# SHM QUALIFICATION PROCESS AND THE FUTURE OF AIRCRAFT MAINTENANCE

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**Keywords:** *Structural Health Monitoring, Qualification Process, CVM, LW, Aircraft Maintenance*

## Abstract

*Structural Health Monitoring (SHM) is a tool that has the potential to revolutionize aircraft maintenance. When compared to current Non Destructive Test (NDT) technologies, SHM can reduce the amount of time and burden of the inspection tasks, it can provide facilitated structural damage detection in areas with restricted access with early detection of flaws, and also allow the reduction of maintenance costs due to less time-consuming and less complex maintenance procedures.*

*There are two different types of application for SHM technologies, Scheduled Structural Health Monitoring (S-SHM) and Automated Structural Health Monitoring (A-SHM), which are commonly recognized by the SHM community. Installation, integration and operation requirements depend on each type of application. Aircraft industry requires reliable SHM systems. In order to determine systems' reliability, Embraer selected two different SHM technologies for a more in-depth study.*

*These two SHM technologies were extensively investigated through ground tests with metallic and composites structural components and assemblies and through tests on-board of a flight test aircraft. After demonstrating strong results on ground tests and in the flight test aircraft, Embraer decided to develop a project using the S-SHM approach for the qualification of Comparative Vacuum Monitoring (CVM) and Lamb Waves (LW) technologies and to validate the performance of such systems in real-life operational environment. This project included laboratory tests for the assessment of detection capabilities and tests with systems installed on a number of operator's aircraft to check operational behavior.*

*Detection capability was demonstrated in terms of Probability of Detection according to the One-Sided Tolerance Interval methodology. SHM sensors and cables were installed into five aircraft operated by an airline, and were periodically assessed, demonstrating their survivability and durability in real operational environment.*

*A formal process for S-SHM implementation was established, allowing the next steps for SHM damage detection systems application. Reliable SHM systems will allow time and cost reduction of structural inspections without affecting, or affecting positively aircraft safety.*

## 1 Introduction

Aiming to meet Embraer's roadmap for the improvement of aircraft maintenance, SHM technologies such as CVM, Electro-Mechanical Impedance (EMI), Acoustic Emission (AE) LW have been studied by Embraer Research and Technology teams [1], including application scenarios for structural damage detection and the improvement of inspection tasks.

According to Airlines for America (A4A) MSG-3 document [2] and the ARP-6461 document from SAE International [3], there are two different types of application for SHM technologies: S-SHM which means the use of SHM devices for inspections at an interval set at a fixed schedule; and, A-SHM that relies on the SHM system to inform maintenance personnel that action must take place. In the Embraer perspective, S-SHM application type considers the installation of SHM sensors, cables and connectors into the aircraft with periodic scheduled structural inspections being performed on-ground with ground support equipment. And, the A-SHM application type will be the installation of not only sensors, cables and connectors, but also SHM interrogators and data recorders into the aircraft. In such a case, the structural inspections would be performed automatically at any time in small time intervals or continuously, what would require to the system to have, at least, a power supply during the regular aircraft operation. These two types of SHM application have different installation, integration and operation requirements depending on the presence of components, such as interrogators, installed in the aircraft, eventually powered up during flight and connected to avionic systems for data transfer.

For both S-SHM and A-SHM applications, reliable SHM systems are required. Two SHM damage detection technologies were selected by Embraer for a more in-depth study, which are CVM and LW.

## 2 Embraer Background on SHM

Embraer has performed laboratory tests with CVM such as the application of the technology for the continuous inspection of rivet holes in a metallic R&D barrel test, the application in different locations of the Full-Scale Fatigue Test of the company's E-Jets aircraft - such as shear clips, splice joints, windows frames and rivet holes - and application in many other structural components and assemblies [4]. Figure 1 shows examples of CVM sensors installed in both the R&D barrel test and in the E-Jets Full-Scale Fatigue test.

