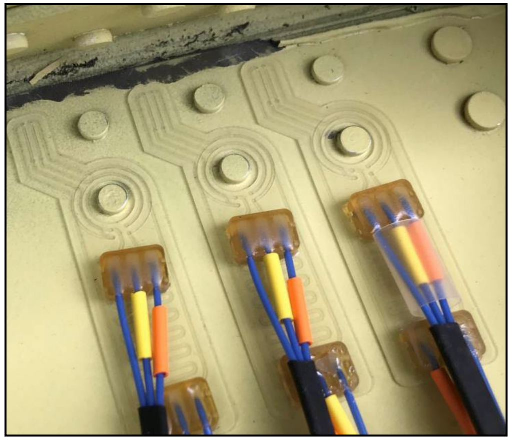
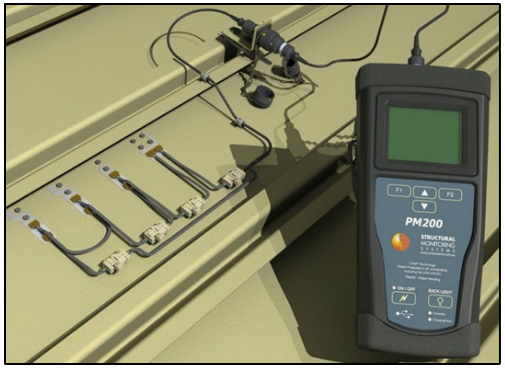
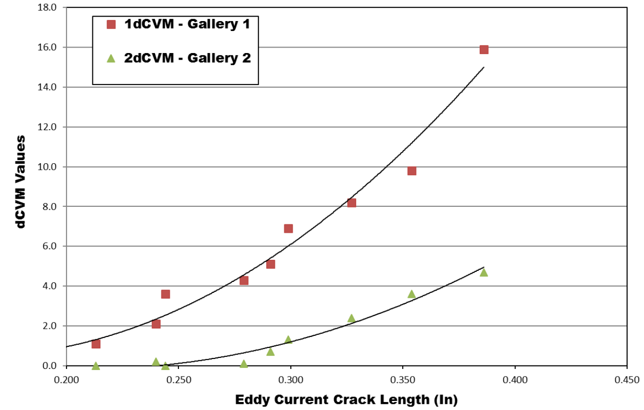
Update on CVM Usage to Improve Aircraft Maintenance Programs







Dennis Roach, Ph.D.
Senior Technical Fellow

Trevor Lynch-Staunton
Chief Technical Officer

Structural Monitoring Systems

STRUCTURAL MONITORING SYSTEMS plc

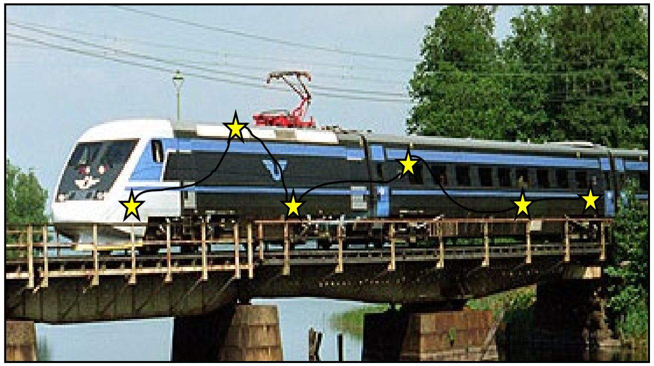
ANODYNE ELECTRONICS MANUFACTURING CORP.

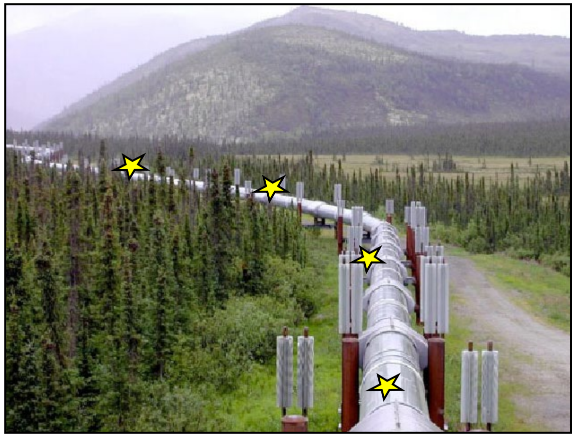
CVM SMART SENSOR SOLUTIONS

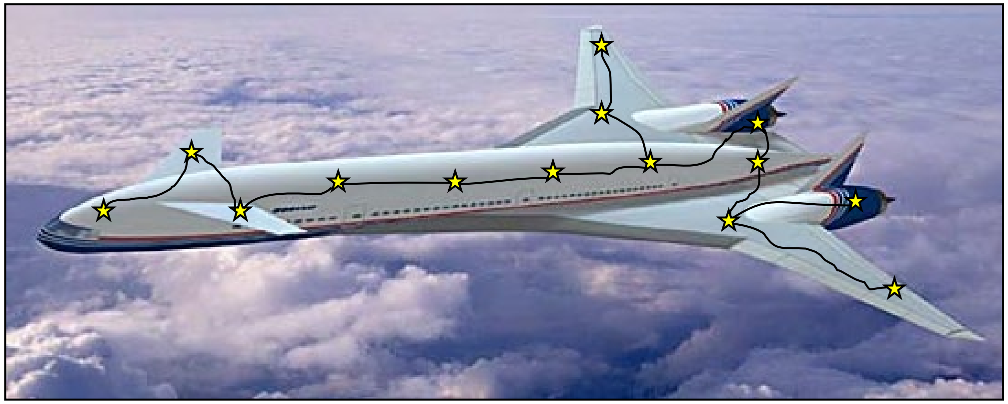
Distributed Sensor Networks for Structural Health Monitoring

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







SHM = In-situ NDI (has guided validation/certification efforts)

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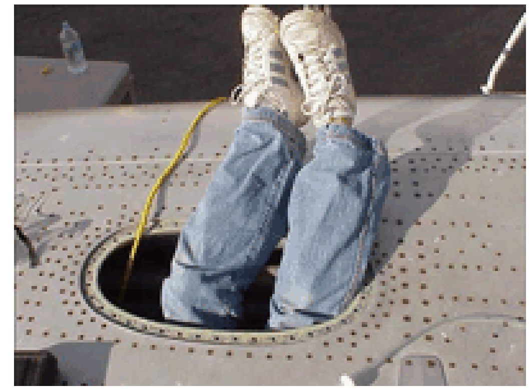
SHM Solutions & NDI Challenges

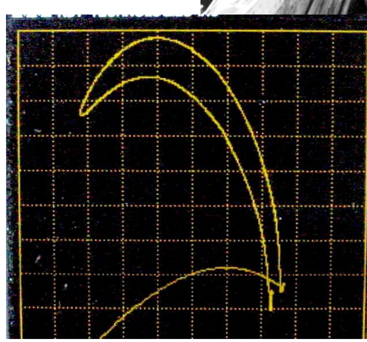
Difficulty in loads assignment, stress and fatigue calculations produces demands on NDI - "You want me to find a flaw where, and how small??"

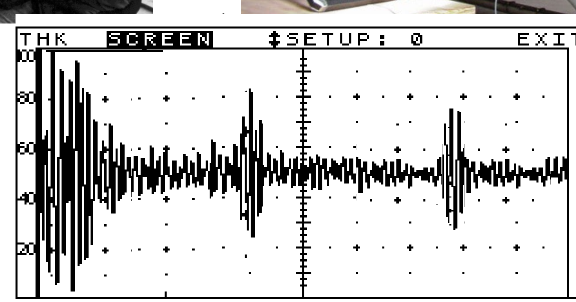
Difficult Conditions



Lots of Rapid Data Interpretation

Viable NDI Signal??





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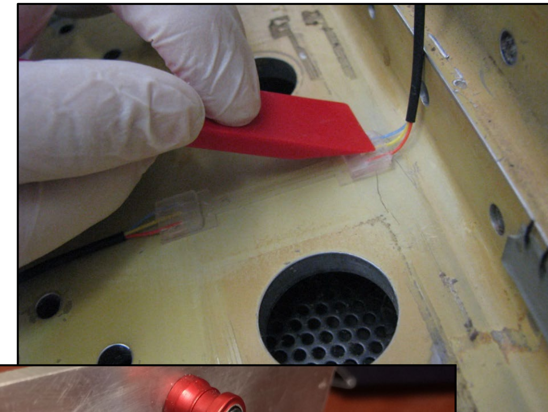
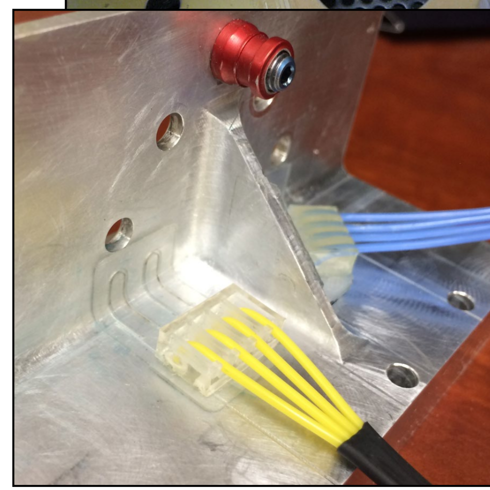
NDI vs. SHM – CVM Technology Deployment

Nondestructive Inspection (NDI) –

- High degree of human interaction
- Local, focused inspections
- Requires access to area of interest (applied at select intervals)



Structural Health Monitoring (SHM) – "Smart Structures;" in-situ sensing, allow for rapid flaw detection



- Greater vigilance
- Overcome accessibility limitations
- Eliminate costly & potentially damaging disassembly
- Minimize human factors with automated data
- Reduced operating and maintenance costs
- Early flaw detection to enhance safety and allow for less costly repairs

- **Easy installation – peel-and-stick; sensors conformable to complex contours**
- **Sensors designed with a fail-safe mode**
- **Easy adoption of technology demonstrated by airlines**

