Validation of a Structural Health Monitoring (SHM) System and Integration Into an Airline Maintenance Program (Part 2)

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Team Effort!

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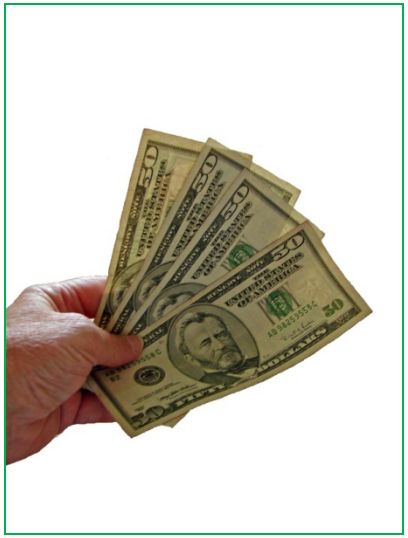
Operator perspective

- Vision for SHM usage at Delta
  - — Initially: alternate inspections of difficult to access areas.
    - Inconvenient MTC visits.
    - Hotspot monitoring – AMOCs.
  - — Medium term:
    - Early warning of issues.
  - — Future: Condition Based Mtc & Crack Monitoring.
    - ‘Smart Signal’ for engines.
    - OEM Support.



- Two main hurdles to implementation.
  - — Business Cases (payback).
  - — Lack of regulatory guidance, education.
- Solution: FAA program with Delta for SHM implementation.
  - — Delta will write the guidance/blueprint for SHM certification.
- G-11 SHM => ARP 6461

SHM is next level of NDT = it’s coming soon

What are we doing? Why?

- **Airlines/MRO under constant cost pressures.**
- **Lots of sensor technologies ready for implementation.**
- **FAA previously funded some technologies.**
  - **— Not implemented in industry on wide-scale:**
    - **Airline/MRO cost benefit analysis.**
    - **Lack of certification guidance in regulations.**
      - **— Alternate NDI technique or change in Maintenance Program?**
- **FAA funded this program to move SHM from 'prototype' to 'mainstream'.**
  - **— Partnership between Boeing/AANC/FAA/Delta/SMS/AEM/AAR.**
    - **Delta will 'live through certification' of SHM application.**
    - **FAA/AANC provides subsidy to Delta.**
    - **All vendor items provided separately: Instrument, sensors.**
    - **Boeing provides program oversight, review.**
    - **FAA-SACO review.**
    - **FAA-TAD is the customer – Guidance is the goal.**
    - **SAE G-11 SHM Aerospace Industry Steering Comm.**

SHM Certification & Integration Activity

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- Certification/usage effort intended to investigate, exercise and evolve the SHM certification path – address all “cradle-to-grave” issues for airlines, MRO vendors, OEMs, and regulators.
- Identify SHM applications with positive cost-benefit analysis.
- Customize SHM system to the selected application(s).
- Develop validation/certification plan – utilize precedents from existing sensors.
- Complete SHM indoctrination and training for Delta personnel (engineering, maintenance, NDI), MRO vendors and FAA as needed.
- Hardware specifications, installation procedures, operation processes, continued airworthiness instructions.
- Complete modifications to Delta maintenance program as a result of SHM use.
- Assess aircraft maintenance MROs to determine their ability to adopt SHM and the FAA support needed to ensure airworthiness.

SHM certification path must be paved

CVM Flight Test – *Internal Approvals*

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- Financial approval form with project summary, NPV.
  - Must be vetted by Finance.
  - Signatures of affected departments (whose budget, where it will be done, when).
- Job Cards produced, vetted via “Process Control”.

Rigorous financial, technical & logistical internal approvals

Challenges!

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THAT'S NOT THE WAY WE'VE DONE IT

Why try something new?

