DAMAGE DETECTION SYSTEMS QUALIFICATION AND THE ADVANCEMENT FOR FIXED WING AIRCRAFT MAINTENANCE PROCEDURES

A4A NDT FORUM 2022

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RICARDO P. RULLI

EMBRAER HISTORICAL CENTER

1994

Embraer is privatized, fusing technological and industry expertise with an entrepreneurial approach.

1946

Brazil launches a national strategic aerospace initiative via the Aeronautics Technical Center (CTA) and the Technological Institute of Aeronautics (ITA).

2017

Embraer is one of the world's leading manufacturers of commercial and executive jets, with substantial and growing operations in defense and security.

1969

Federal Government creates Embraer to develop aeronautical engineering and manufacture aircraft in Brazil.

BUSINESS UNITS

COMMERCIAL AVIATION

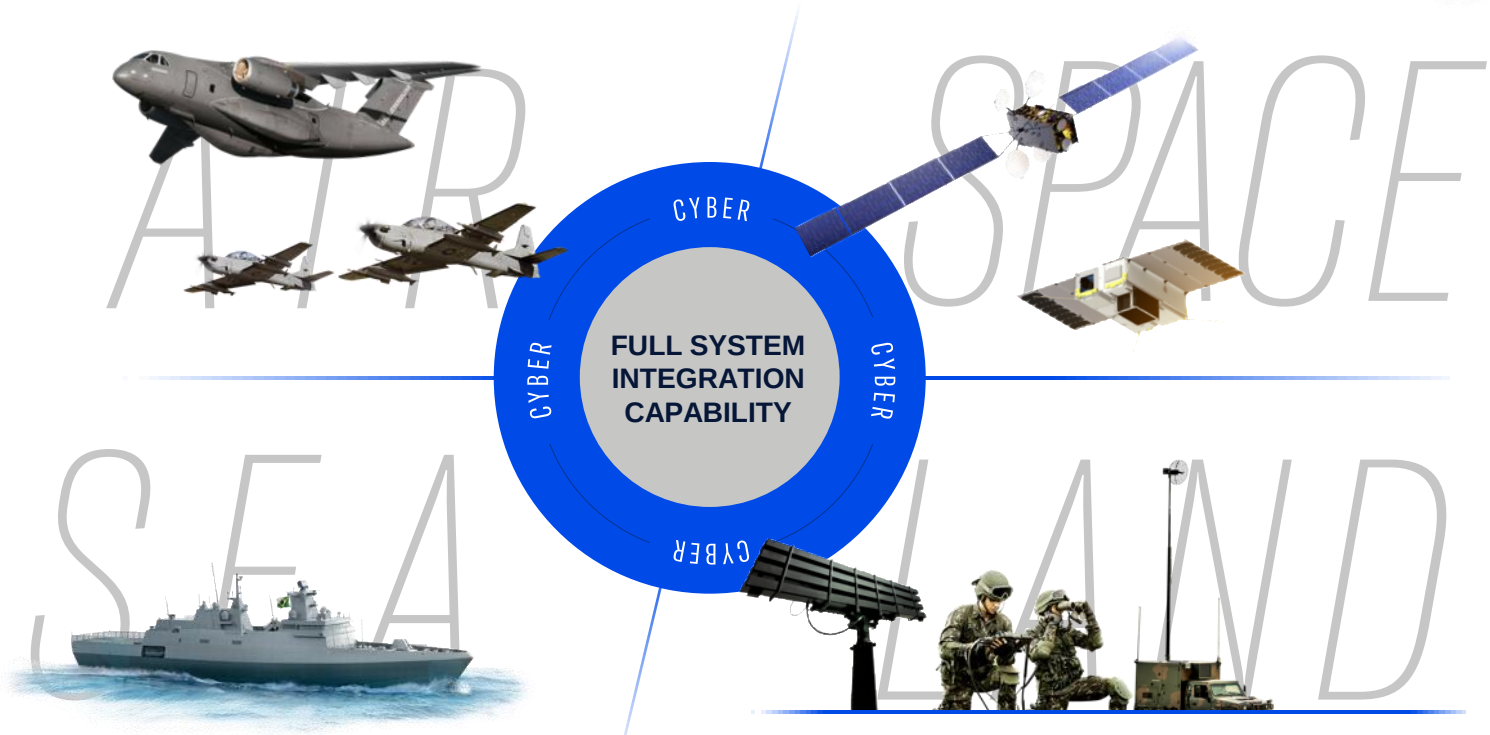
EXECUTIVE JETS

DEFENSE & SECURITY

SERVICES & SUPPORT

DEFENSE & SECURITY

A GLOBAL LEADER IN DEFENSE & SPACE