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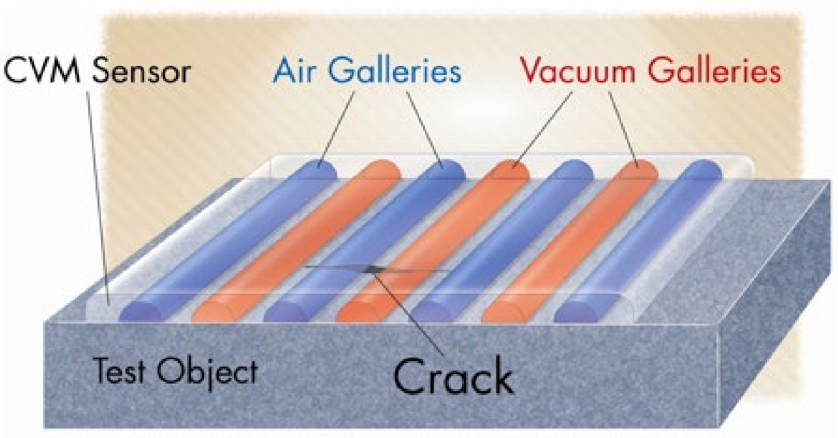
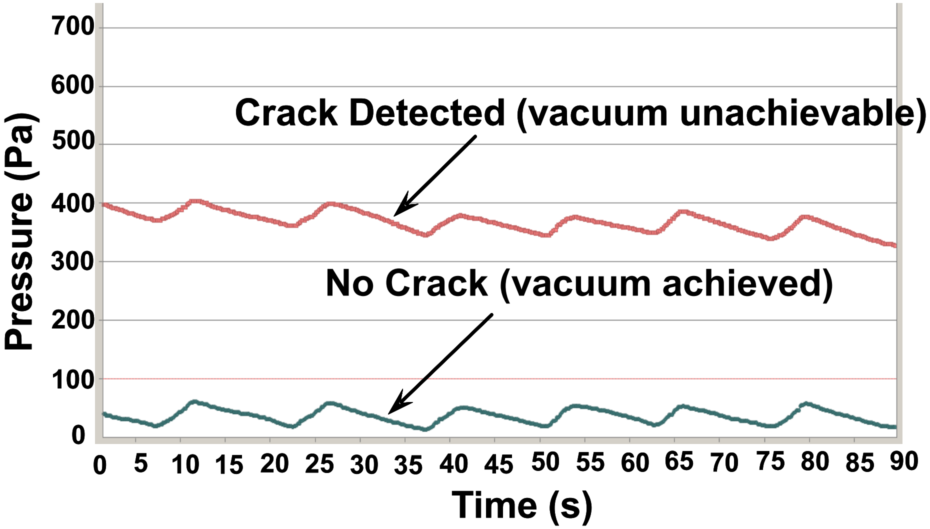
CVM Technology – How it Works

- Uses the principle that a vacuum maintained within a small volume is extremely sensitive to pneumatic leaks.
- Provides a measure of the differential pressure between alternating channels (galleries) containing air at vacuum pressure, and air at atmospheric pressure.
- Leakage path produces a measurable change in the vacuum level.
- Passive system that doesn't require electrical excitation.
- Sensors are fully customizable.





- Crack detection: if dCVM (vacuum) is low = no crack
- Fail-safe check – want continuity (flow) high = no gallery blockage

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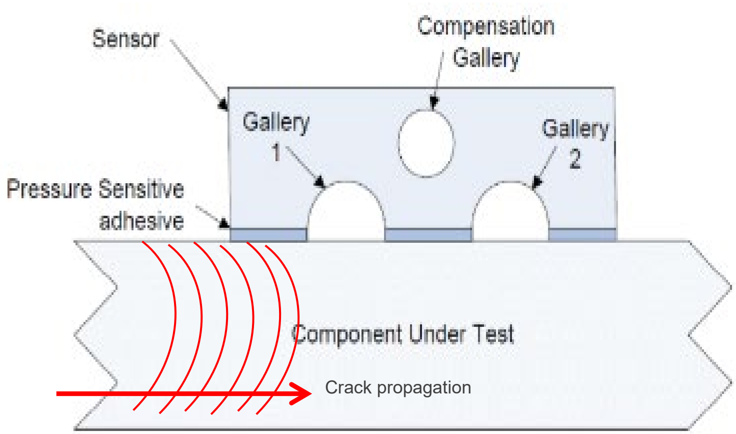
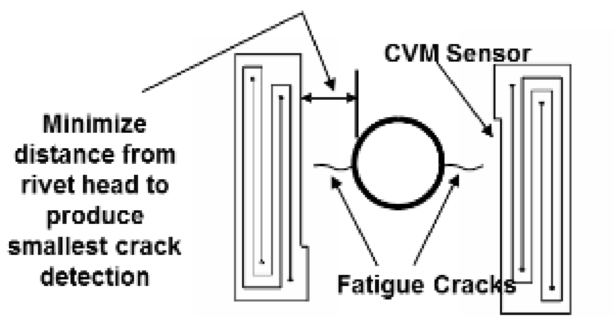
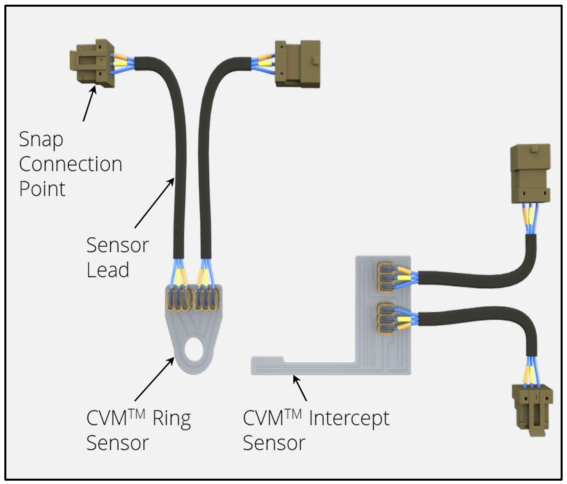
Comparative Vacuum Monitoring System

- **Overcome accessibility problems; sensors ducted to convenient access point**
- **Improve crack detection (easier & more often)**
- **Real-time information or more frequent, remote interrogation**





CVM™ Sensor Adjacent to Crack Initiation Site



SMART SENSOR SOLUTIONS

SHM Validation/Utilization Programs Supporting Safe Adoption of SHM Systems

Timeline

2005 — FAA — **General SHM Validation**

- Assess performance for fuselage applications
- Lab & field testing
- CVM adoption into Boeing NDT Standard Practices Manual

2010 — FAA — **SHM for Commuter Aircraft**

- Trial on known damage prone area
- Successful detection on-aircraft
- Transport Canada participation
- Assess repair as-needed

2012 — Embraer — **SHM for Families of Aircraft Applications**

- CVM & PZT usage over range of A/C applications
- Quantify performance
- Use approval via SBs
- ANAC & FAA interface

2014 — FAA — **SHM Certification & Adoption by Airlines**

- Wing box CVM application
- Formal validation & flight tests
- CVM added to NDT Manual
- SB released – first routine use of SHM

2019 — Sikorsky — **SHM for Rotorcraft**

- Alleviate high-cycle fatigue issues
- Mock certification with FAA
- Integration into rotor maintenance depots
- Integration into HUMS

2020 — Delta Eng — **CVM for Aircraft WiFi**

- Alleviate difficult access
- FAA certification via STC
- Introduced FAA Issue Paper certification guidance

2025 — Boeing — **SHM for Aft Pressure Bulkhead**

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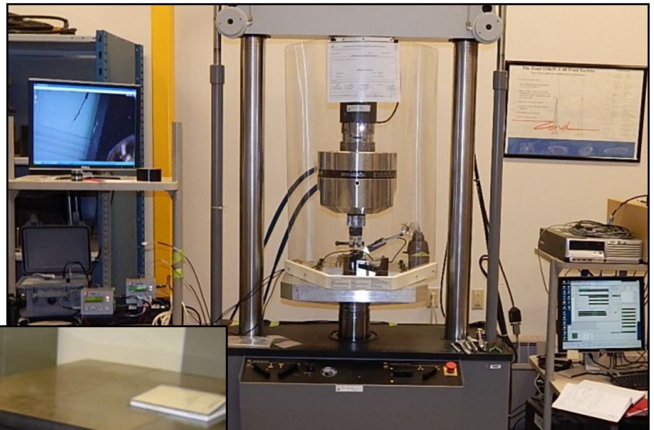
SHM Validation - Technical Considerations for SHM Usage

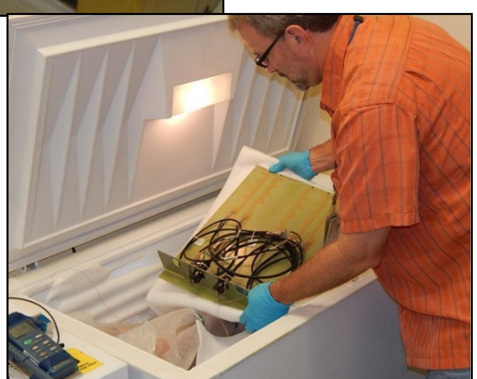
- **Performance Assessments**
  - Probability of Detection (damage detection)
  - Environmental Conditions
  - Lab-based testing vs. Field Operation (repeatability, durability, reliability)
  - Baseline vs In-Use Monitoring Conditions (effects of temp, load, chemicals, etc.)
  - Accounting for possible structural variations (rivet process, geometry, sealants) – example of edge reflections and sensor placement
- **Failure Analysis**
  - Failure Modes & Effects Analysis; Mean Time Between Failure

- **Optimum OEM, Airline, SHM Co. & FAA Team Interactions**
  - Agree on test plans (factors, proper representation of aircraft structure & damage)
  - How many data points needed to assess POD, structural variations
  - Participants (witness/review) in each part of validation testing & evaluation to ensure sufficiency
  - SHM education process
  - Data presentation
  - Approval process

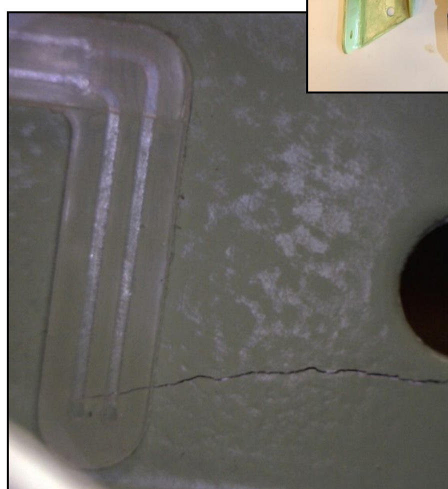
Validation of SHM Capability – Certification for Use

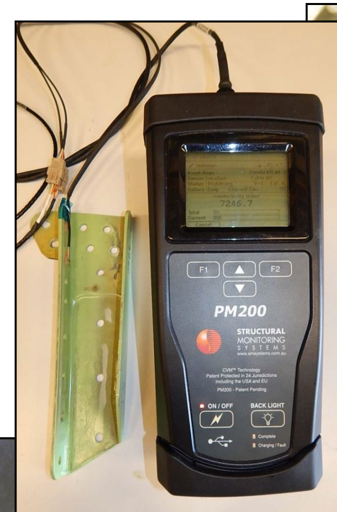
Laboratory Tests - quantify performance (POD), durability, reliability





