

Testing for Certification of CVM™ Sensors on the 737NG Aft Pressure Bulkhead

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ABSTRACT

Boeing has invested in the development of health monitoring sensors over the years and is currently working multiple projects to implement such technology as viable inspection methods. In 2016, Boeing added Comparative Vacuum Monitoring (CVM™) sensors as an alternative inspection method on the 737NG Center Wing Box fittings utilizing an economic service bulletin. In 2018, Boeing partnered with Anodyne Electronics Manufacturing (AEM) Corp and Delta TechOps to pursue using CVM sensors on the web of the 737NG Aft Pressure Bulkhead as an alternative inspection to Service Bulletin (SB) 737-53A1248. This is a safety bulletin due to reported in-service cracks on the 737 classic models and is mandated by the FAA with an Advisory Directive (AD). In 2022, Boeing launched the certification project.

This paper will cover some of the testing that went into the certification of CVM sensors for this targeted application. Boeing has received FAA approval for their method of compliance issue paper and certification plan. Boeing has completed all tests and demonstrated that the CVM sensors are as effective as low frequency eddy current (LFEC) inspections for this application. Service Bulletin (SB) 737-53-1418 is being developed to allow operators to use CVM for this application. Boeing is currently finalizing the certification documents for submission to the FAA.

CVM sensors were installed at the critical location - the web to “Y” chord attachment between stringers 5 to 7 on the left side and stringers 5 to 9 on the right side. The proposed CVM option will demonstrate equivalency to LFEC and utilize the same inspection interval. The CVM system is expected to reduce the inspection time from 24 hours to 15 minutes by eliminating the access removals (aft galley, insulation blankets) or tailcone entry, needed to allow inspector admission to conduct the traditional nondestructive inspection.

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INTRODUCTION

Structural Health Monitoring (SHM) is now at a level of maturity for consideration for applications on primary structure of commercial aircraft. SHM sensors can provide active data collection, during aircraft flight operation. Or passive data collection, on ground during routine maintenance inspections. SHM sensors provide data on a structures' performance. An important structural performance criterion is that it will not crack or fail.

Structural performance can be monitored by carrying out a General Visual Inspection (GVI), Detailed Visual Inspection (DVI) or instrumented nondestructive inspection (NDI). NDI methods include eddy current or ultrasound, which use a probe or transducer. All these examples involve the collection of data which is processed to determine the condition of a structure. The data allows an airline operator to make a decision or take an action. Is the condition acceptable, does it need to be repaired, or is there other actions needed?

Structural inspections are used to identify cracks in structure to ensure continued operational safety of the aircraft. Existing service bulletin inspections are implemented where there is a known history of crack findings occurring in a specific aircraft fleet and are potential candidates for SHM applications. An SHM solution, in place of traditional nondestructive testing methods, would eliminate removal and restoration tasks (seats/sidewalls/galley/laboratory) which are often required to access the inspection area and quickly return aircraft to service. There has been much research of CVM sensors such as that sponsored by the FAA and tested at Sandia Labs as early as 2000 [1-6]. The advantages of CVM are 1) it doesn't require electrical excitation, 2) it is a simple damage detection scheme, and 3) it is self-monitoring for sensor health and failure. Disadvantages are 1) damage detection only limited to surface cracking and 2) sensors must be placed on crack paths.

The CVM sensor that Boeing is using was developed by Structural Monitoring Solutions (SMS) and Anodyne Electronics Manufacturing (AEM) Corp. The CVM sensors are manufactured from multiple layers of fluorinated ethylene propylene (FEP) sheets, laminated together with an acrylic pressure-sensitive adhesive. The same adhesive is on the bottom layer and facilitates the adhesion to the aircraft. Sensor shapes are fully customizable, allowing for specific crack detection sensitivities, targeting specific crack lengths, and specific sections of the aircraft. Each sensor has three lasered channels called Gallery 1, Gallery 2, and the Compensation Gallery (Fig. 1). Galleries 1 and 2 are exposed channels on the base of the sensor and become sealed once the sensor has been installed onto a component surface. Instrument readings from Galleries 1 and 2 are used to identify the presence of a crack while the purpose of the Compensation Gallery is to provide a stable reference which improves the signal-to-noise ratio that have been influenced by environmental conditions such as temperature and humidity. Sensor Lead Socket (SLS) leads provide the ability to route the sensor network to a convenient location that's easy to access in the aircraft. When an inspection is required the socket mates to the pneumatic plug on the PM200 Instrument Lead completing the connection between the sensor network and the PM200 test instrument.

