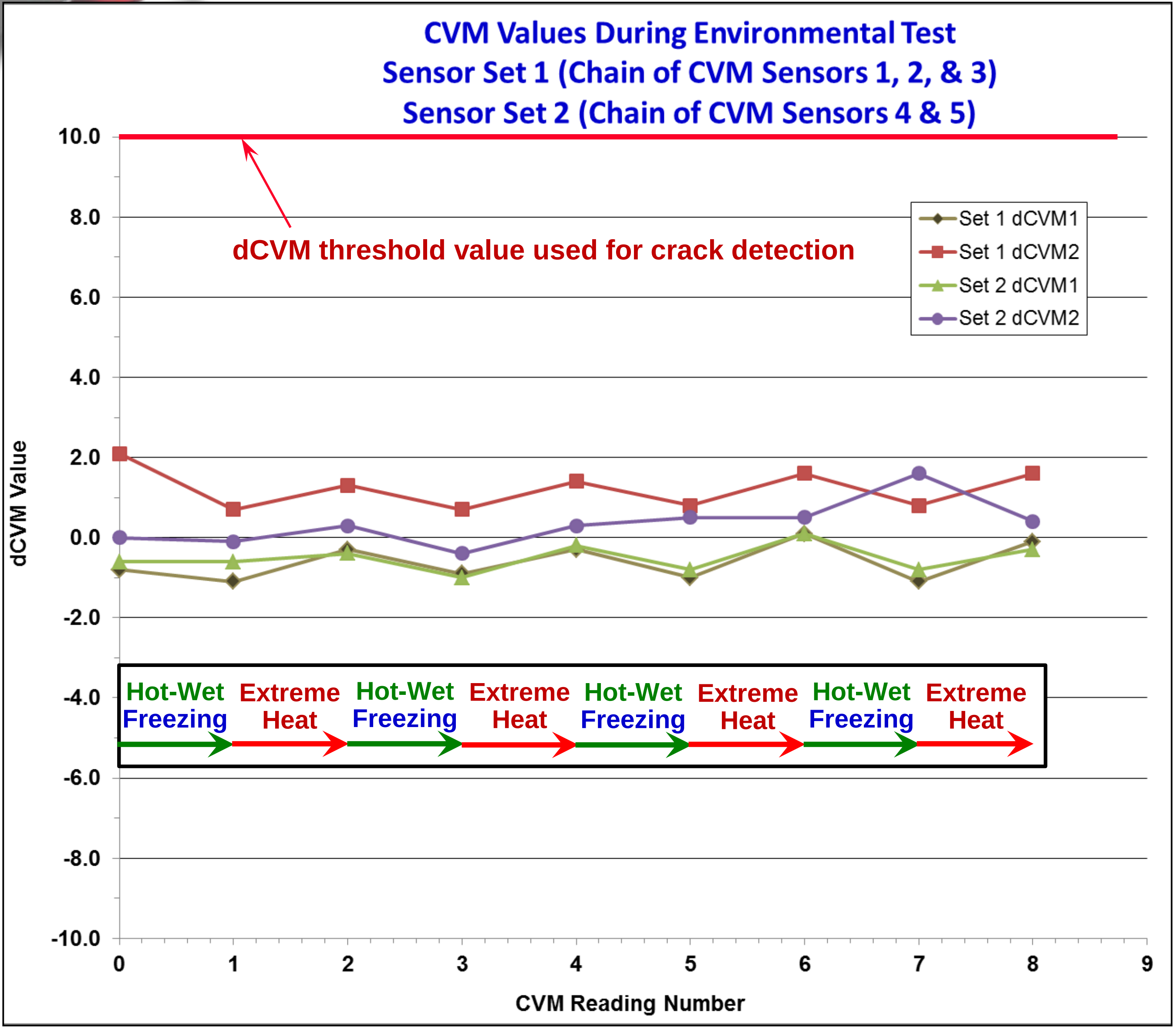


Loading Specimen in Temperature-Humidity Chamber


Loading Specimen into Freezer

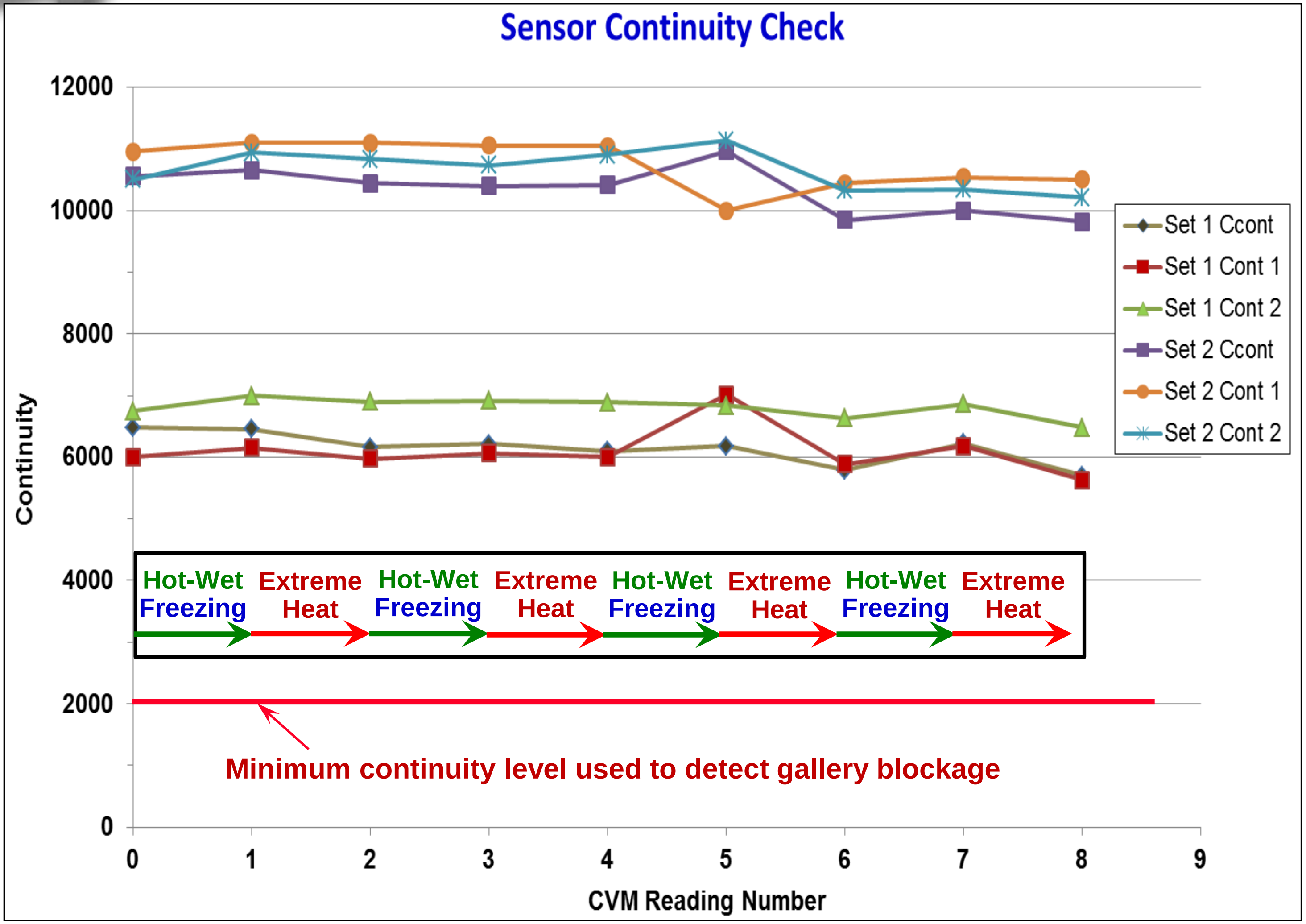
CVM Sensor Readings – Unchanged During Environmental Tests



Sensor readings during 40 day environmental tests remained small compared to threshold level required for crack detection:

- dCVM values ranged +/- 2.0; crack detection set for dCVM = 10.0
- Good durability of SHM system; no degradation
- Signal-to-noise (S/N) for crack detection is a minimum of 5 (most exceeded 20 in fatigue tests)
- Desired S/N for normal NDI operations is a minimum of 3