Challenges - Internal

- Issues:
  - ~7 months to approve, including changing approval requirements => “merger integration”.
  - EP-12 Financial Form issues.
  - EA/AA Dual Author, AMDS cards authored.
    - Materials (repair/modification kits).
    - Planning.
  - Process Control = 3 months to ‘open’ with ‘priority level’.
  - Organizational changes – merger fallout & others.
    - SHM Vision presented to Sr. Mgmt Nov 2012.
    - April 2013 = Process for project approval changed.
      - Operational Reliability Team.
      - Engineering Project Approval Board.
  - Coordination with Planning – shift to ATL, shorter visits.
  - Redoing effectivity and location – Process Control part 2.
  - Q1 2014 = Install occur on 7 B737-700s.

Laborious internal process for approval

Challenges - External

- External:
  - AAR Coordination visit October 2012.
  - SHM Workshop – ABQ November 2012.
  - AAR visits for measurements, layout; dry-run.
  - Delta-Sandia-AEM coordination for procedure development, layout, and installation drawings
  - Boeing = NDT, Engineering, DT/Structures, ARs, etc.
- Initial Installs:
  - 3 attempts at AAR-IND for install unsuccessful (Q3/4 2013).
    - Fittings already contained small cracking, but not in sensor area.
  - AMDS Cards changed for effectivity, location (ATL) Q1 2014.
    - Younger aircraft (fewer cycles), but shorter visit (5 days).
  - AEM/Sandia coordination for site visits.
    - Shorter visit drove pressure.

Thorough collaboration & coordination required

Job Cards

CVM SENSORS AT WING CENTER SECTION SHEAR FITTINGS (STA 540), 737 - INSTALL; SECTION 01 -3

Zone: 130 - Subzone - Body STA 540 to STA 727

WBS No.

7066542

A/C **3602** Card **5711-01044-01-3** Crew **12**

DELTA **B737** A.A. Workcard **Page 2 of 4**

Scan Pages 2 of 4

Job # **059-0003**

INFORMATION:

For AA details, access the AA via the AA Management System. AA Management System and tutorial are located on TOHP under "Maintenance Links".

1. Ensure disposition of each of the 10 shear fittings from 5711-01044-01-2.

   A. If four (4) or more shear fittings contain cracks, then all 10 shear fittings will be replaced; contact Planning and proceed to 5711-1044-04 (N/A this card).

   B. If only one, two or three fittings are cracked, then only those fittings will be replaced (contact Planning and proceed to 5711-01044-04 for replacement of those fittings; N/A the steps corresponding to sensor installs for those affected fitting zones on this card).

      (1) The remainder of the fittings (in a non-cracked zone) will undergo sensor installation; proceed to next step.

Disposition
Inspector

2. Locate center wing box front spar shear fittings at Left Buttock Line (LBL) 54.60, 40.87, and 32.40 at Body Station (STA) 540. Install CVM sensors on all three fittings per Delta Technique Sheet SHM 100-57: B737-800 CVM Installation at Wing Center Section - Front Spar Shear Fittings (STA 540).

NOTE: If one or more of these fittings were found cracked in 5711-01044-01-2, then N/A the step for that fitting and replace only the cracked fitting or fittings via 5711-01044-4. Installation of CVM sensors will not occur on the affected fitting(s). Refer to Delta Technique Sheet SHM 100-57: B737-800 CVM Installation at Wing Center Section - Front Spar Shear Fittings (STA 540), for details about 'capping' the tubing to bypass the intended sensor location on the affected fitting(s).

NOTE: If the surface needs primer touch-up, accomplish via BSOPM 20-44-04 prior to installing sensors. Ensure surface meets requirements of Delta Technique Sheet SHM 100-57: B737-800 CVM Installation at Wing Center Section - Front Spar Shear Fittings (STA 540).