Boeing’s implementation of CVM sensors started in 2014 with testing of a solution for premature cracking of 737NG wing box clips as shown in Fig. 2 [1, 4]. SMS, Sandia Labs, Boeing, Delta TechOps and Delta Air Lines participated in the test program which included sensor design, environmental test and Probability of Detection (PoD) study to create a solution. The solution was installed on seven Delta Air Lines 737NG’s and monitored every 90 days from 2014 to 2016. In mid-2014, the test partners along with the SAE Aerospace Industry Steering Committee on Structural Health invited the FAA to participate in the study and review results. The successful completion of the test program in 2016 allowed a revision to the economic Service Bulletin (SB) 737-57-1309 to install CVM as an alternate method of inspection. That project also led to the publication of the first SHM procedure in Boeing’s Nondestructive Test (NDT) manual (737 Part 5, 57-10-01 Wing Center Section – Shear Fittings at the Front Spar) for commercial fleet support.

In 2018, SMS and Delta TechOps partnered to create a CVM solution for the 737NG Aft Pressure Bulkhead (Fig. 3) for Service Bulletin (SB) 737-53A1248. This is a safety bulletin due to reported in-service cracks on the 737 classic models and is mandated by the FAA with an Advisory Directive, AD 2005-21-06 & AD 2016-18-15. CVM sensors will be installed at the critical location - the web to “Y” chord attachment between stringers 5 to 7 on the left side and stringers 5 to 9 on the right side. This area has inspections that do not align with regular maintenance intervals. The bulletin allows operators two inspection methods – low frequency eddy current (LFEC) from the aft side every 1,200 flight cycles or high frequency eddy current (HFEC) from the forward side every 3,800 flight cycles. The aft inspections are difficult due to the small access space and the forward inspections require the removal of the aft galley. The proposed CVM option will demonstrate equivalency to LFEC and utilize the same inspection interval. The CVM system is expected to reduce the inspection time (including access) from 24 hours to 15 minutes.

Delta Air Lines began installation of the sensor network as a temporary installation for the purpose of collecting in-service data. In 2022, Boeing began the certification work for CVM sensors for the 737NG Aft Pressure Bulkhead. Point design test requirements, PoD definition and testing, and service bulletin validation were just some of the activities performed to support CVM as a viable alternate inspection method. As of March 2025, Delta Air Lines has installed 62 aircraft with the CVM system.