TECHNOLOGY AND PEOPLE

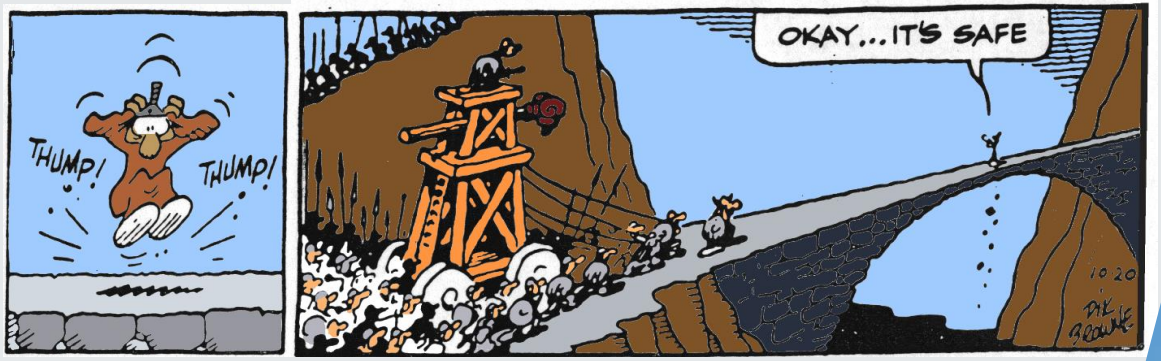
Our future first passes through our people. They are the ones who will lead us to a promising future.
Electrification, industry 4.0, internet of things, virtual reality among so many extraordinary technologies.

WE ARE MANY

17,800
All around the world

1,800
In our subsidiaries

THE GREAT QUESTION!!!



AIRCRAFT MAINTENANCE

- **Corrective maintenance** is used after the item breaks down or presents malfunction. It includes all unscheduled maintenance actions.
- **Preventive maintenance** is used to prevent failures, safety violations, malfunction, or unnecessary production costs and losses of the item. It includes all scheduled maintenance actions
- **Predictive maintenance** is to predict when failures will occur and to take preventive measures accordingly.

CURRENTLY

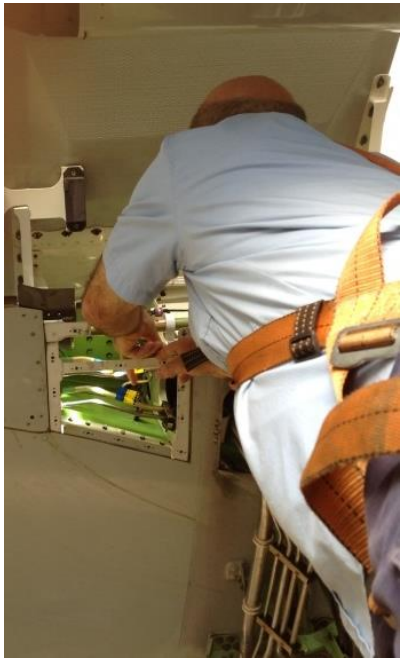
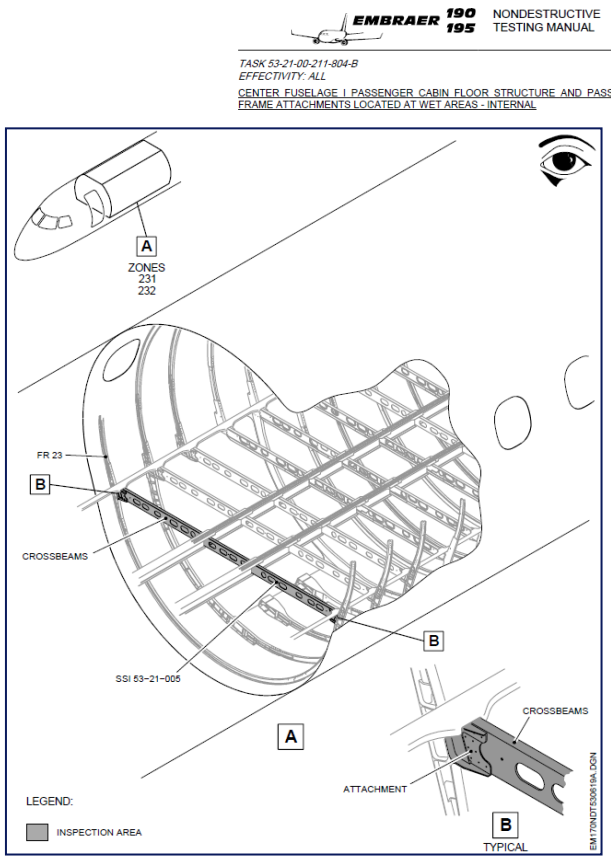
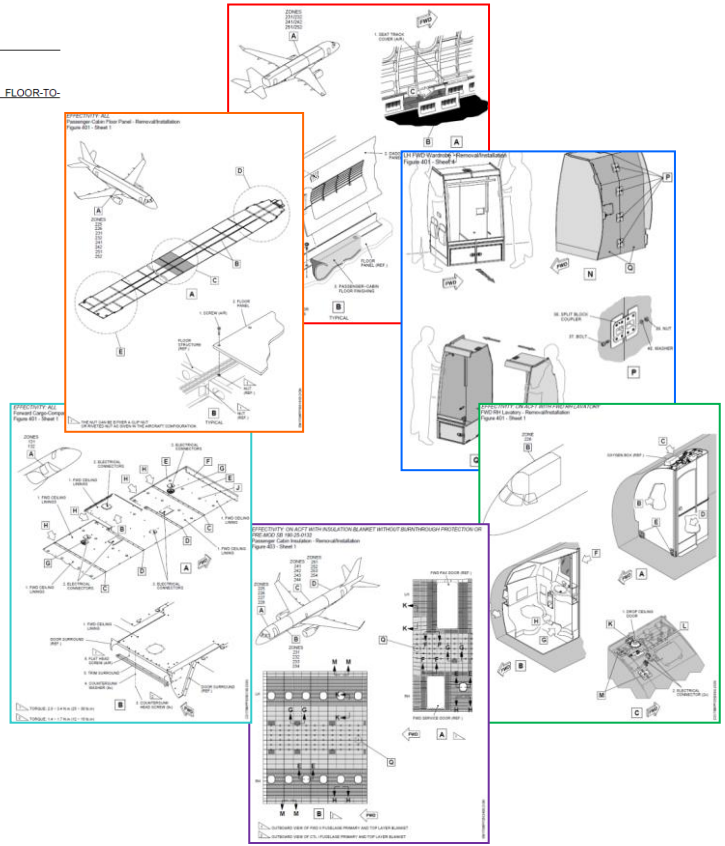