LBL 54.60	LBL 40.87	LBL 32.40
Mechanic	Mechanic	Mechanic

- Job Cards point to ‘Technique Sheet’
- Delta Technique Sheet used for Install
  - Date/revision controlled by Level III
  - Not sign-off
- Second T-sheet for Monitoring/Inspection
- Correct sign-offs needed (I/M)
- “What if” scenarios covered

Job Card to Technique Sheet

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Delta Air Lines, Inc.	NonDestructive Testing Technique Sheet	SHM 100-57 Date: 03-07-2013 J. Bohler rev. b

B737-800 CVM Installation at Wing Center Section – Front Spar Shear Fittings (STA) 540

REFERENCE

EA 12-509365-03, AA 5711-01043
SB 737-57-1309
Delta PS 900-1 No. 04
PS 900-7-1-1 No. 03, Fastweld 10 option
B737-678 AMM 28-11-00-300-804
PM200 dCVM Operations Manual, available at http://dpi948/dledmprod:/Main530/equipmanuals/027

PURPOSE

This procedure provides instructions on how to prepare surfaces, install and overcoat CVM™ FEP Sensors at (LBL) 54.60, 40.87, 32.40, 15.04, 6.14 and (RBL) 54.60, 40.87, 32.40, 15.04, 6.14, at Body Station (STA) 540. The installation consists of 10 sensors. The 3 outboard sensors will be daisy chained together and the 2 inboard sensors will be daisy chained together on each side. See fig. 3. The final installation will have 4 Sensor Lead Sockets (SLS) to connect the PM200 to.

T-sheets are used as 'Job Aides' at Delta

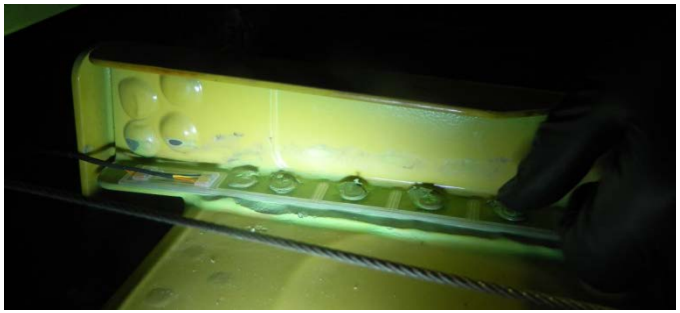
Human Factor Issues

- Training – new technology/process.
  - Change in location = new one-on-one training.
  - Challenging with 5 day visit.
- Time pressure = 5 day visit (vs 23 day).
- NDT instincts:
  - HFEC prior to sensor application; Knowledge of prior ‘hits’.
- Install vs Monitor job descriptions.
- Delicate installation.
  - Do not rush surface prep!
- Repetitive inspections (90 days) done “on the line”, overnight.
  - No time for thorough investigations.

Human factors loom large, even with sensors

Lessons Learned

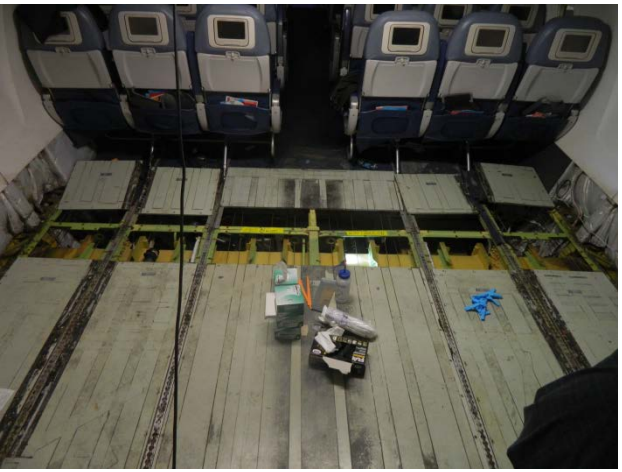
- Tedious application of sensors, especially in difficult-to-access areas and tight geometry (free edges). Re-install of sensors was needed.
- Non-symmetric and size of sensor was a challenge.
- One week time window for installation during minor check was challenging.
- Leaks observed after sensor installs and check out were corrected/attributed to the jumper connectors (tubes pulled out of Snap-Click Silicon blocks).
- Templates/tool – not used a whole lot = hand application was best.
- Minimizing adjacent movement and air flow in the cabin helped reduce sensor failures.
- Needed to educate inspectors regarding where to look and how (GVI was required not a DVI).
- PM200 software programming.
- Use of spray-on primer helped a lot.