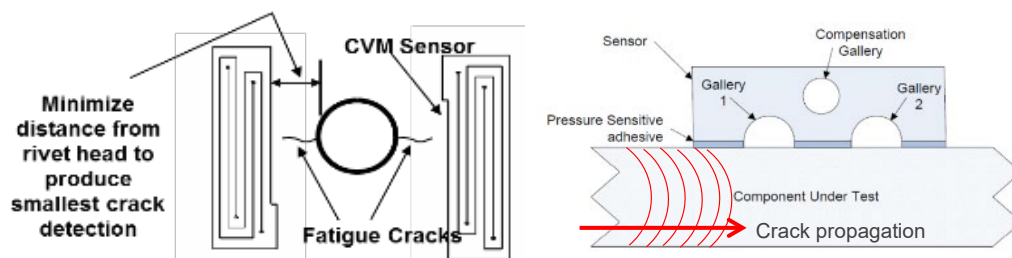


Figure 1. How the Comparative Vacuum Monitoring (CVM) sensor works

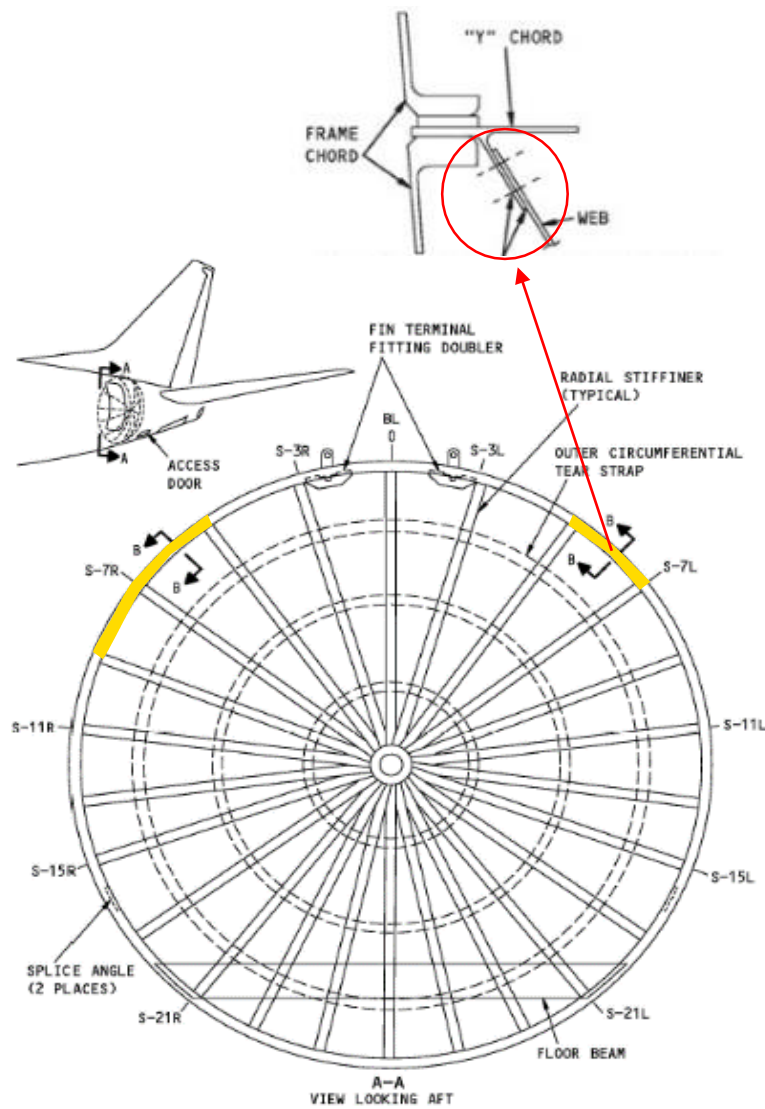


Figure 2. Frequent inspection area on 737NG aft pressure bulkhead

APPROACH

Structural Health Monitoring for the detection of structural damage is a topic on the Transport Airplane Issues List (TAIL), so a project specific issue paper is typically required. To help applicants certify SHM applications, the FAA created a generic Issue Paper in 2021 for a Method of Compliance. The FAA decided to use this approach instead of an Advisory Circular. It is a 13-page template which provides guidance for certification. Applicants can coordinate with the FAA and use the template as a starting point to create a specific issue paper for their project. It can be summarized into four topics – Performance Capability, Reliability and Durability, Continued Airworthiness, and Compliance Considerations.

FUNCTIONAL TESTS

A set of functional tests were performed to validate that the CVM system can function in a variety of conditions – temperature, humidity, altitude, vibration, icing, and tension. See Figures 3 and 4. These tests did not involve detection of a crack. The components of the systems were exposed to ensure the system could function after being subjected to environments. Boeing was able to leverage tests from the prior wing box fitting tests performed at the supplier and SANDIA. Only tension tests were needed to be performed during the CVM project.