photo: West Star Aviation

MOTIVATION





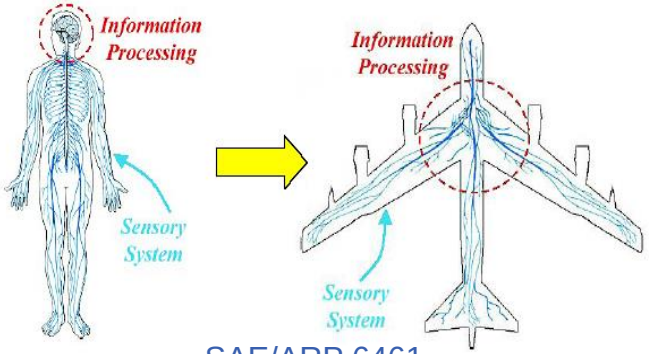
STRUCTURAL HEALTH MONITORING

For Embraer, Structural Health Monitoring (**SHM**) can provide facilitated damage detection in areas with restricted access with early detection of structural damages and reduction of maintenance costs for current and future aircrafts, besides minimizing the effects of "human-factors" during an inspection.

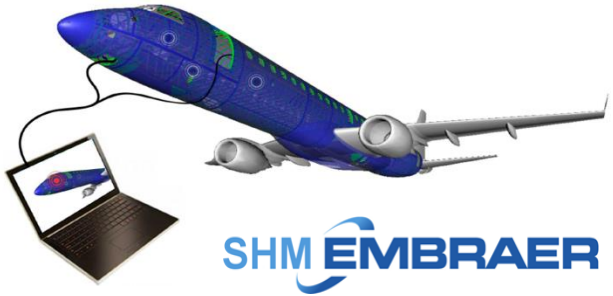
Main goal is to assure the continued airworthiness.

SHM

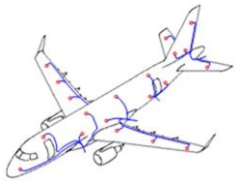
STRUCTUAL HEALTH MONITORING



SAE/ARP 6461



Direct Detection
(Damage Detection Systems)



- 5 Technologies developed
- 1 Technology under development
- 2 Technologies in qualification process
- Application on Full-Scale Fatigue Test

Assessment
(eSRM)

- eSRM - Phase 1 and 2 finished and transferred to Commercial Aviation
- eSRM Composites under development

Management
(SHM Portal, AdHUMS)

- SHM Portal was a proof of concept developed
- AdHUMS is a upgrade under development and in transfer process to Embraer Defense & Security

STRUCTURAL HEALTH MONITORING

SHM Potential Benefits

Airplane Operation and Maintenance:

- **Reduction** of inspection time.
- **Minimized** “human-factor” effects (that may also lead to safety enhancements).
- **Elimination** of disassembly processes.
- **Less costly** repairs.
- **Reduction** of operating and maintenance costs.

Airplane Design:

- Structural efficiency **improvements** and **weight savings**.

STRUCTURAL HEALTH MONITORING

- Scheduled SHM (**S-SHM**)

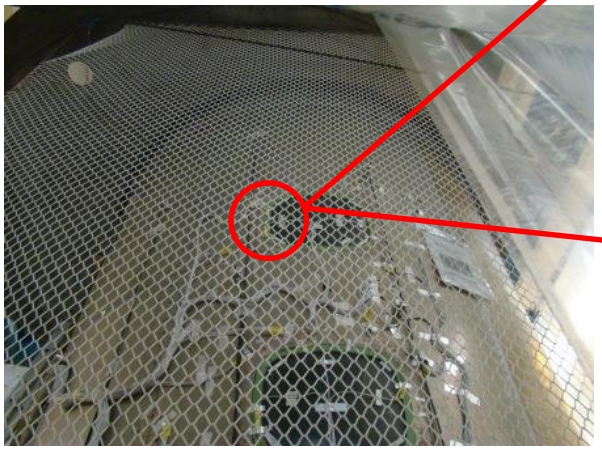
The act to use/run/read out an SHM device at an interval set **at a fixed schedule**.