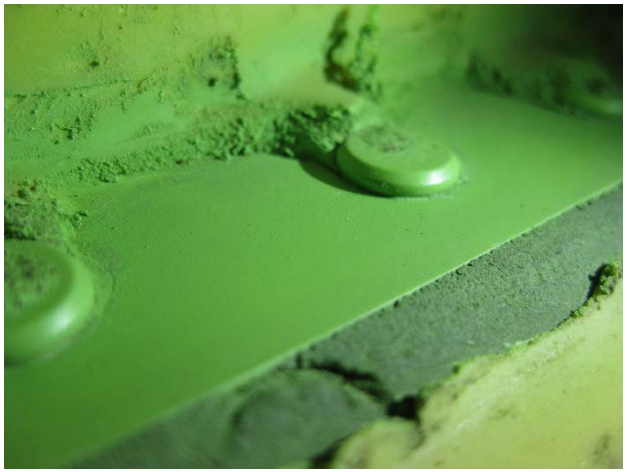


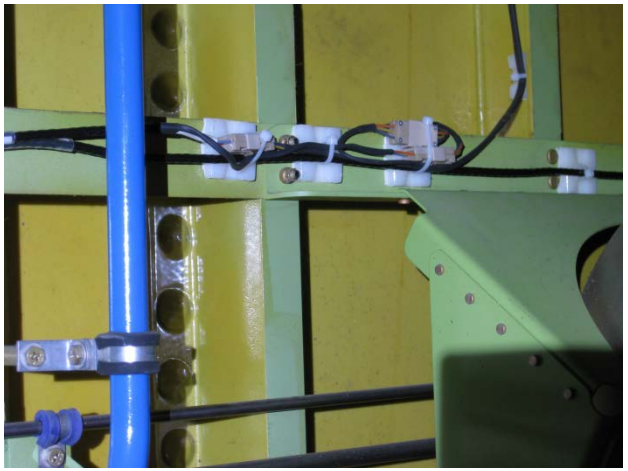
Devil is in the details

Lessons Learned

- Need better specification on the tie-down points.
- Diluted application of FVB and use of smaller and more delicate reapplication of rivet sealant (smaller, artist paint brush) – could allow for better visual inspections.
- Use of 10-sensor kits was good, but need extras for ‘oops’.
- Cabin interior crew was in and out so some coordination was needed – but SHM did not impede progress on adjacent tasks.
- CVM Install Workshop – was a good activity.
- Job Cards/T-sheet - made things more flexible rather than changing the Job Cards and going back through the full approval process.
- Education Process within Delta – Needed to be broader, more efficient.







Flight Test Data

- Repetitive inspections every 90 days.

- Goal is to produce the data package with 1 to 1.5 years of monitoring (5-6 readings after installation).
  - Combine this with the lab performance data at Sandia.
  - With the Baseline data, that is 5 checks for a total of 70 sensors X 5 checks = 350 data points.

- Review by Boeing ARs and presented to the FAA for approval.
  - Visual inspection (assume DVI = 2” long crack).
    - Sensor fingers placed between fasteners => 0.5” crack detection.
    - Boeing desire for side-by-side comparisons with visual.
    - Fuel vapor barrier and cap sealant in the way of visual.
      - Boroscope to confirm.

Flight test data accelerated to benefit FAA program

SHM Local/Global Approval

- CVM procedure already in NDT Manual, but needed to be adapted for application.

- Delta internal Engineering Documents and Job Cards created = 'Minor alteration' under Delta's 14 CFR 121.379(b) authority.
  - If this Service Bulletin were 'safety' instead of 'economic', then it would be a 'major alteration', requiring FAA (or DER) approval.