CVM Continuity – Unchanged During Environmental Tests

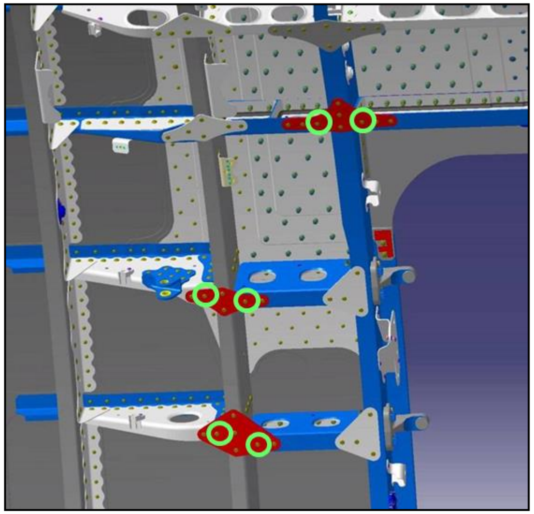


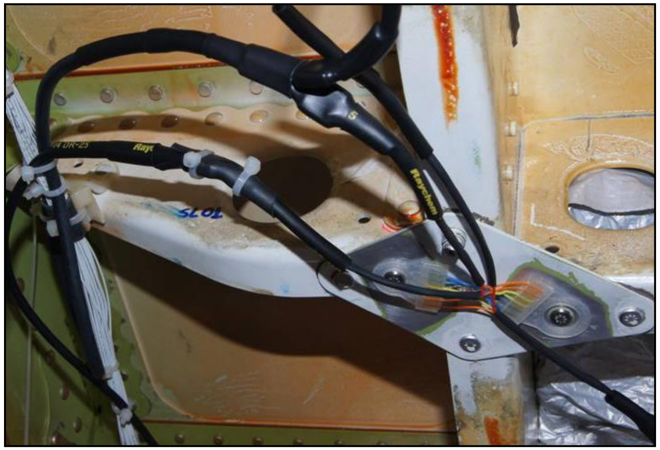
Sensor continuity measures for possible gallery blockage. During 40 day environmental tests, continuity remained large compared to lower threshold level that indicates blockage:

- **Continuity values ranged 6,000 to 12,000; minimum levels allowed Cont = 2,000**
- **Good durability of SHM system; no degradation**

CVM and PZT Flight Test Program

SHM Sensor Installation & Monitoring on Azul Airlines Fleet & Embraer 190 Flight Test Aircraft



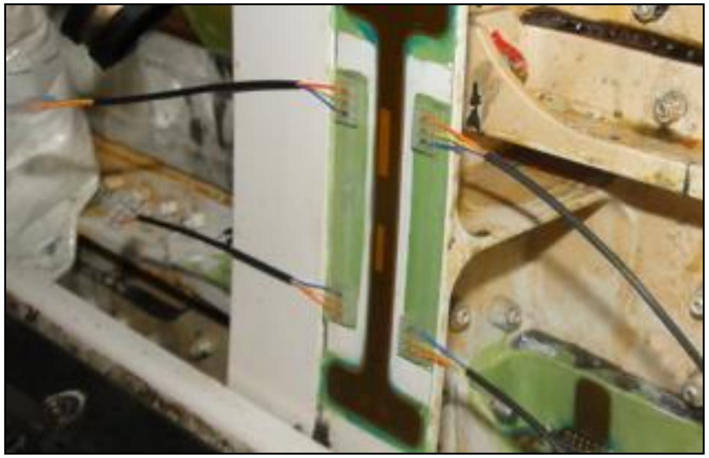


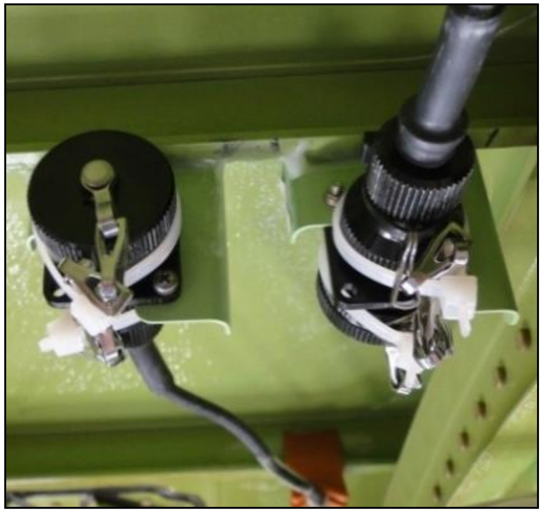
Embraer Application #1: CVM – Fwd Door Surround Brackets