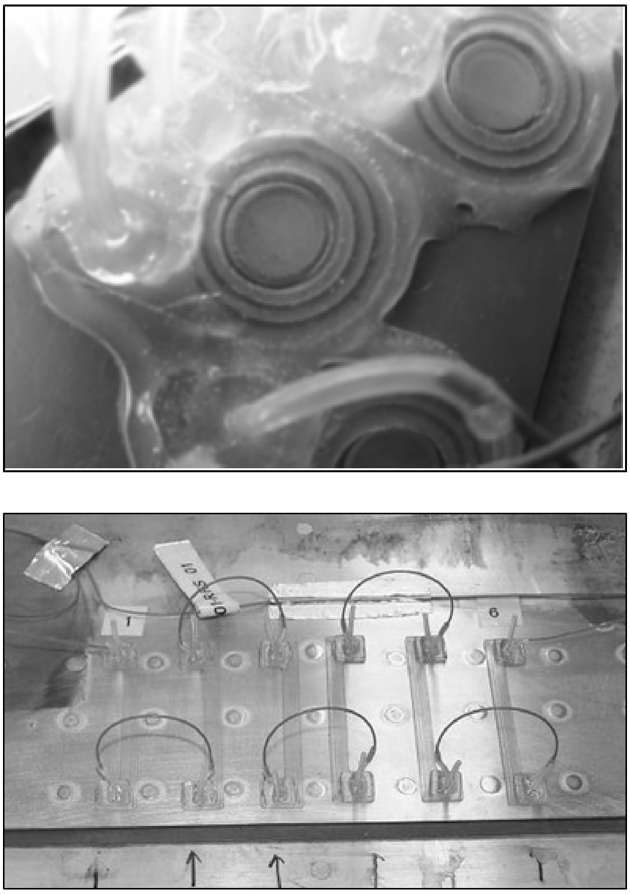

**Fig. 1** Examples of CVM sensors installed in a metallic R&D barrel test and in the E-Jets Full-Scale Fatigue test

Laboratory tests with LW technology have also been performed in metallic and composite structural components (Figure 2) and assemblies, such as coupons, E-Jets Full-Scale Fatigue Test, barrel tests and others [5].

Besides the laboratory tests, Comparative Vacuum Monitoring and Lamb Waves technologies were installed in the Embraer-190 flight test aircraft in 2010, as showed in Figure 3. In this study, only sensors, cables and connectors