- To take credit for the sensor inspections versus the Maintenance Program, we would need Boeing AR/FAA approval.
  - AR approval is needed to bless the alternate inspections. We would need this if we wanted to substitute the alternate inspection for the existing inspection. Example includes not opening up an area for a HFEC or visual and instead use a sensor.

- Flight Test Data
  - 90 day repetitives (temporary)

CVM Sensors in NDT Manual – but adoption is slow

Current Project Approval Path

- Boeing (AR) receives the CVM performance data package via Customer Support NDT Engineering (John Linn).
  - Lab tests, flight tests, previously acquired data.
  - Other sensors must have this data prior to approval!
- Delta requests an alternate approval for entire 737NG fleet.
  - Use CVM inspection instead of Visual Maintenance Program
- Boeing approves alternate actions in some cases and recommends approval in other cases (depends on category of activity).
- FAA makes final approval based on data package and Boeing recommendations (FAA-SACO).
  - Coordination with Seattle ACO: 737 Wing Engineer, Lead Engineer, & ACO coordinator.
- Boeing can go the step further and recommend a “Global approval” to allow CVM use on all 737NG aircraft (preferred).
  - Boeing modifies SB to allow CVM on the 737NG Wing Box
  - Another option is for Boeing to issue a Service Letter that allows CVM use on 737NG wing box.

Delta will go to Boeing, FAA for alternate approvals

Future SHM Approvals

- Future is 'condition based maintenance' program vs scheduled.
  - Philosophy shift.
  - Hard to reach areas, laborious access.
  - Early warning system; Proactive mtc.
- Success dependent upon OEM and FAA 'side-by-side' timeframe.
  - Get comfortable with new technology/philosophy.
  - Operator pay-back, financials directly dependent upon this.
- Positive response of "Boeing should look for as many SHM applications as possible and start putting SHM solutions into action."
- Some sensor programs could go the Supplemental Type Certificate (STC) route from either the operator, sensor vendor, Boeing, or any combination.
  - For STCs, OEMs shy away from supporting; MRO must have resources to handle (Engineering, Inspection).
  - Operators wary of an OEM having control of everything.
    - OEM has to balance their 'time and money'.
- Establish the framework by which operators and sensor vendors can satisfy concerns that Boeing and FAA may have.

Initial approvals will unleash torrent of applications

Other applications

- Other Potential CVM Applications –large focus on the Long Beach fleet, which is a different FAA office (underscores need for this program & guidance).

Some Potential SHM Applications:

- 737 aft pressure bulkhead
- 737 center wing box spar fitting
- 747 fuselage
- MD-88 and DC-9 substructure
- MD-88 belly skin
- MD-88 and 90 Stringer Cracking
- 767 frames
- MD-88 and MD-90 vertical & horizontal stabilizers