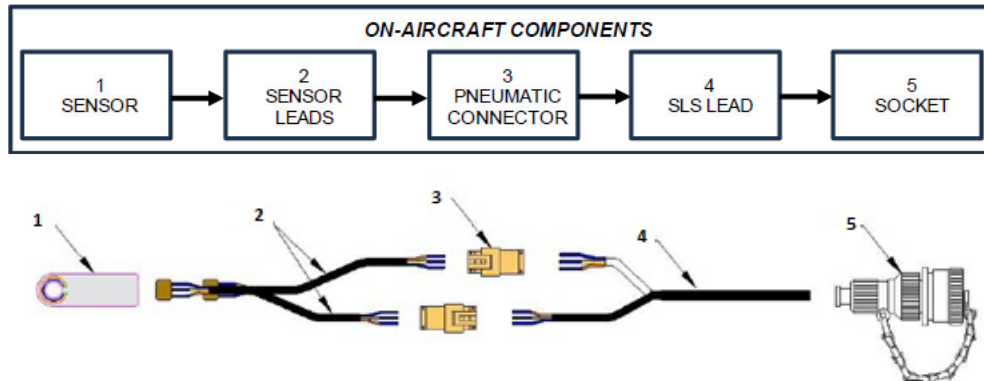


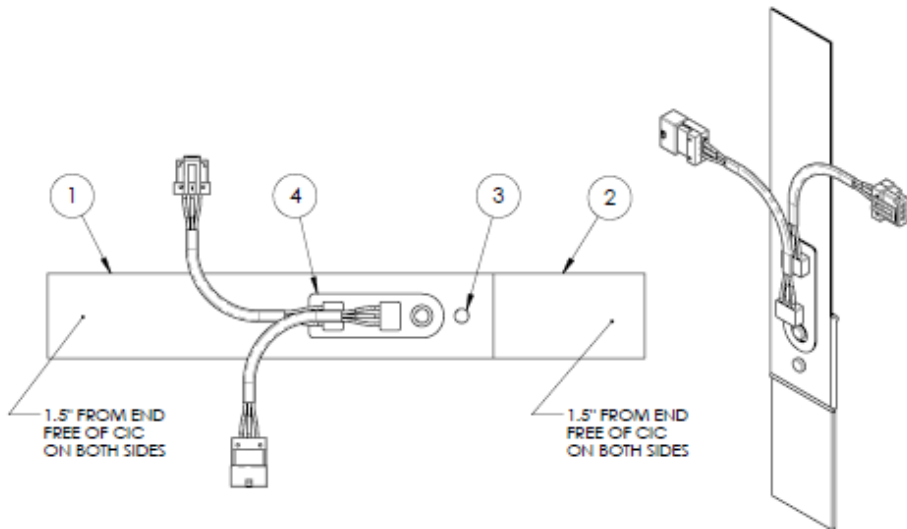
Figure 3. On-aircraft components tested



Figure 4. Components being tested

DETECTION TESTS

Additional tests (Figures 5 and 6) were performed to validate that the CVM system can detect cracks within the operating conditions on the ground. Cracks were grown under both high and low stress levels. Once a crack was detected, the coupon was subjected to temperature, humidity, altitude, icing, and compression. The initial crack detection data was used to generate a probability of detection (POD) to validate that the system was equal to or better than the traditional NDI inspection it was replacing.



- 1 Test Coupon, 737 APB, 0.032" Web
- 2 Test Coupon, 737 APB, 0.080" Y-Chord
- 3 Rivet, Solid Aluminum, 5/32" x 0.250"
- 4 Ring Sensor 8.62 mm, MF, 2x3, 120mm

Figure 5. Test coupon

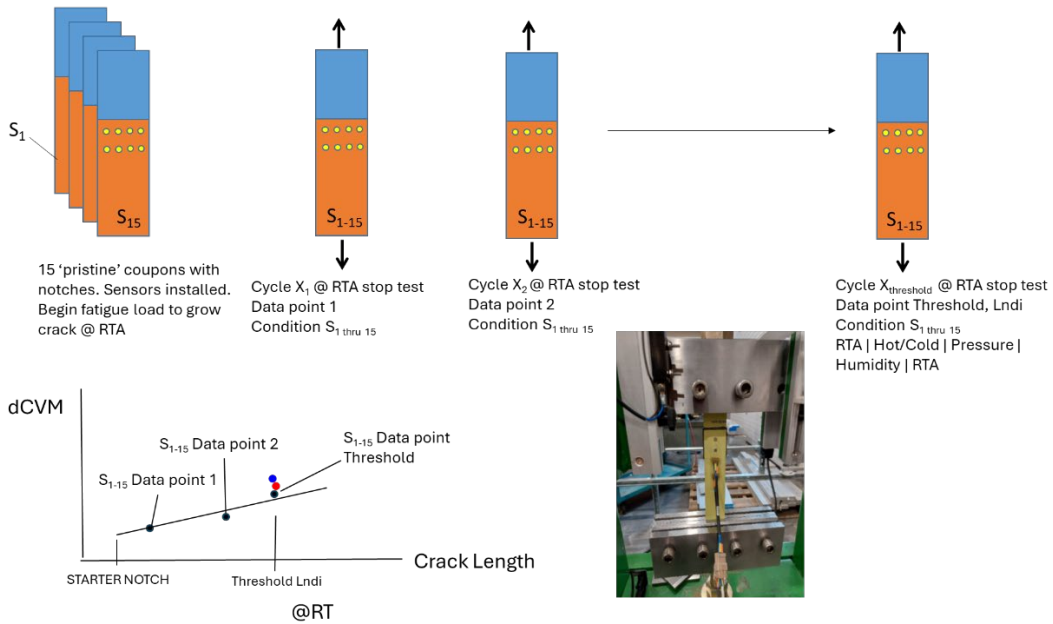


Figure 6. SHM system environmental effect at threshold PoD

COMPRESSION TESTS

Additional tests were performed to validate the CMV system can detect cracks under compressive loads that could close the air leak path. A special fixture was designed to prevent the coupon specimen from buckling (Figure 7). POD coupons with existing detectable cracks were used to show that there is no effect in detection for configuration.