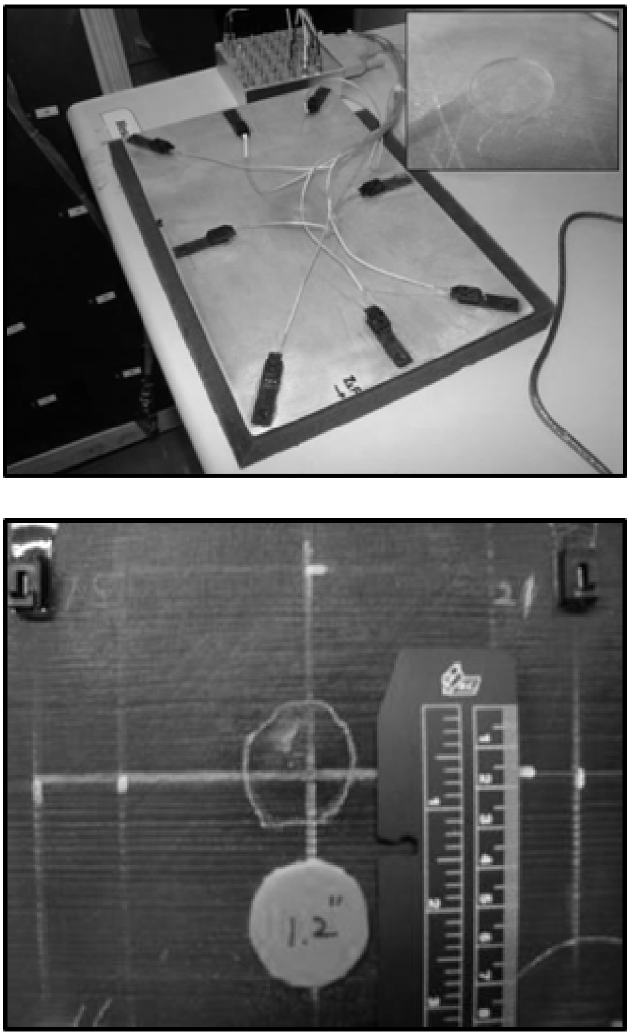

**Fig. 2** Examples of LW application for damage detection in metallic and composite materials

**Fig. 3** Examples of LW and CVM sensors installed in the Embraer-190 flight test aircraft

were installed in the aircraft. Inspections were performed periodically using ground support equipment.

## 3 Qualification of CVM and LW Technologies

After demonstrating strong results on ground tests and in an Embraer-190 flight test aircraft, Embraer decided to step forward. In an effort to move S-SHM into routine use for aircraft maintenance procedures, a project was developed for the qualification of CVM and LW technologies and to validate the performance of such systems in real-life operational environment. The work aimed to develop and carry out a qualification process for SHM damage detection systems, which includes laboratory tests (Figure 4) for the assessment of detection capabilities in terms of Probability of Detection (POD) and to verify durability, and tests with systems installed on a number of operator's aircraft to check operational behavior, survivability and stability of the systems.

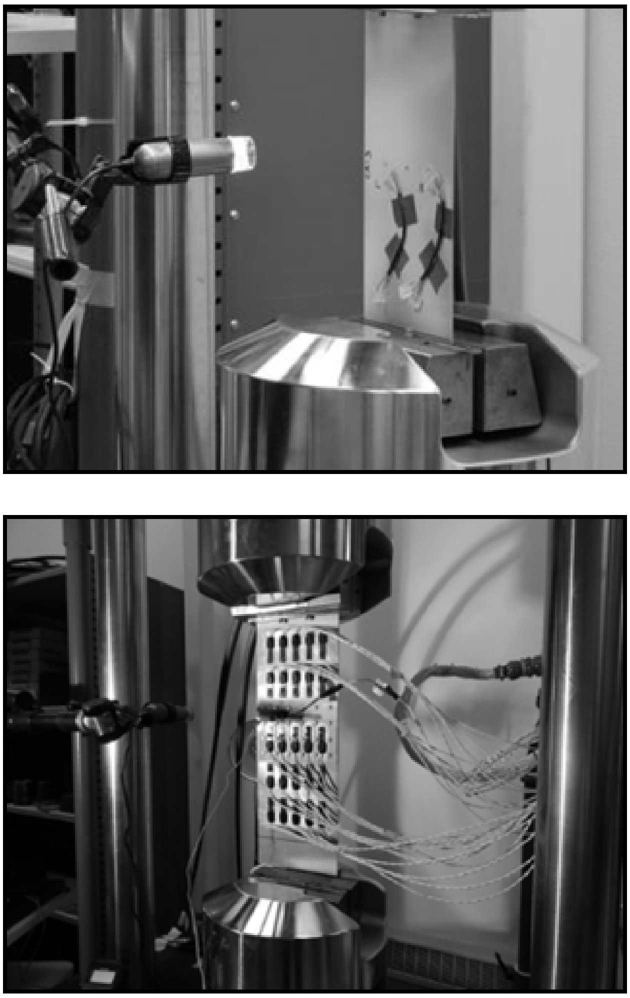

**Fig. 4** Mechanical tests for CVM and LW systems installations

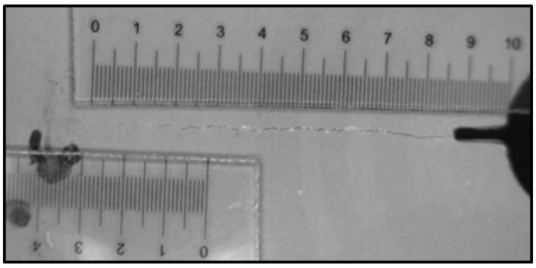

**Fig. 5** Specimen with a crack detected by CVM

### 3.1 Laboratory Tests

The aim of the laboratory tests was to evaluate two major aspects of the SHM technologies, Detection Capability in terms of POD, and Durability. Considering specific scenarios for CVM and LW solutions, the target for detection capability was to determine crack length having 90% probability of detection with 95% of confidence. Specimens used in those tests represented regions of an Embraer aircraft structure. The Figure 5 shown a crack detected by CVM sensor during a POD testing program.