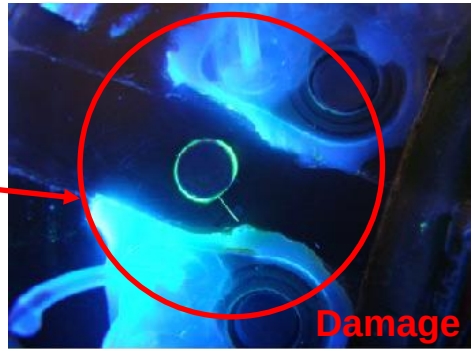
- Automated SHM (**A-SHM**)

That relies on the SHM system to inform maintenance personnel **that action must take place**.

EMBRAER BACKGROUND

R&T Metallic Barrel Test (CVM)



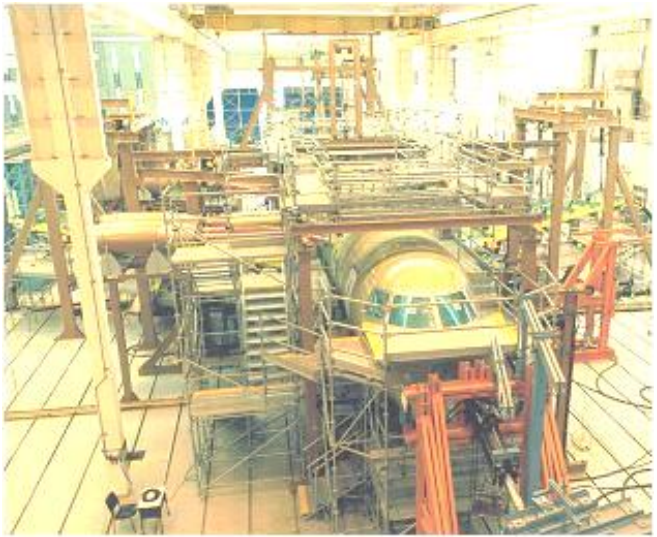


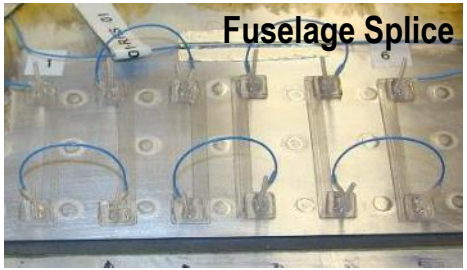
EMBRAER BACKGROUND

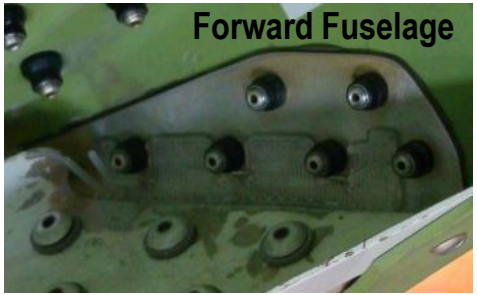
CVM

Ground Tests since 2007

E-Jets Full Scale Fatigue Test







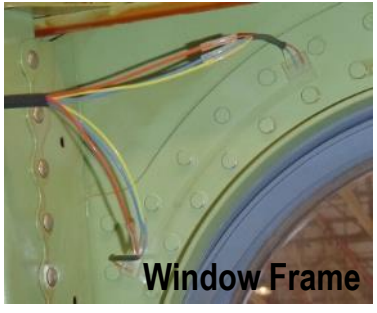
- 260 Sensors Installed (Silicone and Sheet Sensors)
- Periodic/Scheduled inspections