Flight Tests – properly deployed with airlines, accumulate successful flight hours, safe adoption by maintenance programs





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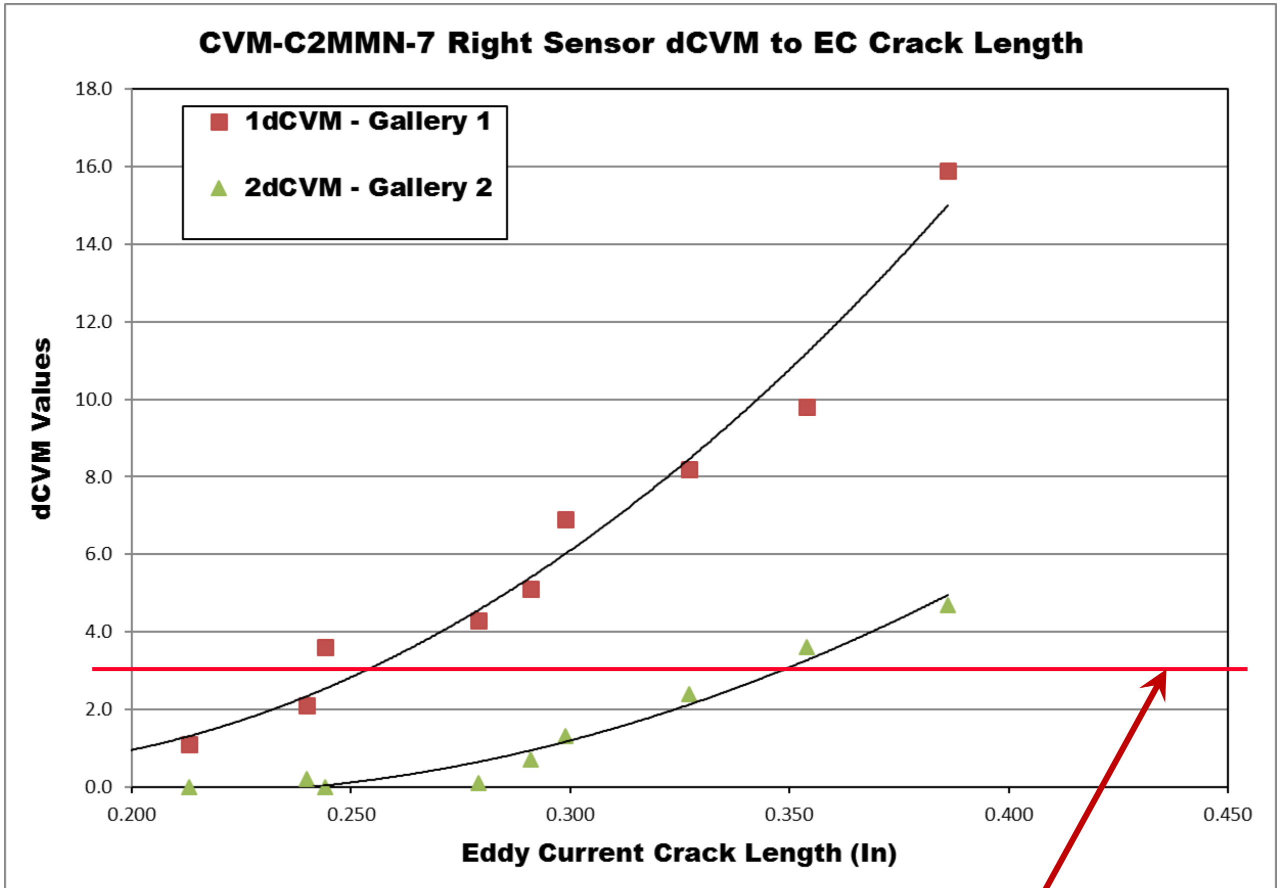
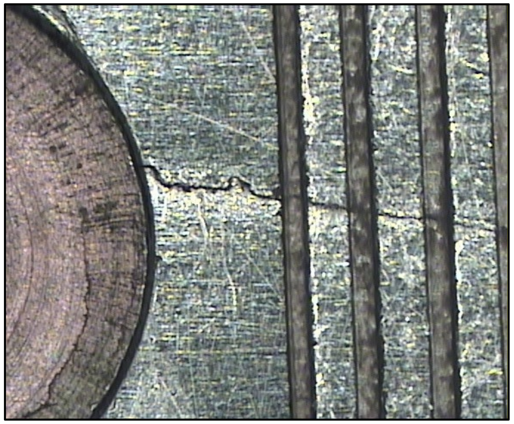
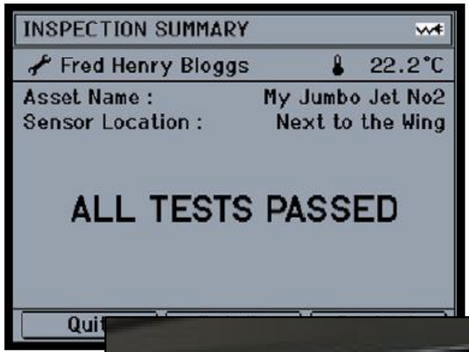
CVM Sensor Response –

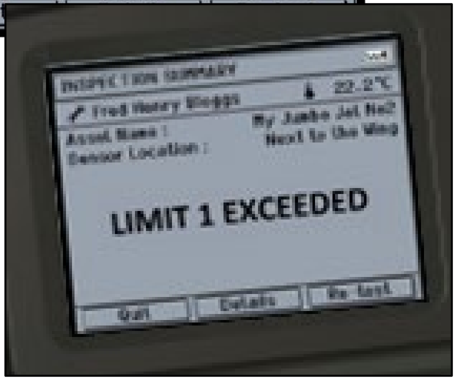
<u>Crack Detection Uses a Damage Threshold</u>





PM200 Readout

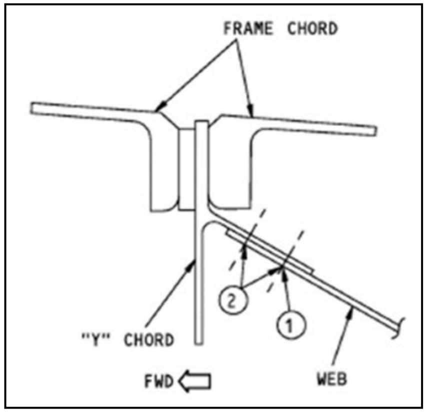


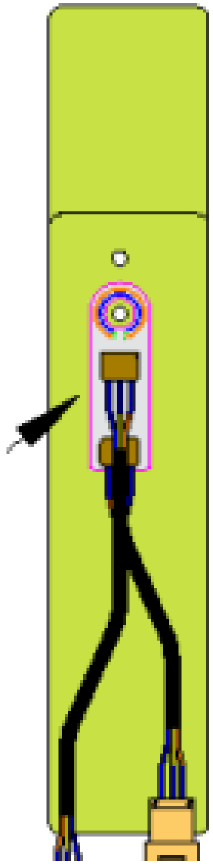


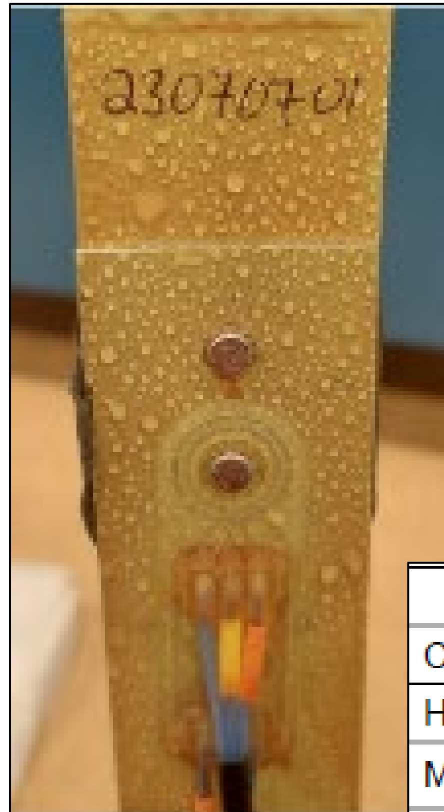
Crack detection occurs when dCVM exceeds Damage Threshold (Green Light – Red Light)

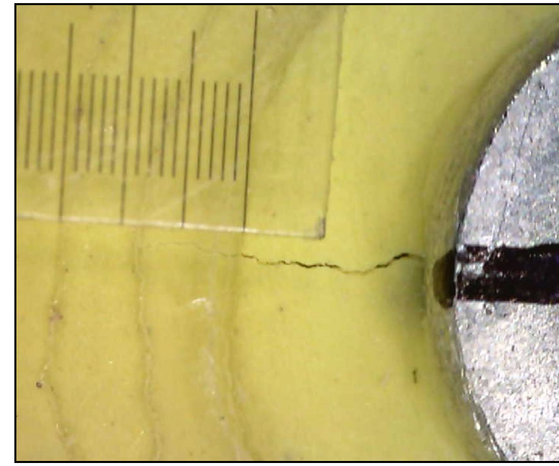
CVM SMART SENSOR SOLUTIONS

Validation Specimen Used to Determine POD for CVM









737 Aft Pressure Bulkhead

Test conditions	Value
Cold temperature (F)	39
Hot temperature (F)	104
Moisture (%)	95%RH
Pressure (feet)	10,000

- **Test specimen matched B737 APB structure; cracks were grown until CVM detection**
- **Sample Challenges: Sensors were exposed to environmental conditions; prove crack detection at low stress levels (~1/3 fuselage stress); CIC/primer will crack with parent structure**