No shortage of ideas for sensor usage

737NG Aft Pressure Bulkhead

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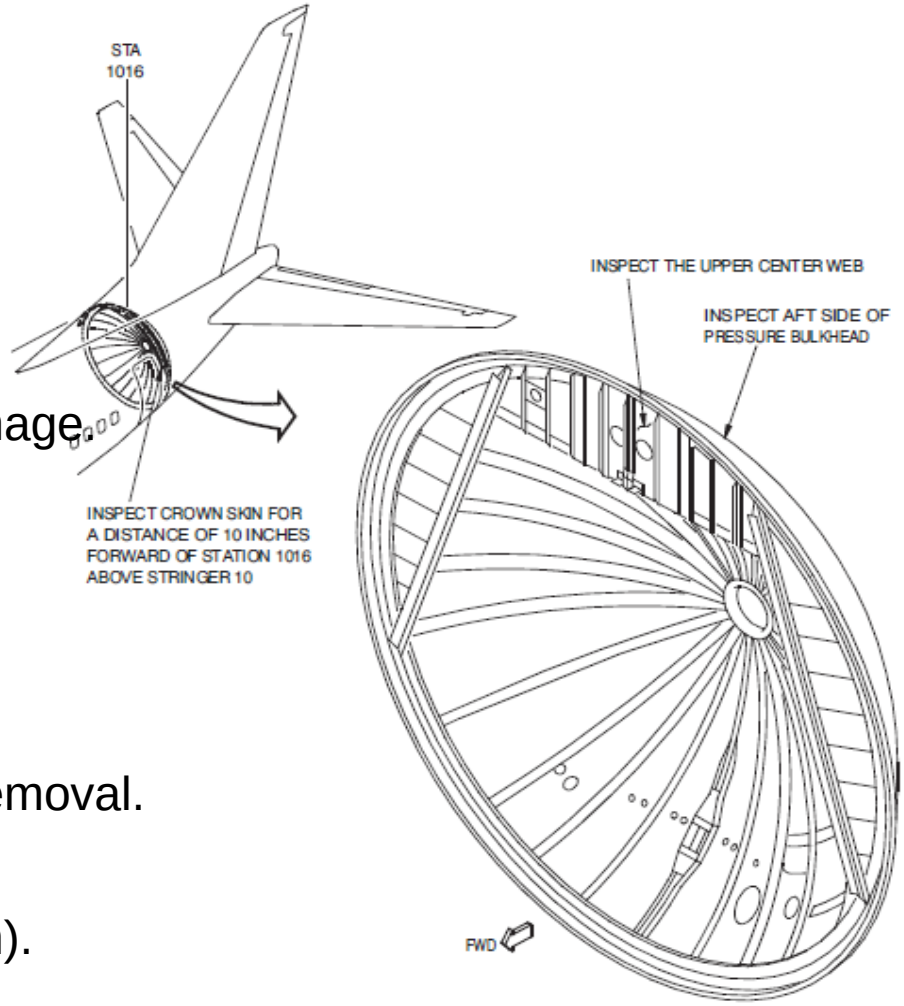
SB 737-53A1238/AD 01-21-51:

- Visual for cracking.
- Incorporated into AMM Ch 5 for:
  - –Hard Landing
  - –Overweight landing
  - –Severe Turb
  - –Tail strike
- Inspect Fwd side if aft side LFEC damage.
  - –Galley removal = 150 mhrs/insp
- Potential sensor on aft side (Human Factors).



Pros:

•Big savings, avoiding open-up/galley removal.

Cons:

•Unknown Payback period (event driven).
•Up-front cost.
•AD, requires AMOC.