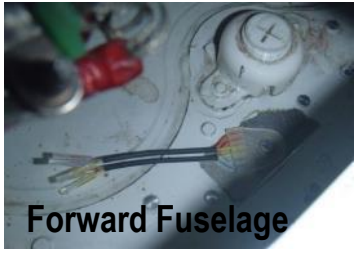
EMBRAER BACKGROUND

CVM

On-ground scheduled data acquisition using the PM200 equipment

** Courtesy Structural Monitoring Systems Ltd.*



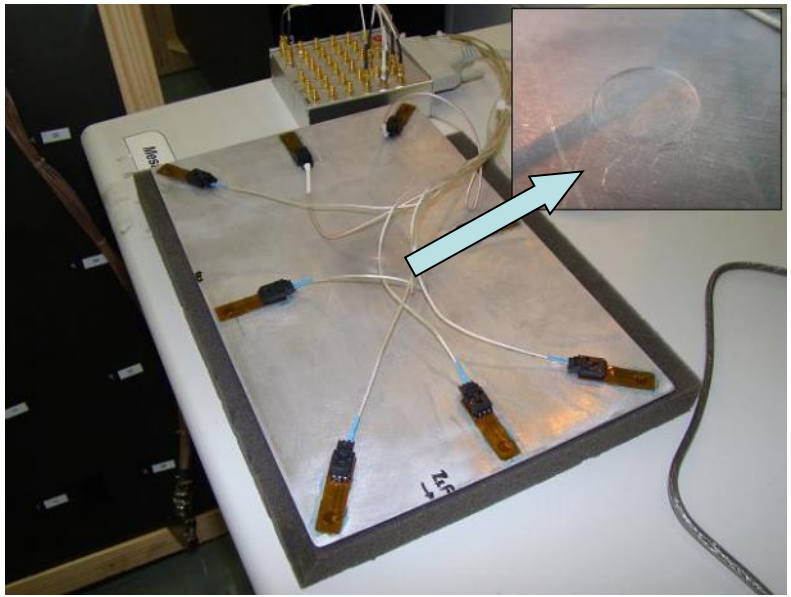


EMBRAER BACKGROUND

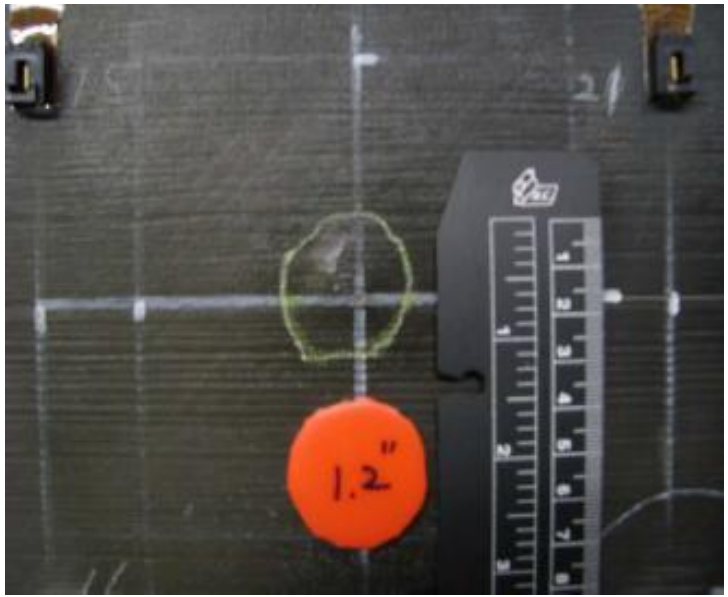
LW

Ground Tests since 2008

Thickness reduction in aeronautical aluminum



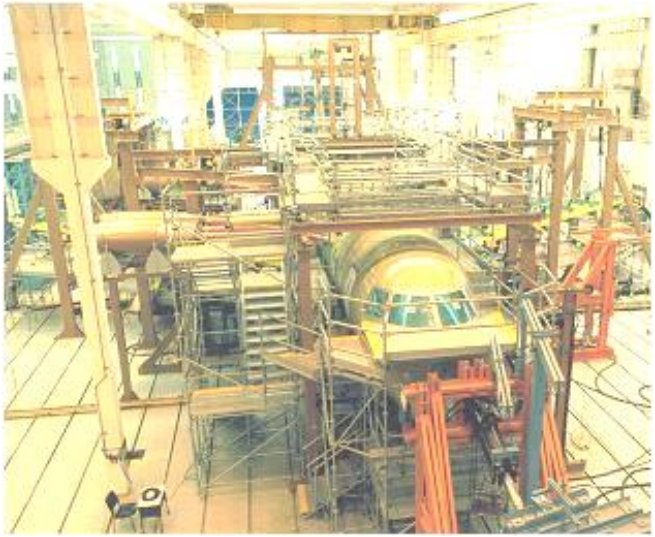
Delamination detection in CFRP



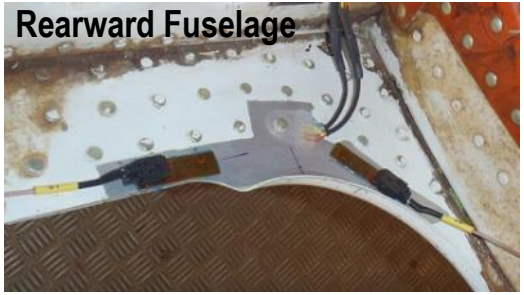