CVM SMART SENSOR SOLUTIONS

Cert Plan 25464 – Damage Detection & Durability

Test Fixture

Temperature

Humidity

Altitude

Vibration

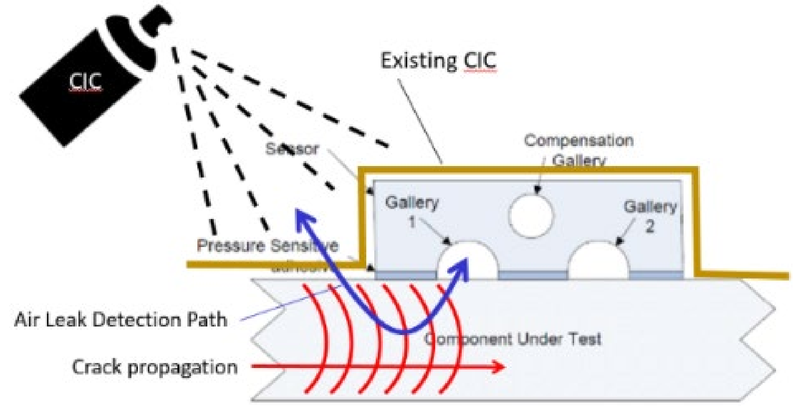
DO-160G Section		Cat.		
4	Temp. & Altitude	C2	15	Magnetic Effect
	Loss of Cooling	-	16	Power Input
5	Temp Variation	B	17	Voltage Spike
6	Humidity	B	18	AF Conducted Susceptibility
7	Shocks & Crash Safety	B	19	Induced Signal Susceptibility
8	Vibration	U2	20	RF Susceptibility
9	Explosion Proofness	-	21	RF Emissions
10	Waterproofness	Y	22	Lightning Susceptibility
11	Fluids Susceptibility	F	23	Lightning Direct Effects
12	Sand and Dust	-	24	Icing
13	Fungus Resistance	-	25	Electrostatic discharge
14	Salt Spray	-	26	Fire, Flammability

DO-160 ENV: some existing some additional testing

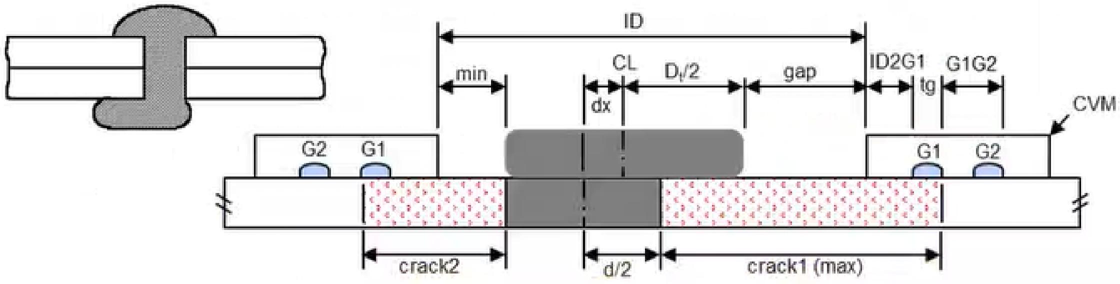
SMART SENSOR SOLUTIONS

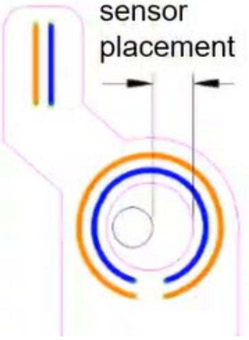
Account for Manufacture Variations & Effects of Chemicals on Sensor Performance

- Assess effects of coatings on CVM performance – can wick into cracks
- No negative effects if CIC fully cured; need to protect against wicking
- Resolution: sensors covered during CIC reapplication



- Issue Paper – must address adverse effects of potential structural variations and sensor placement
- Allowable gap between sensor and rivet tail was adjusted to accommodate off-center rivet upset (100% rollover)





CVM SMART SENSOR SOLUTIONS

FAA Issue Paper- Qualification of a SHM System for Detection of Damage in Structure (Nov 2019)

FAA IP on SHM represents the first formal set of guidelines from the FAA for certification of Structural Health Monitoring (SHM) systems in routine maintenance activities.

Generic SHM Certification IP

ISSUE PAPER

PROJECT:	*[Applicant]* Model *[make & model]* Project No. *[project number]*	**ITEM:** A-# **STAGE:**	
REG. REF.:	14 CFR § 21.50, § 25.571, §25.1529, Appendix H	**DATE:**	
NATIONAL POLICY REF:	AC 25.571-1D	**ISSUE STATUS:** Open	
SUBJECT:	Qualification of a Structural Health Monitoring System for Detection of Damage in Structure	**OFFICE ACTION:** AIR-621, AED **COMPLIANCE TARGET:**	

Method of Compliance

STATEMENT OF ISSUE:
The applicant proposes to install a Structural Health Monitoring (SHM) system on a model <Enter TCDS Model(s)> airplane. An SHM system evaluates the integrity of structure by acquiring and analyzing data from on-board sensors that interface with an electronic device (either on-board or off-board) that processes the data and provides an indication of the health of structure in terms of the existence of damage (e.g., fatigue damage). A SHM technology capable of reliably detecting damage of a specific nature and size over a specific line, area or volume is a candidate alternative to conventional non-destructive inspections (NDI) such as visual, eddy current, ultrasonic and X-ray inspections methods. This approach for detecting structural damage may supplement or eliminate the need for an inspector to physically access and assess structure. Over the past 30 plus years, industry has relied on accessing structure to assess its overall integrity and, as part of that assessment, perform NDI such as visual and eddy current inspections, to detect structural damage. The current industry practice and guidance used to validate conventional NDI techniques may not be adequate as a method of compliance with title 14, Code of Federal Regulations (14 CFR) 25.571 and 25.1529 for an SHM system. Therefore, this issue paper is necessary to establish an acceptable method of compliance.

- **Uniform certification approach - technical decisions & the rationales employed**
- **SHM system can replace existing ICA for compliance demonstration with §§ 25.571 and 25.1529 (functionality & performance)**
  - **Sensor durability/repeatability and reliability**
  - **Means for determining damage detection capability in all operating environments (POD is as good or better than existing NDI)**
  - **In-service experience**
  - **Maintenance and continued airworthiness needs**

CVM SMART SENSOR SOLUTIONS

FAA Issue Paper- Qualification of a SHM System for Detection of Damage in Structure (Nov 2021)

Compensating for Limited In-Service Experience and Technical Data – Section intended for proper and sufficient use of representative lab-based testing to establish performance

Sample Challenge: FAA Certification Team Interpreted this as compensating for limited in-service experience by requiring additional in-service experience including actual damage detection in the field

- Results in a "Belt and Suspenders" approach (alternate EC with CVM) - still provides value to airlines but at a lessened level
- Prospects for crack occurrence is rare which extends complete dependence on SHM downstream for X years
- Single CVM detection on operating aircraft not recognized – separate Air Canada program (involved Transport Canada but not FAA)

Sample Challenge: IP interpretation issues can arise – need to always update and clarify IP (underway)

Sample Challenge: Could not leverage as much of previous work as SHM team deemed possible

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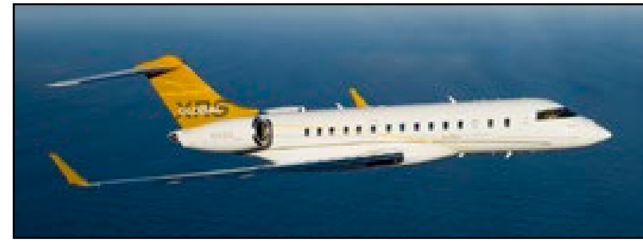
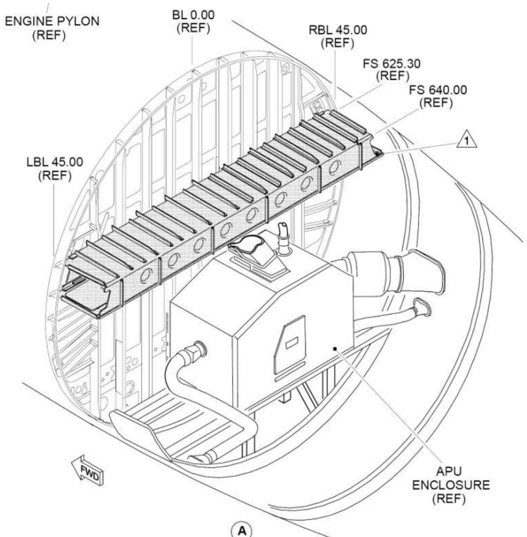
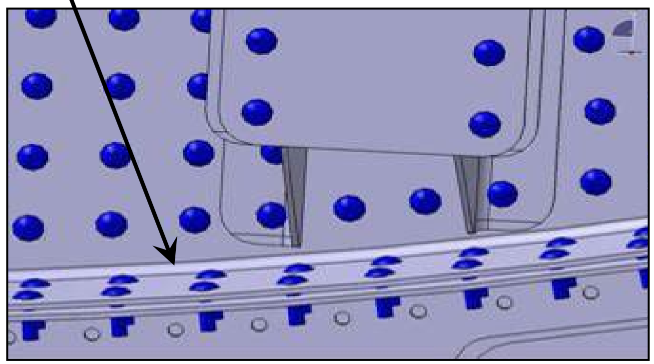
Crack Detection by CVM Sensor

BOMBARDIER | AIR CANADA | Transport Canada | Sandia National Laboratories | STRUCTURAL MONITORING SYSTEMS | FEDERAL AVIATION ADMINISTRATION





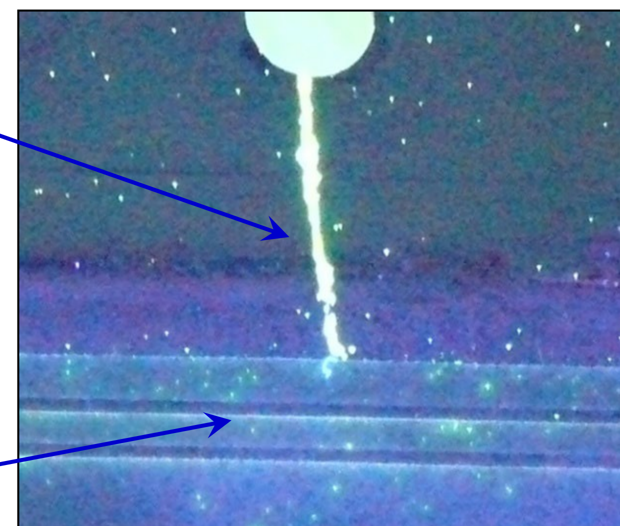
Inspect in the radius



Location	CVM Measure Gallery 1	Conducti-vity Gallery 1
	CI	CI
Calibration block	-0.3	2390
Engine Beam - LHS lower web	2947	7807
Engine Beam - RHS lower web	4276	7339

Aft Equipment Bay

First detection of a fatigue crack on an aircraft (confirmed by dye penetrant test)



CVM Sensor

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Additional Certification Challenges

How to obtain full technical & economic benefits from SHM - achieved through full certification and reliance on SHM