CVM Flight Test Result – Aircraft PR-AYW

Installation Summary

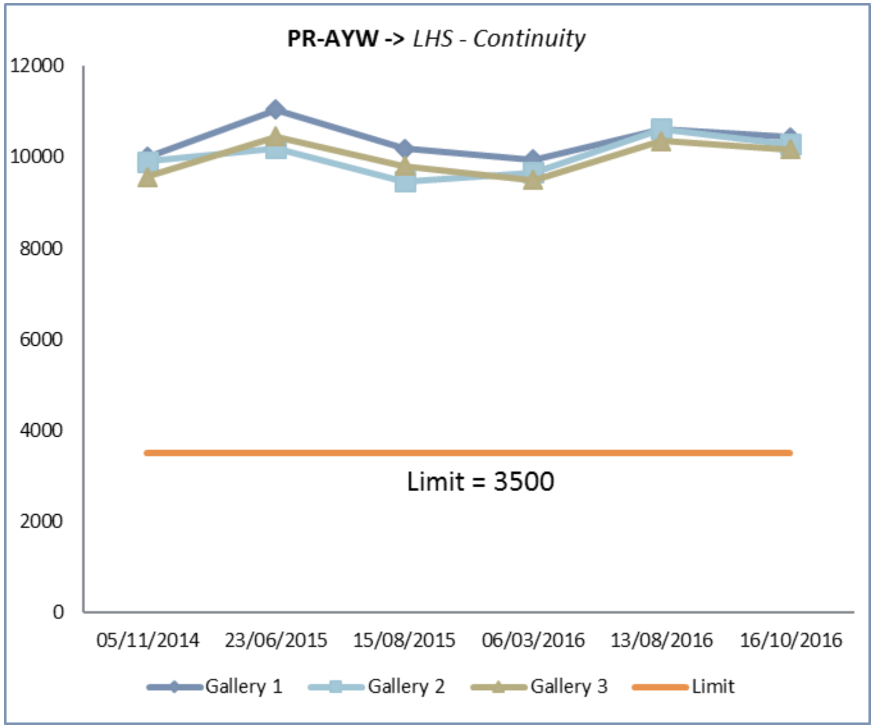
- **Date of Installation: Nov/2014**
- **Service Bulletin: SB190-00-0029**
- **Zone: Central Fuselage II**
- **One sensor mesh per side**
- **2 CVM sensors per mesh**



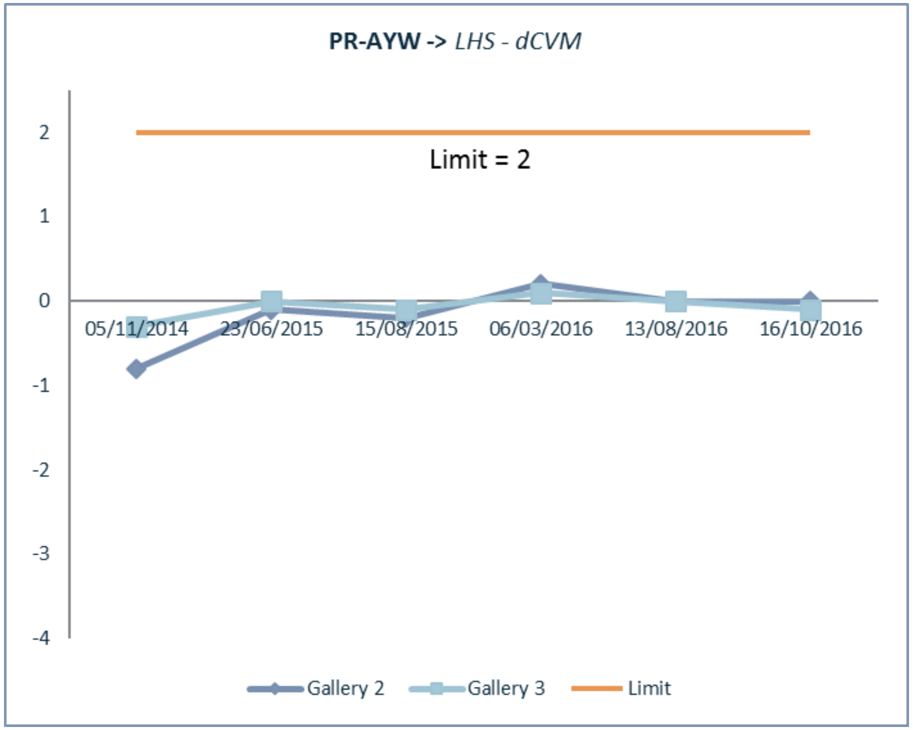


CVM Flight Test Result – Aircraft PR-AYW

Consistent CVM Data Over Two Years of Flights (LHS of Aircraft)