EMBRAER BACKGROUND

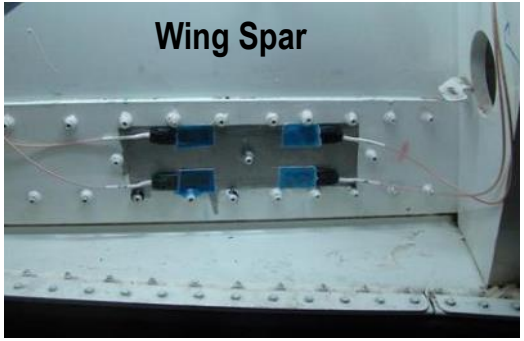
LW

E-Jets Full Scale Fatigue Test



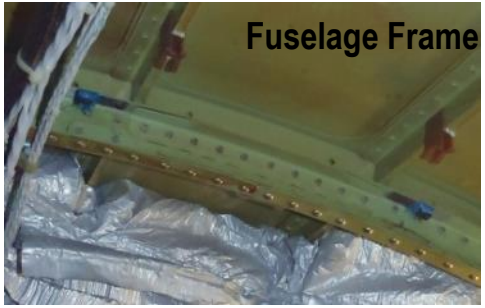
Periodic inspections





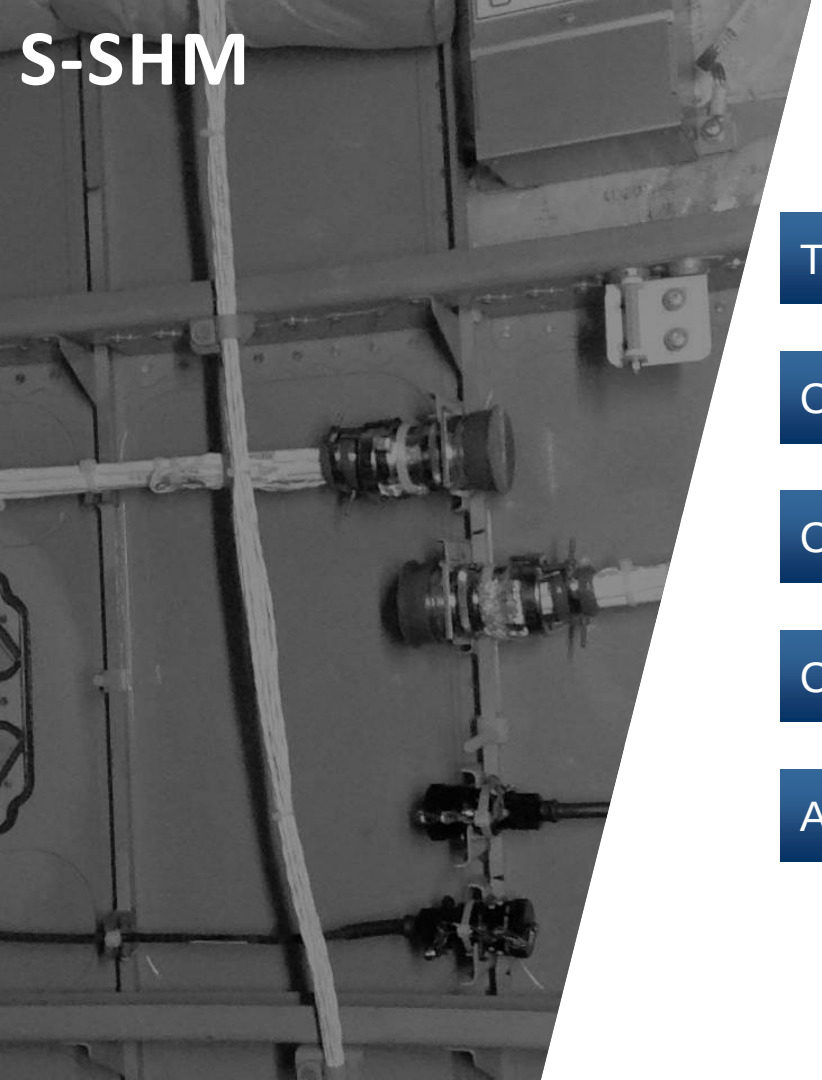
EMBRAER BACKGROUND

LW



On-ground scheduled data acquisition

** Courtesy Acellent Technologies Inc.*



What do we need?

- Technical Feasibility
- Consistent Business Case
- Compatible Requirements
- Certification Approval
- Acceptability by Operators