- Ensure FAA approve all Cert Test Plans (specimen designs, loads, DAQ)
- Allow FAA to play a stronger role on the in-service data (participation)
  - Observe data acquisition to improve pedigree of data from operating aircraft
  - Review data immediately with knowledge of monitoring event & ensuring Job Card sign-off
- Work with regulators during project execution to ensure sufficient & suitable data
- Currently ignoring 2.5M hours of successful CVM flight operation AND actual crack detection on an in-service aircraft

Sample Challenge: Time available for certification body to review all of the CVM performance data – newness of technology coupled with extensive demands on FAA personnel time; No time to attend installations or monitoring events

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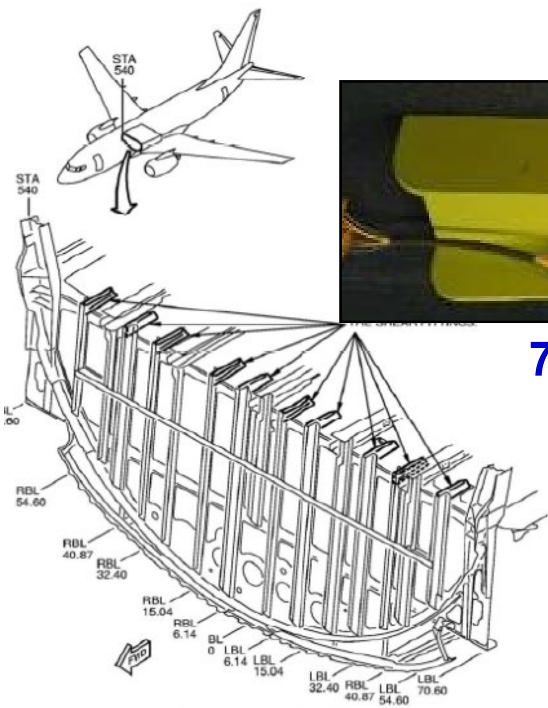
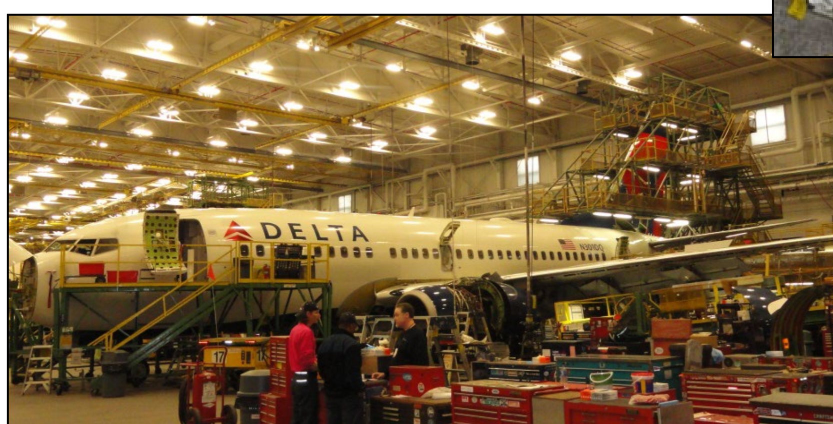
CVM Sensor Network Applied to <u>737 Wing Box Fittings</u>

Certification via Boeing SB 7373-57-1309 Rev 1

- **Comprehensive performance assessments completed: sensitivity, reliability, durability**
- **Flight testing: successful operation on flying aircraft**
- **Formal approval from aircraft manufacturers and aviation regulators**



737 Wing Box Fittings



~ 1.5 M hours of successful flight history

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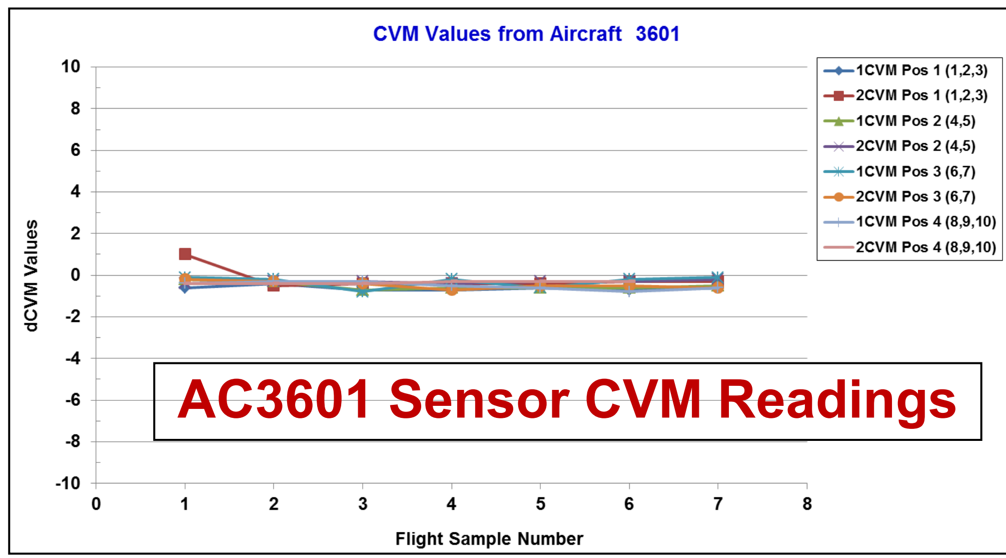
737NG Center Wing Box – Accumulating Successful Flight History

Aircraft Parked at Gate After Final Flight of the Day

Access to SLS Connectors Through Forward Baggage Compartment

Connecting SLS Leads to PM-200 to Monitoring Sensor Network



More than 7 years of operational testing involving airline, OEM and SHM company

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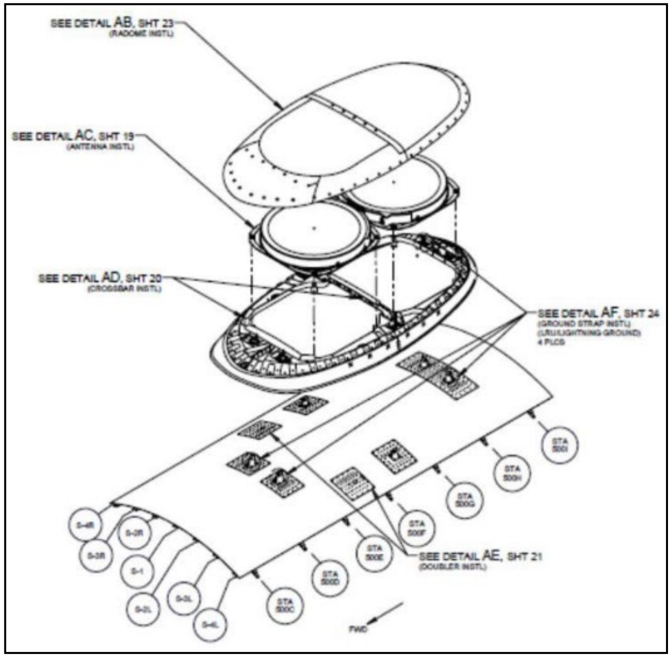
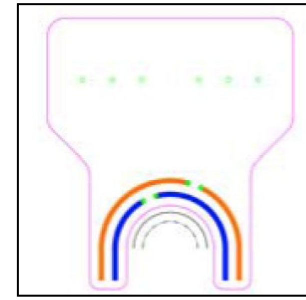
CVM Application – WiFi Antenna Installation Structure

Multiple aircraft types, multiple airlines

Certification via FAA STC ST04103NY

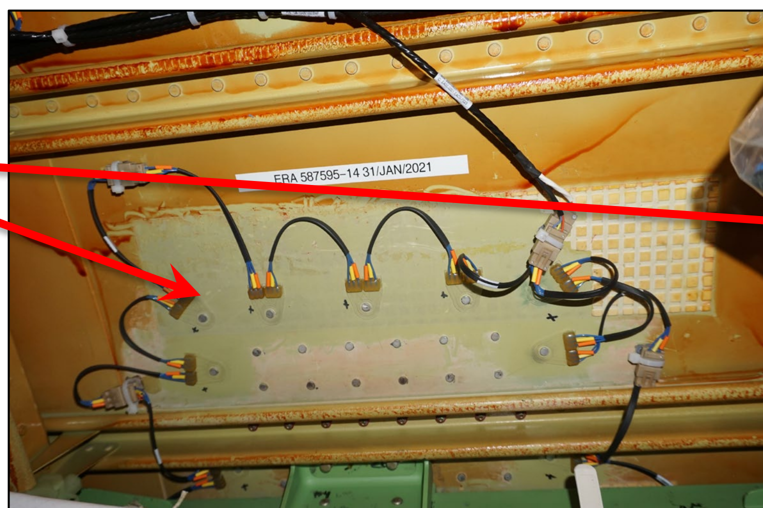




CVM Sensor Design

CVM sensors used to rapidly complete frequent, repeat HFEC/LFEC inspections required on internal structure hidden behind interior panels.

B737 Wi-Fi Antenna Support



CVM SMART SENSOR SOLUTIONS

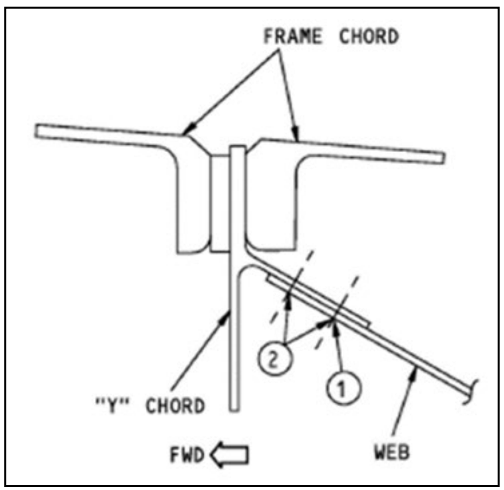
CVM Application – Aft Pressure Bulkhead Fitting

Joint SHM Certification Program with:

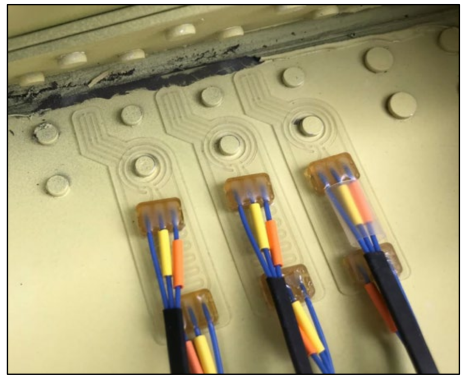
BOEING

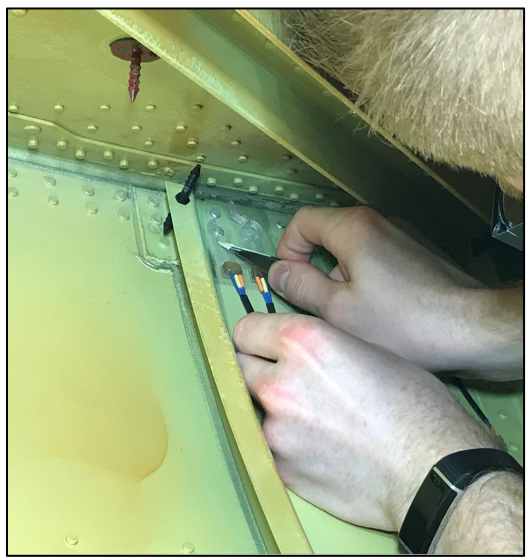
Delta Air Lines

Circumferential cracks at fasteners connecting the web assembly to the bulkhead "Y" chord.