The document MIL-HDBK-1823A [6, 7] presents an approach for POD determination which was originally intended for traditional non-destructive testing. Another approach for assessing the system's detection capability is the One-Sided Tolerance Interval methodology [8], which was selected for POD determination in this project.

As part of the durability investigation environmental tests were performed with CVM and LW sensors and cables installed in plates mimicking actual aircraft installations (Figure 6. These plates were submitted to hot-wet plus freezing cycles aiming to provide information about the durability of systems' components subjected to harsh environment.

**Fig. 6** Environmental Tests and Test Aparatus

## 3.2 In-service Aircraft Tests

Both CVM and LW technologies were installed into five aircraft operated by Azul Airlines in selected regions in order to verify the operational behavior, survivability and stability of the systems (sensors and cables) subjected to a real operational environment, for a period of time of at over 24 months. No damage detection was envisaged in those aircraft.

Data acquisition has been performed periodically during overnight intervention (Figures 7 and 8) allowing accumulation of a very representative amount of data. The SHM system installations involved a total of 32 CVMs sensors and 26 LW Smart Layers. Installations were performed in the facilities used by the airline for regular maintenance according to ervice Bulletins (SB) issued by Embraer on Passenger Door Surrounding and Central Fuselage II. Sensors and cables of Comparative Vacuum Monitoring and Lamb Waves damage detection technologies were installed in different opportunities.

**Fig. 7** Accessing the interface connector by removing a single panel


**Fig. 8** Data acquisition with a ground equipment

## 3.3 Results of the Qualification Project

SHM detection capability for the selected structural components was obtained with laboratory tests for both Comparative Vacuum Monitoring and Lamb Waves systems through the determination of Probability of Detection.

All data were compiled and analyzed by Embraer and then submitted for Brazilian regulatory agency (ANAC) approval. A formal process for S-SHM implementation was established with the close consultation of the ANAC, and the feasibility and the durability of damage detection systems were also demonstrated to support the validation.

## 4 The Future of Aircraft Maintenance with SHM

In the short term S-SHM has the potential to become a reality, where damage detection systems' components (such as sensors and cables) will be installed in the aircraft for the accomplishment of scheduled inspection tasks, providing an alternative to traditional Non Destructive Inspection (NDI) methods, for instance.

During maintenance inspections ground support equipment will be attached to connectors (strategically placed in the aircraft in easy access locations/hatches), sensors will be interrogated and results will be displayed immediately by these ground equipment. This will expedite inspections, providing accurate information about the presence of damage, avoiding unnecessary disassembly, reducing time and cost without affecting, or affecting positively aircraft safety.

However, current available technologies have different readiness levels for aircraft application. Demonstrating the reliability of SHM damage detection systems adequately is very important. For instance, considering the two SHM technologies involved in this work, CVM demonstrates a high level of maturity, having not so complex installation and operation procedures. It presented good performance during the tests, being considered by Embraer as a possible option for hotspot inspections (as an alternative means of compliance). Lamb Waves has also demonstrated good results on both laboratory and in-service tests, but it requires further studies in order to better understand variables which affect system responses and to develop more robust installation and operation procedures.

In the long term, with the maturation of SHM damage detection systems and their evolution to the Automated Structural Health Monitoring concept, these systems will be monitoring the aircraft structure and, when detecting an event, they will be capable to inform maintenance personnel that an action is required, leading to the realization of the Condition Based Maintenance concept.

## 5 Acknowledgements

The authors wish to acknowledge the participation and the support of the involved personnel from Embraer S.A., Sandia National Labs, Azul Airlines and Brazilian regulatory agency (ANAC).

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