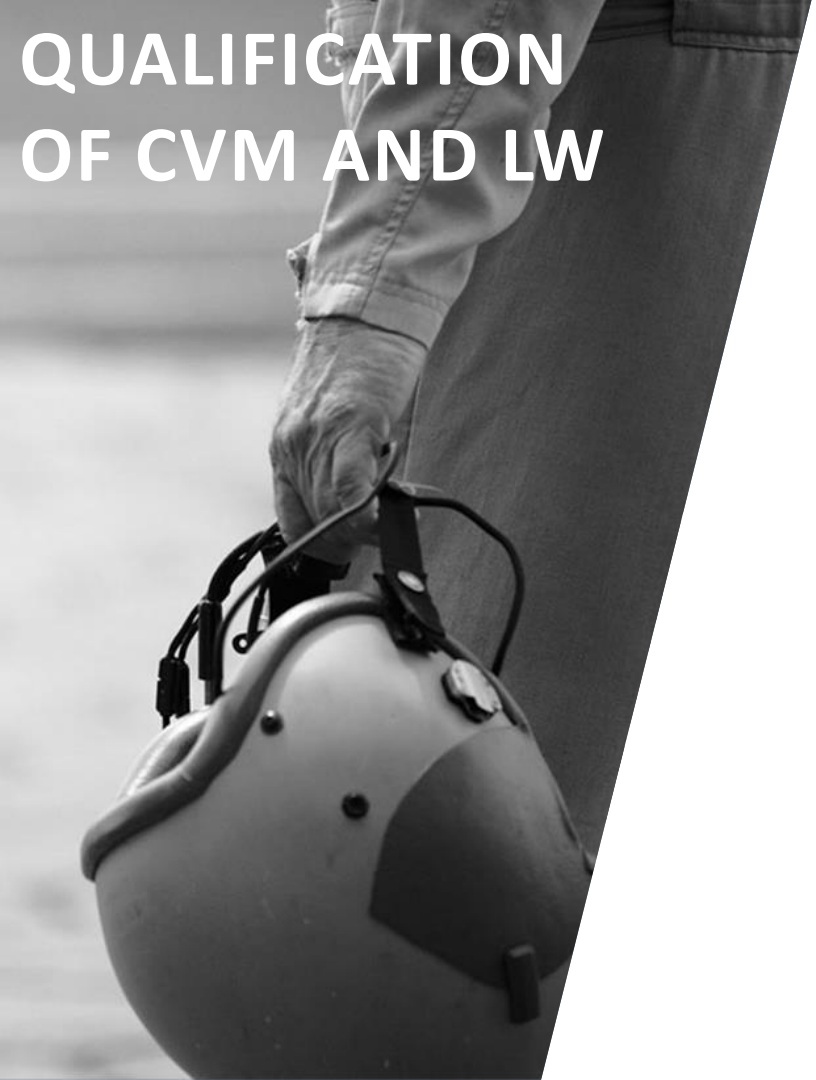
★ ★ ★ ★

SUCCESSFUL

SHM

SOLUTION

★ ★ ★ ★



QUALIFICATION OF CVM AND LW

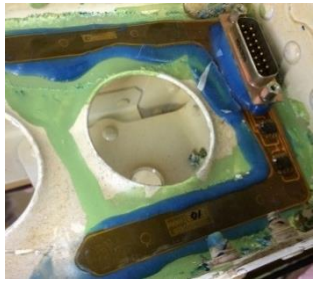
After Demonstrating strong results on ground tests and in an Embraer-190 flight test aircraft, Embraer decided to step forward. In an effort to move S-SHM into routine use for aircraft maintenance procedures, a project was developed for the qualification of CVM and LW technologies and to validate the performance of such systems in real-life operational environment.

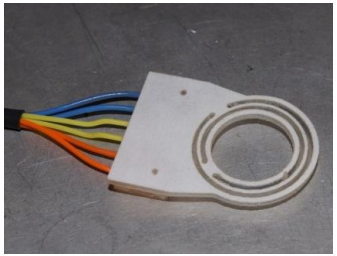
The work aimed to develop and carry out a qualification process for SHM damage detection systems, which includes laboratory tests for the assessment of detection capabilities in terms of Probability of Detection (POD) and to verify durability, and tests with systems installed on a number of operator's aircraft to check operational behavior, survivability and stability of the systems.

QUALIFICATION PROJECT

Objectives

- Qualification (formal process) of two SHM damage detection technologies
  - Comparative Vacuum Monitoring (CVM)
  - Lamb Waves (LW)



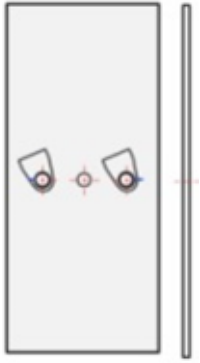


- Laboratory Tests for Environmental/Durability and Probability of Detection (POD)
- Installation and monitoring of sensors and cables into in-service aircraft
- Close consultation of ANAC (Brazilian Civil Aviation Agency)

QUALIFICATION PROJECT

- Laboratory Tests – Detection Capability

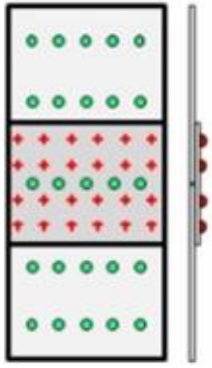
Comparative Vacuum Monitoring (CVM)



AL 7475

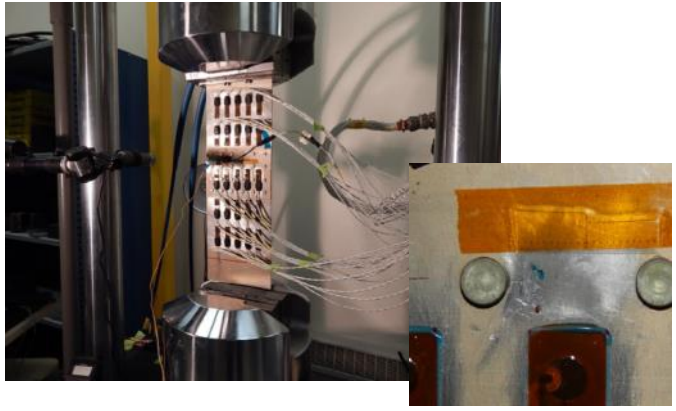
Comparative Vacuum Monitoring

Lamb Waves (LW)



AL 2024

Lamb Waves

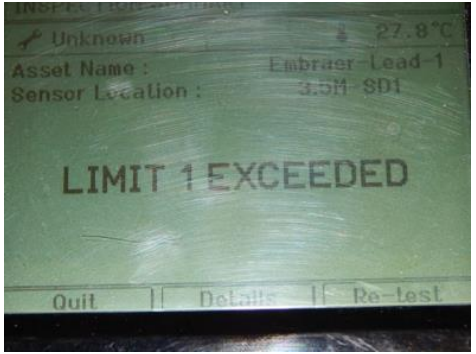


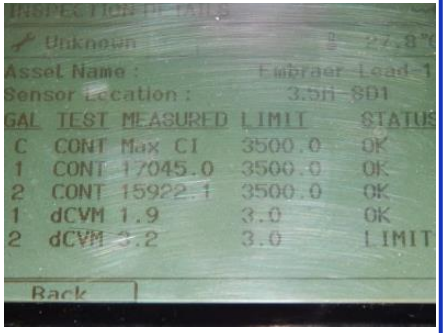
QUALIFICATION PROJECT

Laboratory Tests – Detection Capability

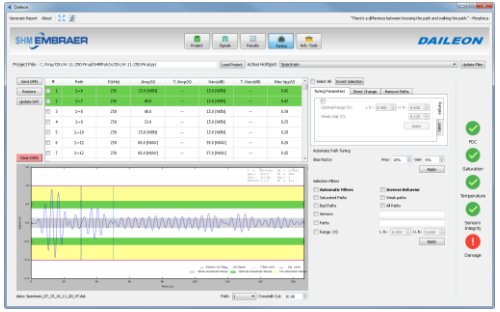
To determine crack length that corresponds to a level of 90% Probability of Detection with 95% Confidence (90/95 POD) – One-sided Tolerance Interval method