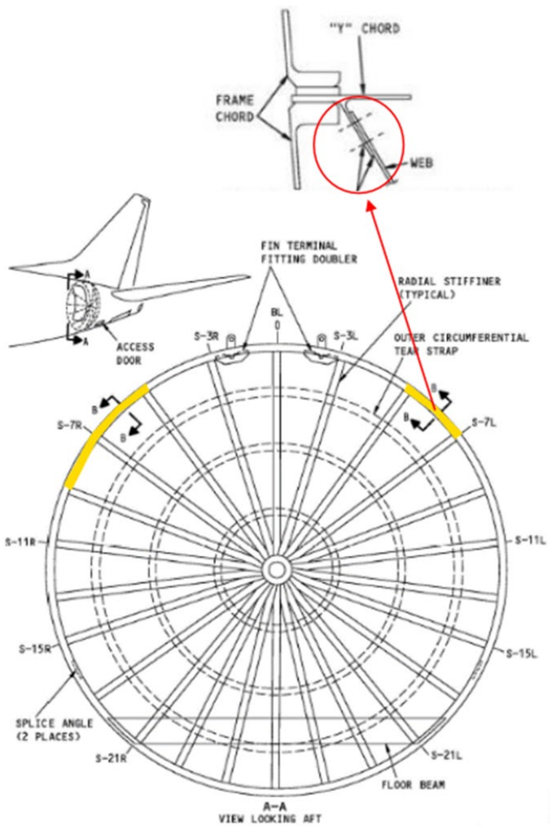
CVM Sensors on B737 Aft Pressure Bulkhead

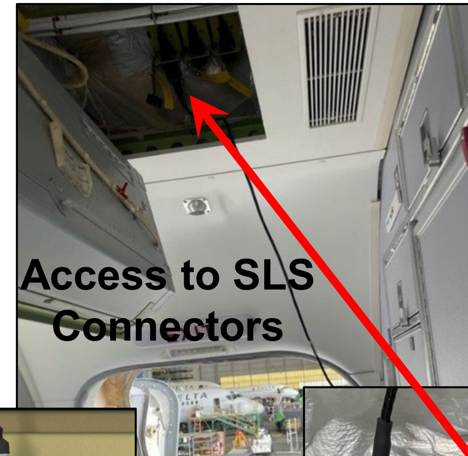




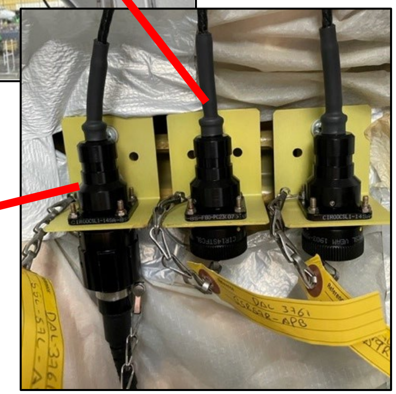
21-23 smart sensors used to monitor up to 47 fasteners per application

CVM Application - 737 Aft Pressure Bulkhead





Inspection - PM200 Monitoring Device



SLS connectors

Reduces inspection time from 24 hr to 15 min

ACTIVE B737NG AIRCRAFT IN DELTA FLEET

71

Replaces hangar time with at-the-gate inspections & restores valuable flight hours

950	111	426
Flight Hours Restored per Annum	Flight Day Gained	Labor Hours Avoided

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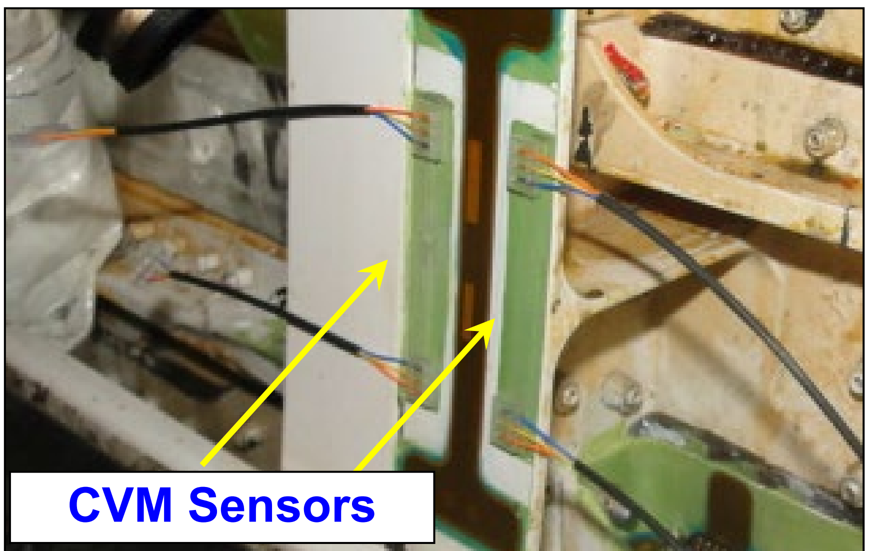
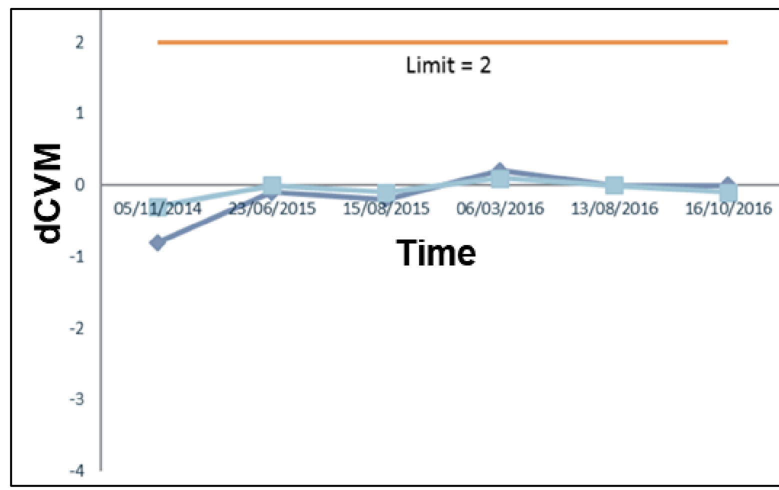
CVM & PZT Flight Tests – Azul Aircraft PR-AYW

Installation Summary

- **Date of Installation: Nov 2014**
- **Service Bulletin: SB190-00-0029**
- **Zone: Central Fuselage II**
- **CVM on Center Fuselage End Fittings**





Consistent CVM Data Over Two Years of Flights - dCVM Well Below Damage Detection Threshold

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CVM Flight Testing – In-Service Reliability

- **Fail safe operation ensured**
- **In-service data was extensive with multiple MRO facilities trained for CVM APB installations (e.g. Atlanta, Indianapolis, Kansas City, Oklahoma, Mexico City, Querétaro, San Salvador, Victorville)**
- **Exceptional success rate - training program conducted with initial installations**
- **Multiple programs produced over 2.5 M successful flight hours of in-service operation including a crack detection**

737 Wing Box Fitting

- **70 CVM sensors on 7 Delta aircraft monitored every 90 days for over 7 years, producing over 1,400 sensor response data points**

737 Aft Pressure Bulkhead

- **Delta Air Lines installed CVM on 737NG APB 60+ aircraft (May 2019 – present); monitored every 90 days**
- **Over 250,000 flights hours producing over 2,900 sensor response data points**

No in-service issue with CVM on 737NG APB after addressing any items stemming from initial installation

CVM
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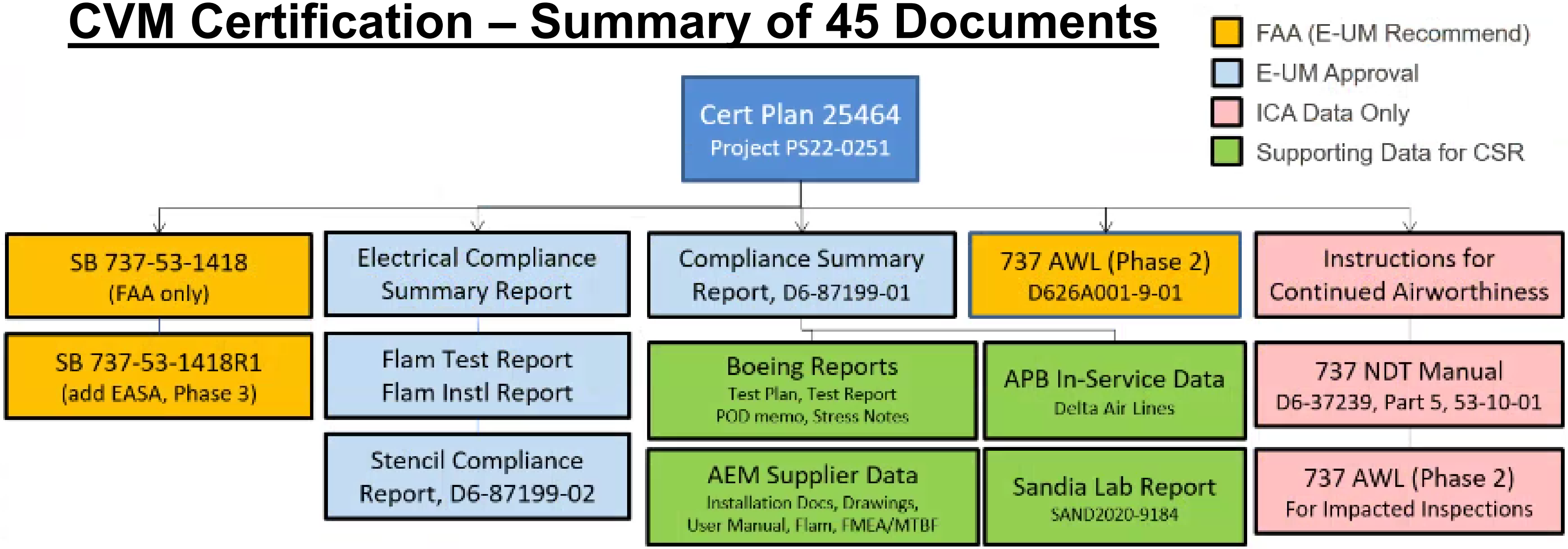
CVM Certification – Summary of 45 Documents