Figure 7. Compression Test Setup

MAINTENANCE ACTIVITY TEST

This test was conducted to understand the effects of normal aircraft maintenance activity performed near the CVM sensors. The primary concern was the application of corrosion inhibiting compounds (CIC). This is a penetrating surface compound that displaces liquids to prevent corrosion. It was determined that a 'Warning' stencil would be placed near the CVM system to alert maintenance personnel to take defined actions to prevent contamination (Figure 8).

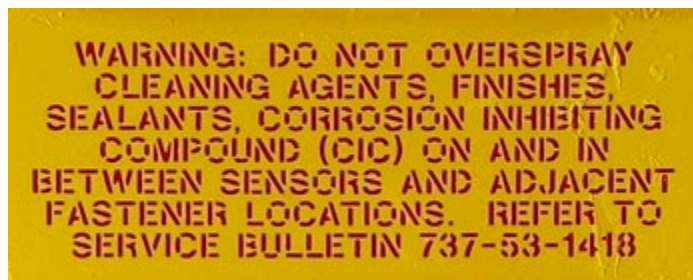


Figure 8. Warning Stencil

LOW STRESS TESTS

Additional tests were accomplished at extremely low stress to validate that the primer and CIC surface finish would separate under the extremely low stress levels and allow an air leak path for CVM sensor detection (Figure 9).

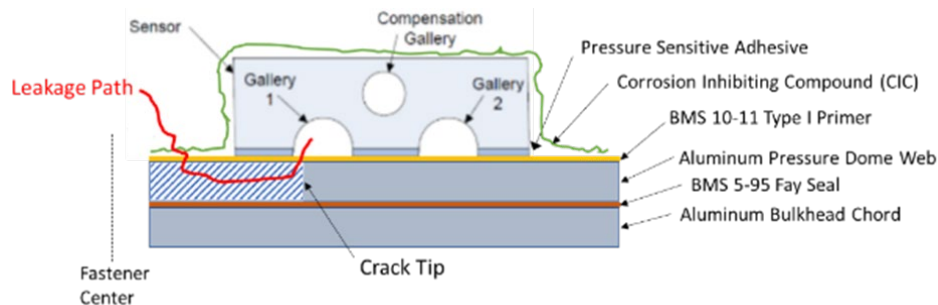


Figure 9. Air Leak Path for CVM sensor

RESULTS AND DISCUSSION

The certification process for the 737NG Aft Pressure Bulkhead included additional tests to verify the performance of the CVM sensor would allow crack detection for compression loads, low stress and aircraft maintenance activities. The CVM sensor passed all load tests, and a preventative action was implemented for maintenance actions.

However, the FAA and Boeing – Safety and Airworthiness community are considering that the traditional NDI still be a part of the continued airworthiness program until sufficient in-service CVM sensor performance is obtained. The most important assistance needed from the IWSHM community, is to develop empirical or statistical methods to validate SHM technology as the single accepted inspection method in future applications. If this challenge is not met, the economic benefit of SHM in aircraft inspection will not advance.

CONCLUSION

During the project, Boeing experienced multiple challenges and lessons learned. For testing, we had many discussions to define the appropriate test requirements for the targeted location and which factors could influence the sensors for durability and detection capability. The team had to develop multiple test article designs to initiate cracks at the desired location and avoid growing multiple cracks. For certification, there were many discussions to define the appropriate path for this novel inspection method since it is being applied in a safety critical location. As for the service bulletin, Boeing went through many iterations to address the impact of other inspection programs and define how best to incorporate CVM as an optional inspection program. The service bulletin has been routed to airline operators for review. Boeing currently in discussion with the regulatory agencies FAA and EASA as they begin to review our certification plan and documents. Release of the Service Bulletin with FAA approval is expected to be December 2025.

ACKNOWLEDGEMENTS

These tests were in support of Boeing's certification project PS22-0251, "737NG Fuselage – Body Station 1016 Aft Pressure Bulkhead – Inspection for Web Cracks at the Y-Chord" with support from AEM Corp and Delta TechOps. They have made significant contributions to the project. The authors would also like to thank Dennis Roach from DR Engineering for his support.

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