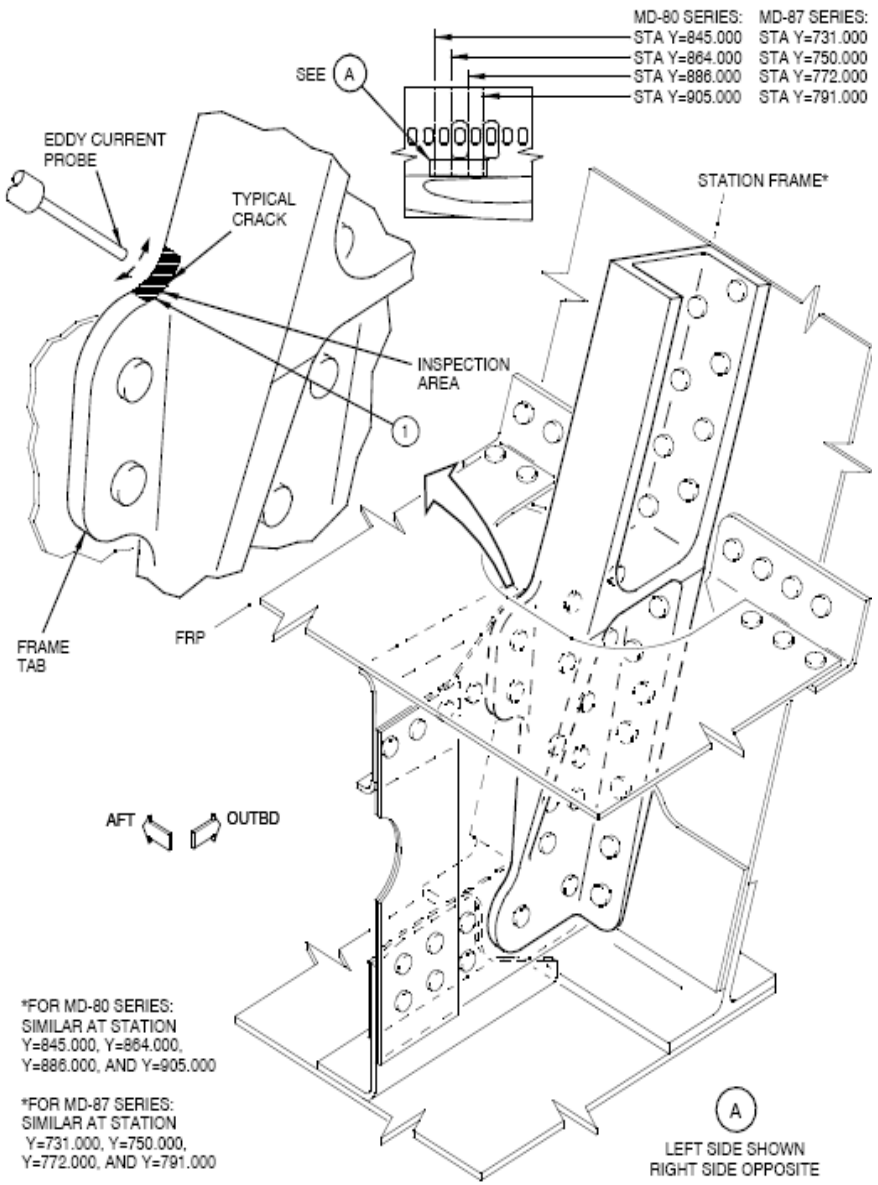
MD88/90 Overwing Frames

SB MD80-53A301:

- Visual and HFEC of Overwing Frames.
- Threshold: 20,000 cycles or 24 months wof.
- ***Repeat inspection: 9,300 cycles***

(4.5-5 years based on usage)