- **Including: 1) APB Stress Analysis, 2) Structures Compliance Summary Report, 3) FAA Certification Plan, 4) APB CVM Qualification Analysis, 5) Electrical Compliance Report, 6) Damage Tolerance Analysis, 7) Failure Modes and Effects Analysis, 9) Probability of Detection Report, 10) CVM Installation and Use Tech Sheets, 11) Flammability Compliance Summary Report, 12) Instructions for Continued Airworthiness, 13) Issue Paper Compliance Summary Report, 14) Boeing CVM Performance Test Reports, 15) APB In-Service Data**

- **Just a final few documents to be released by Boeing - anticipated approval of new Service Bulletin 737-53-1418 (AMOC) for CVM usage in Q1 of 2026**

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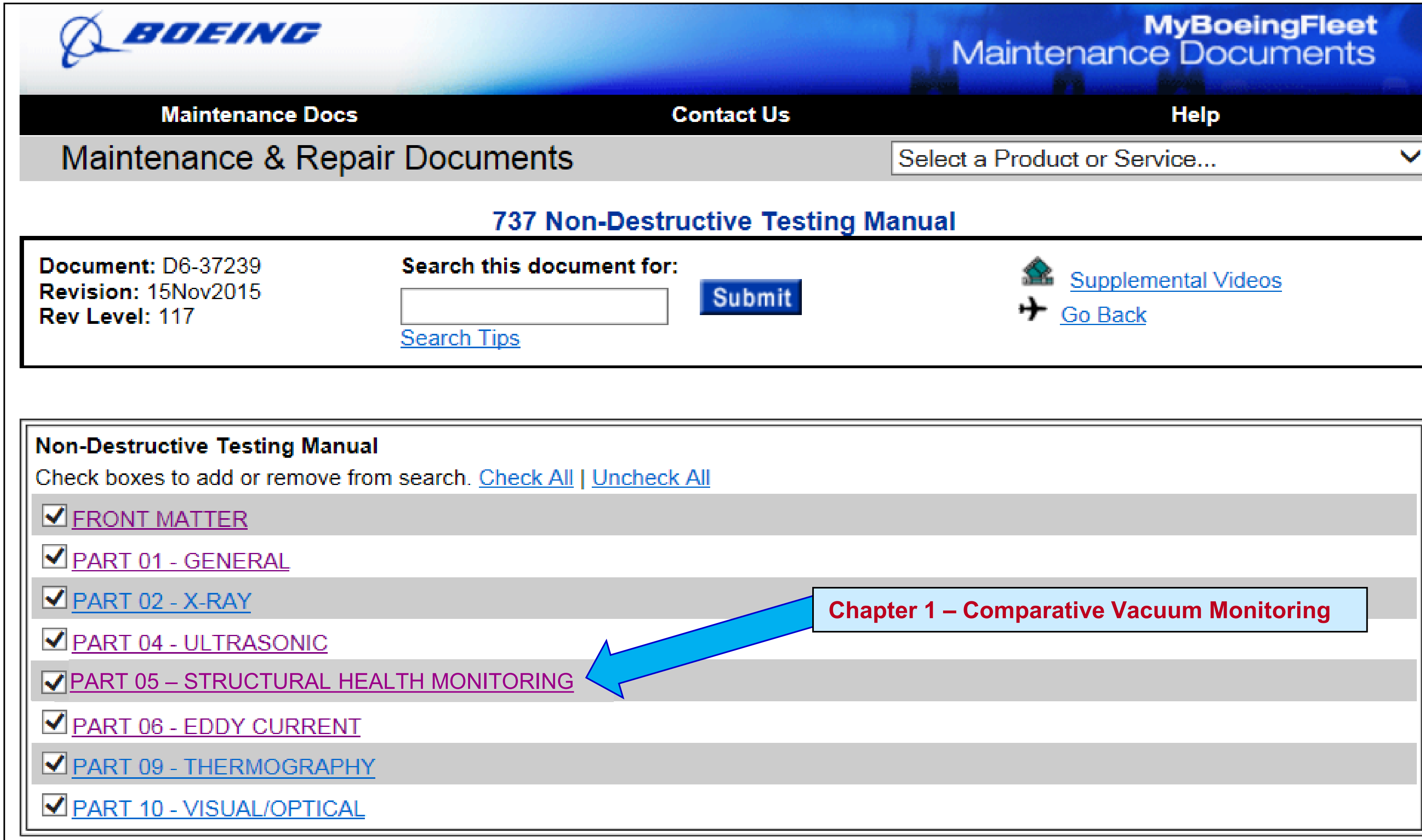
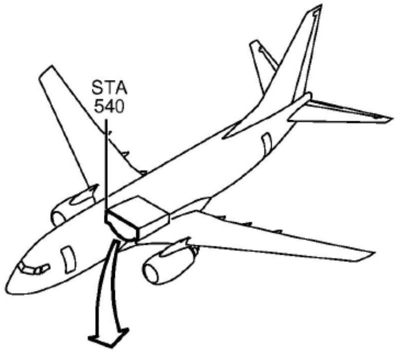
737 NDT Manual - New SHM Chapter Published (Nov 2015)

Building Block to Approval for Routine Use of SHM



FAA Approval - CVM Certification for Routine Use



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.

Wing Box Fitting – Service Bulletin Approval (2016)

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

WiFi Installation – STC Approval (2022)

FAA Issued <u>first ever STC for SHM,</u> to Delta Engineering (licensed to SMS) for use of CVM on Go-Go (Intelsat) Wi-Fi antenna inspection requirements, for the B737 aircraft.

FEDERAL AVIATION ADMINISTRATION

United States of America
Department of Transportation
Federal Aviation Administration
Supplemental Type Certificate
Number: ST04103NY

Description of Type Design Change:
Installation of Structural Monitoring Systems Comparative Vacuum Monitor (CVM) Sensors in accordance with Delta Engineering Master Data List 0106-10998-2499 Revision A dated Mar. 2, 2022 or later FAA approved revisions to Delta Engineering Master Data List previously listed. The Instructions for Continued Airworthiness as listed on the Master Data List is required with this installation.

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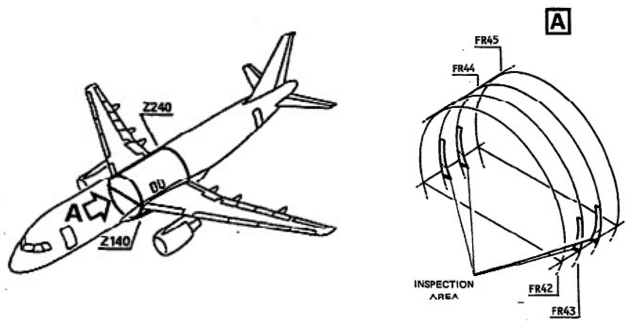
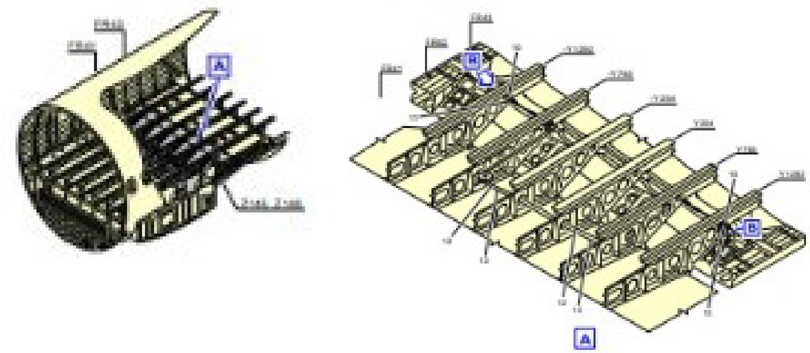
POSSIBLE CVM™ APPLICATIONS FOR AIRBUS AIRCRAFT

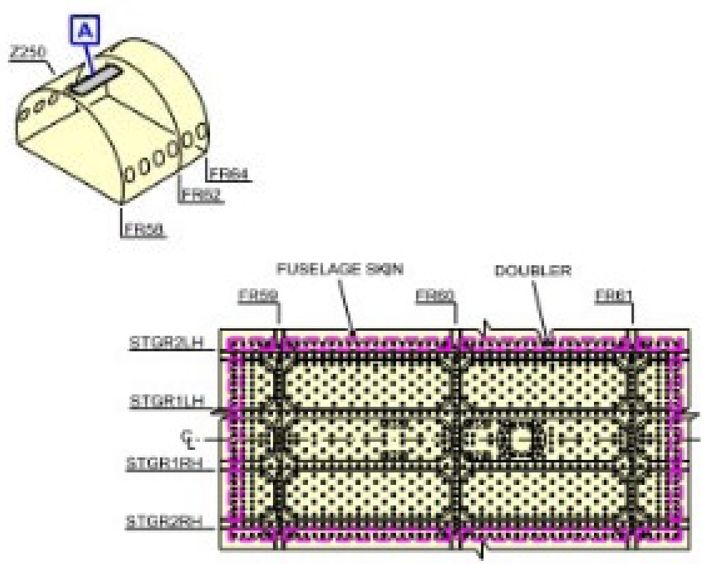
FRAME-TO-PRESSURE-FLOOR CONNECTION BOLTS & FITTINGS



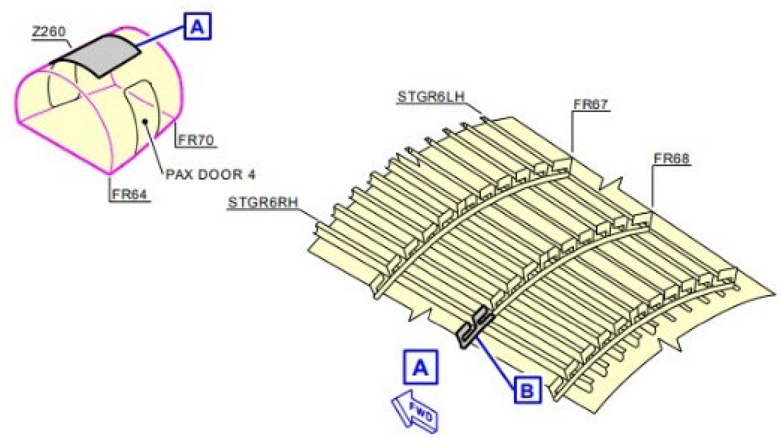
UPPER SURFACES OF PRESSURE DECK MEMBRANES AND SIDE BOXES, BETWEEN FR 42 AND FR 46