Continuity (flow) Much Above Lower Threshold



dCVM (detection) Much Below Upper Threshold

Validation of CVM Sensors for SHM Crack Detection

- CVM sensor detects cracks in the component it is adhered to
- Inspection process and diagnosis is fully automated – rapid and remote
- Early detection = less costly repairs
- CVM system is fail-safe (inert sensors produce an alarm)
- Lab performance & multi-year flight test program completed
- Integration of CVM in NDT Manuals
- AMOC for SBs and ADs – safety driven use is achieved in concert with OEMS & regulatory agencies
- Specific application-oriented studies have led to approval for routine use & spawned larger, families of SHM applications
- Approval through regulatory framework established with Sandia-Boeing program

Conclusions on Use of SHM Approach

- Recent advances in health monitoring methods have produced viable SHM systems for on-board aircraft inspections
- Sensors must be low-profile, easily mountable, durable, reliable & fail-safe
- Calibration for flaw identification (damage signatures) is key
- Reliability/POD assessments depends on sensor system, flaw type/orientation and application
- Ease of use allows for more frequent inspections – minimize repair costs through early detection of structural damage
- SHM can decrease maintenance costs (NDI man-hours; disassembly) & allow for condition-based maintenance
- SHM may be a desirable alternative to meet new inspection requirements or to address unexpected phenomena
- AMOC for SBs and ADs or STCs – safety driven use is achieved in concert with OEMS & regulatory agencies

"SHM is the next level of NDT = it's coming soon"

Agradeço a vossa atenção. Por favor fazer quaisquer perguntas que você pode ter.

Adoption of SHM Systems to Address Families of Aircraft Integrity Checks

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Tom Rice
FAA Airworthiness Assurance Center
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Adoption of SHM Systems to Address Families of Aircraft Integrity Checks

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Brazil

Structural Health Monitoring (SHM) is the next adaptation of inspection technology. Reliable SHM systems can automatically process data, assess structural condition and signal the need for human intervention. The FAA has funded sensor development and SHM system validation programs over the years to produce quantitative assessments for sensitivity, durability, and repeatability. This has provided a database on SHM performance and laid the foundation for implementation of SHM solutions. Several aircraft manufacturers (OEMs) have embraced SHM with some even incorporating it into their NDT Manuals. This paper presents an OEM-Sandia Labs-regulator effort to move SHM into routine use for aircraft maintenance procedures. This program addressed formal SHM technology validation and certification issues so that the full spectrum of concerns, including design, deployment, performance and certification is appropriately considered. The Airworthiness Assurance NDI Validation Center (AANC) at Sandia Labs, in conjunction with Embraer, Azul Airlines, and Agencia Nacional de Aviação Civil (ANAC) completed a study to develop and carry out a certification process for SHM. By conducting assessments of families of aircraft applications, this effort focused on widespread implementation of SHM for many, similar structures. Validation tasks were designed to address the SHM equipment, the health monitoring task, the resolution required, the sensor interrogation procedures, the conditions under which the monitoring will occur, and the potential inspector population. An important element in developing SHM validation processes is a knowledge of the structural and maintenance characteristics that may impact the operational performance of an SHM system. In this study, statistical methods were applied to laboratory and flight test data to derive Probability of Detection (POD) values for SHM sensors in a fashion that agrees with current NDI requirements. This program is helping to establish an optimum OEM-airline-regulator process and determining how to safely adopt SHM solutions. Statistical methods applied to test data quantified sensor performance while close consultation with regulatory agencies was used to produce a process that is acceptable to both the aviation industry and ANAC. The activities conducted in this program demonstrated the feasibility of routine SHM usage and supported the development of regulatory guidelines and advisory materials to reliably and safely implement SHM systems. Formal SHM validation will allow the aviation industry to confidently make informed decisions about the proper utilization of SHM.