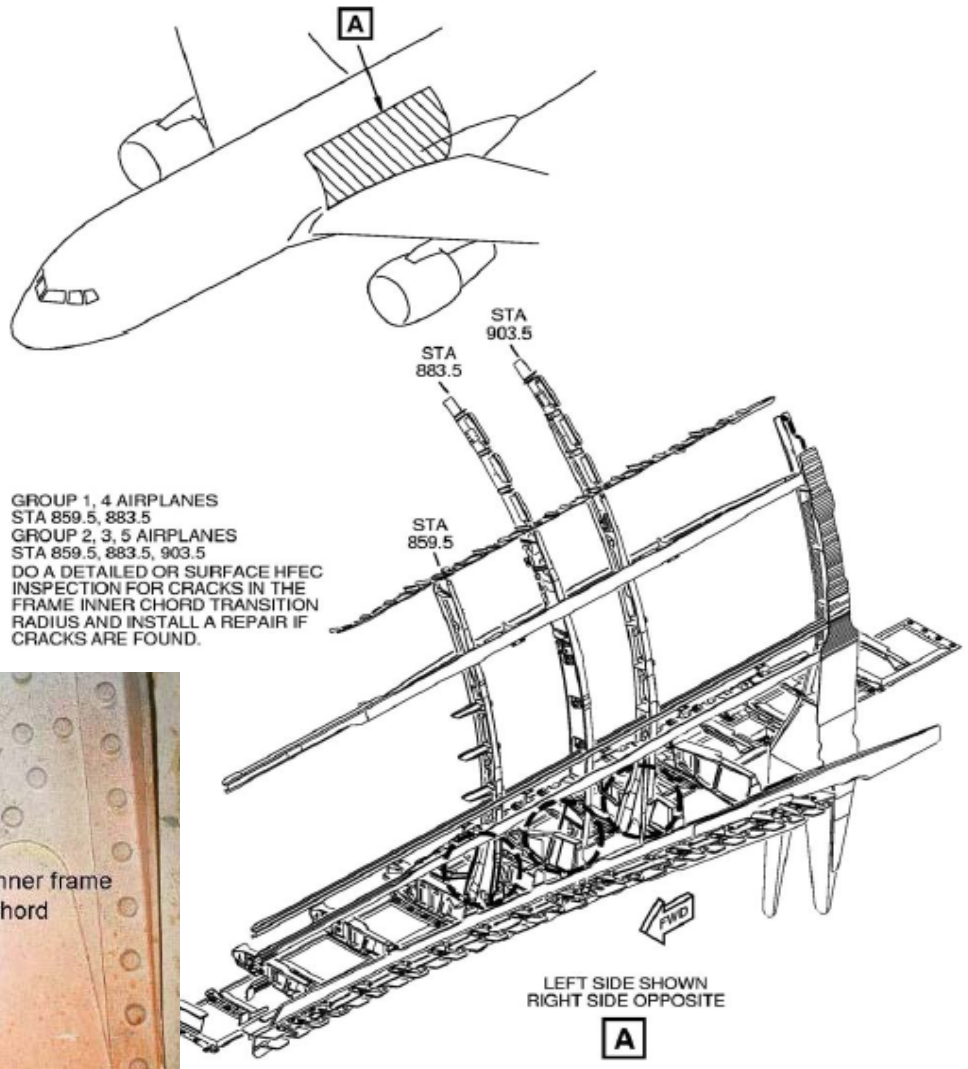
- 4 operators, 6 instances of cracking (found visually at HMV).
- Handful of findings at Delta.
- Major impact to fleet (2/3 special schedule).

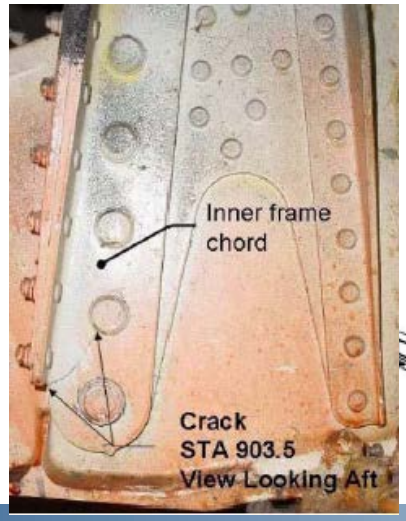


767 BS 903.5/883 Frame Inner Chord

SB 767-53A-0209:

- Visual and HFEC of 3 frames
- Threshold: 14,000 cycles or within 3K of SB release, wof
- Repeat inspection: 3,000 cycles if DVI, 6,000 if HFEC
- Post repair inspection 12K cycles after installation
- 25 mhrs to accomplish inspections
- Affects AD 2003-18-10
- Required for Winglet mod
- Lots of findings at Delta





Summary

- SHM adoption into Maintenance Programs has faced issues.
- Solution: FAA program to move from ‘prototype’ to ‘mainstream’
  - Delta will write the guidance/blueprint for SHM certification.
- Extensive coordination
  - Internal: NDT Programs, Fleet Engineering, Supplier Ops, Finance, Planning, Maintenance Programs, Process Control.
  - External: Delta-Sandia-AEM-SMS-Boeing-AAR-FAA.
- Installs completed at Delta, Q1 2014 (Repetitives on-going).
- CVM Lab test data.
- CVM Flight test info.
  - “Challenges”, Lessons learned.
- Certification process to streamline SHM usage.
  - Boeing tasks, FAA interfaces & approvals.
- Project completion: Path paved for future SHM adoption.

Questions?

KEEP CLIMBING

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