INTERNAL SKIN UNDER THE CABIN SWIFT BROADBAND ANTENNA

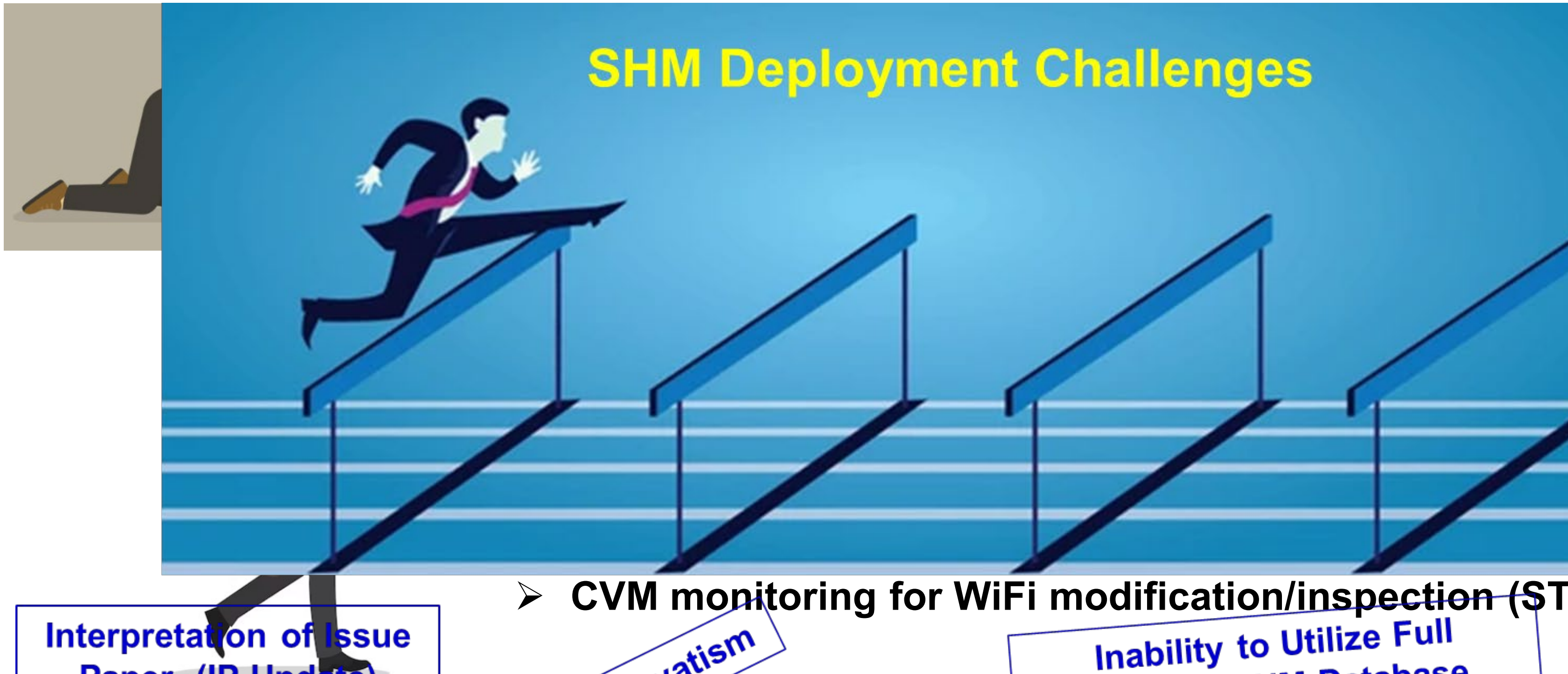


LATERAL FR 68 JOINT TO UPPER FR 68 BETWEEN STRINGER 4 AND STRINGER 5, LH/RH



SMART SENSOR SOLUTIONS

SHM Utilization and Approval – Crawl, Walk, Run Approach



Interpretation of Issue Paper (IP Update)

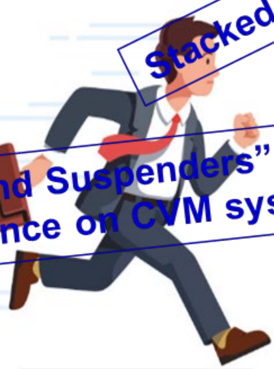
- CVM monitoring for WiFi modification/inspection (STC)

Stacked Conservatism

Inability to Utilize Full Existing SHM Database

Limited Time Available from Heavily Burdened FAA Cert Personnel

Foundation Improvements for SHM Approval (validation, training, data pedigree)



"Belt and Suspenders" (partial reliance on CVM system)

- Safety of Flight application – Aft Pressure Bulkhead
- Comprehensive OEM Cert Plan validation in concert with FAA
- Formal approval application from Boeing (45 documents)
- Goal: full reliance on SHM system

CVM SMART SENSOR SOLUTIONS

Conclusions on Routine Use of SHM Solutions

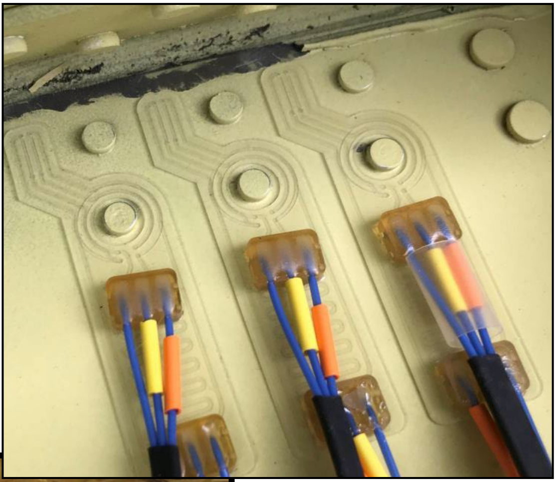
- Strong industry interest in SHM – maximize fleet utilization by reducing hangar-based downtime
- Adoption of CVM replaces time-consuming, costly manual inspections
- CVM for monitoring in hard to access locations, has been found to be a common use-case across OEMs
- Airline operator adoption of CVM has occurred (SB & STC approvals)
- Firmer foundation for SHM deployment/approval: industry guidance, certification & regulatory framework has evolved (IP), OEM formal processes (POD, ENV, QA), operational data growing, & SHM training
- Full dependence on SHM: Revisit APB application (CVM) after initial approval for relaxation of Belt and Suspenders
- Obstacles remain to full reliance on SHM to replace NDI: FAA time, full use of existing performance & reliability data, full use of lab-based testing, stacked conservatism, more stringent requirements for SHM approval vs. NDI
- These must be addressed to achieve safe use of SHM and associated technical and economic benefits to airlines

Historical CVM Partners for
Integration into Routine Maintenance

Delta Air Lines
RYANAIR
FEDERAL AVIATION ADMINISTRATION
Sikorsky
Azul Linhas Aéreas Brasileiras
BOEING
easyJet
AIR CANADA
EMBRAER
BOMBARDIER
Sandia National Laboratories
AIRBUS
AEM ANODYNE ELECTRONICS MANUFACTURING CORP.
AIR FRANCE
Transport Canada
KLM
United Airlines
American Airlines
STRUCTURAL MONITORING SYSTEMS
JAPAN AIRLINES
JAL
jetBlue
DE HAVILLAND AIRCRAFT OF CANADA LIMITED
DH
CANADA
SOUTHWEST AIRLINES
TESTIA AN AIRBUS GROUP COMPANY
ANAC
ANA All Nippon Airways
EASA European Aviation Safety Agency
Emirates
Lufthansa

Technical and Oversight Considerations for Reliable SHM Utilization

Dennis Roach
Trevor Lynch-Staunton
Structural Monitoring Systems
(Anodyne Electronics Manufacturing Corp.)



SMART SENSOR SOLUTIONS

Update on CVM Usage to Improve Aircraft Maintenance Programs

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Trevor Lynch-Staunton
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(505)235-9516

Reliable Structural Health Monitoring (SHM) systems can automatically process data, assess structural condition and signal for timely human intervention only when necessary. In-situ sensors, coupled with remote interrogation capabilities, effectively overcome traditional inspection challenges related to limited accessibility, complex geometries, and the location and depth of hidden damage. Recent efforts by regulators, OEMs, airlines and SHM developers have moved SHM into routine use for aircraft maintenance. Specifically, Comparative Vacuum Monitoring (CVM) technology has been deployed to address multiple aircraft monitoring needs. These programs have progressed CVM through rigorous certification processes with regulators and OEMs leading to formal adoption and routine use by airlines. Official applications have allowed CVM to rapidly assess the structural integrity of wing box fittings, structure associated with WiFi installations and aft pressure bulkheads. Currently, new CVM applications are being considered for a wide array of structures including frames, stringers, spars, straps, keel beams, skin splice joints, and equipment racks, across multiple aircraft platforms from multiple OEMs. These SHM integration programs have addressed formal SHM technology validation and certification issues so that the full spectrum of concerns, including design, performance, deployment, and continued airworthiness were appropriately considered. This paper will provide an update on CVM deployment and certification, streamlined processes for airline adoption, and prospects for SHM to further compliment NDI activities. Formal documents have been modified by aircraft manufacturers, including NDT Manuals and Service Bulletins, to accommodate SHM usage. The FAA has published an Issue Paper that provides essential guidelines for SHM system designers and procedures for assessing the performance of SHM systems. In addition, the Aerospace Industry Steering Committee for SHM (AISC-SHM) has developed standards to facilitate integrating and certifying SHM use on aerospace structures. The application of SHM technology in the sustainment of structures and mechanical systems can reduce maintenance costs, allow for minimized repairs via early damage detection, compensate for uncertainties in material aging and avert premature failures. Furthermore, replacement of present-day manual inspections with automatic health monitoring can substantially reduce the associated life-cycle costs. These efforts are allowing SHM solutions to efficiently and safely improve aircraft maintenance programs.