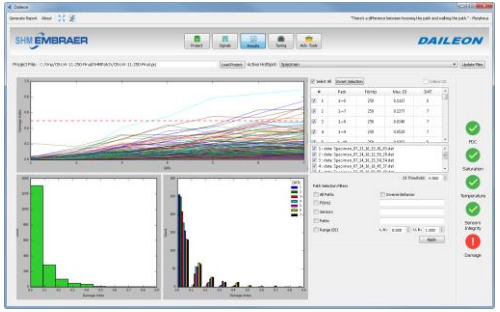
Comparative Vacuum Monitoring (CVM)





Lamb Waves (LW)





PROBABILITY OF DETECTION (POD)

OSTI

- **Data captured is crack length at CVM detection**
- **Reliability analysis – cumulative distribution function provides maximum likelihood estimation (POD)**
- **One-sided tolerance bound for various flaw sizes:**

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

X = Mean of detection lengths

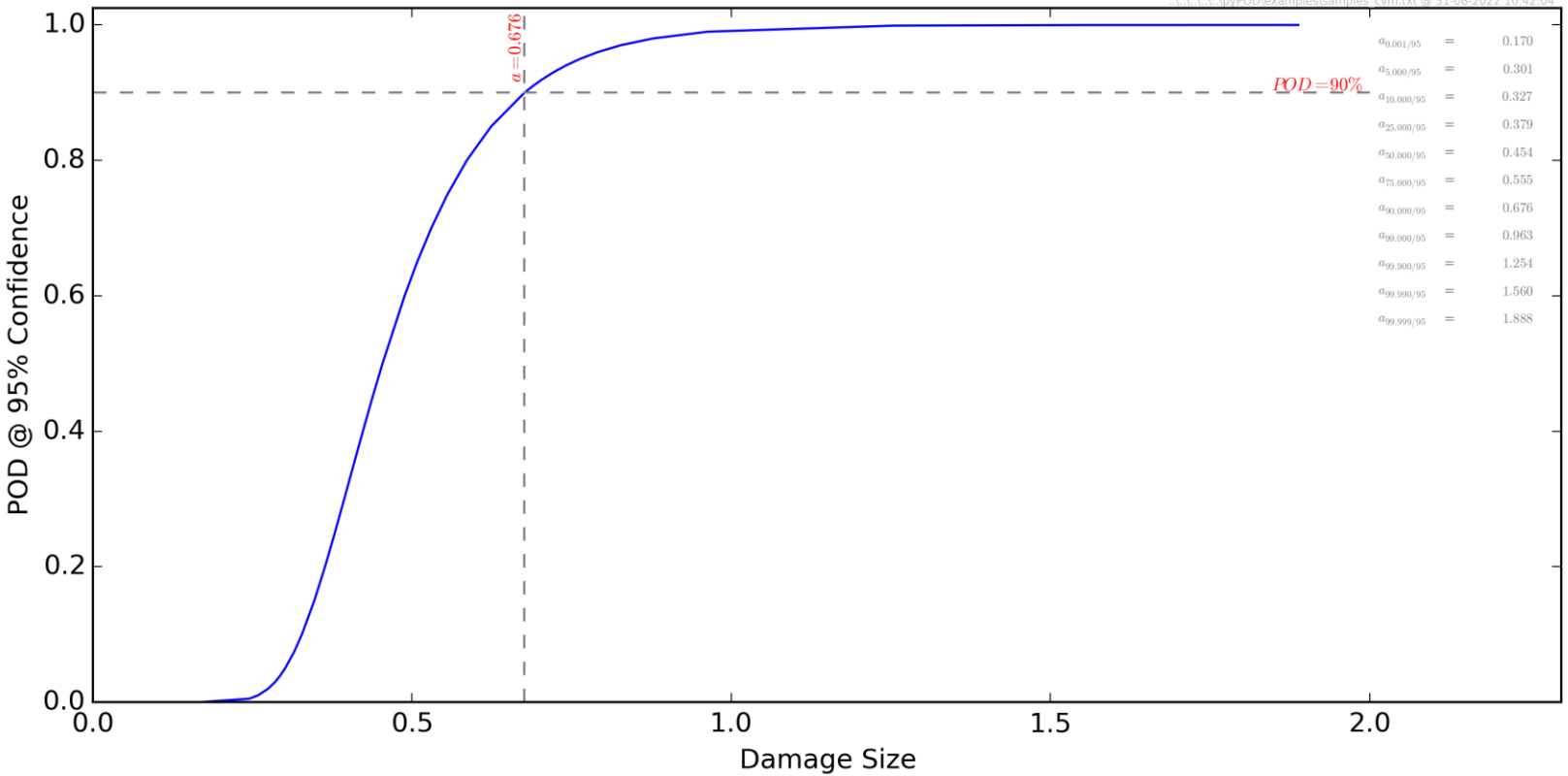
K = Probability factor (~ sample size, confidence level)

S = Std. deviation of detection lengths

n = Sample size

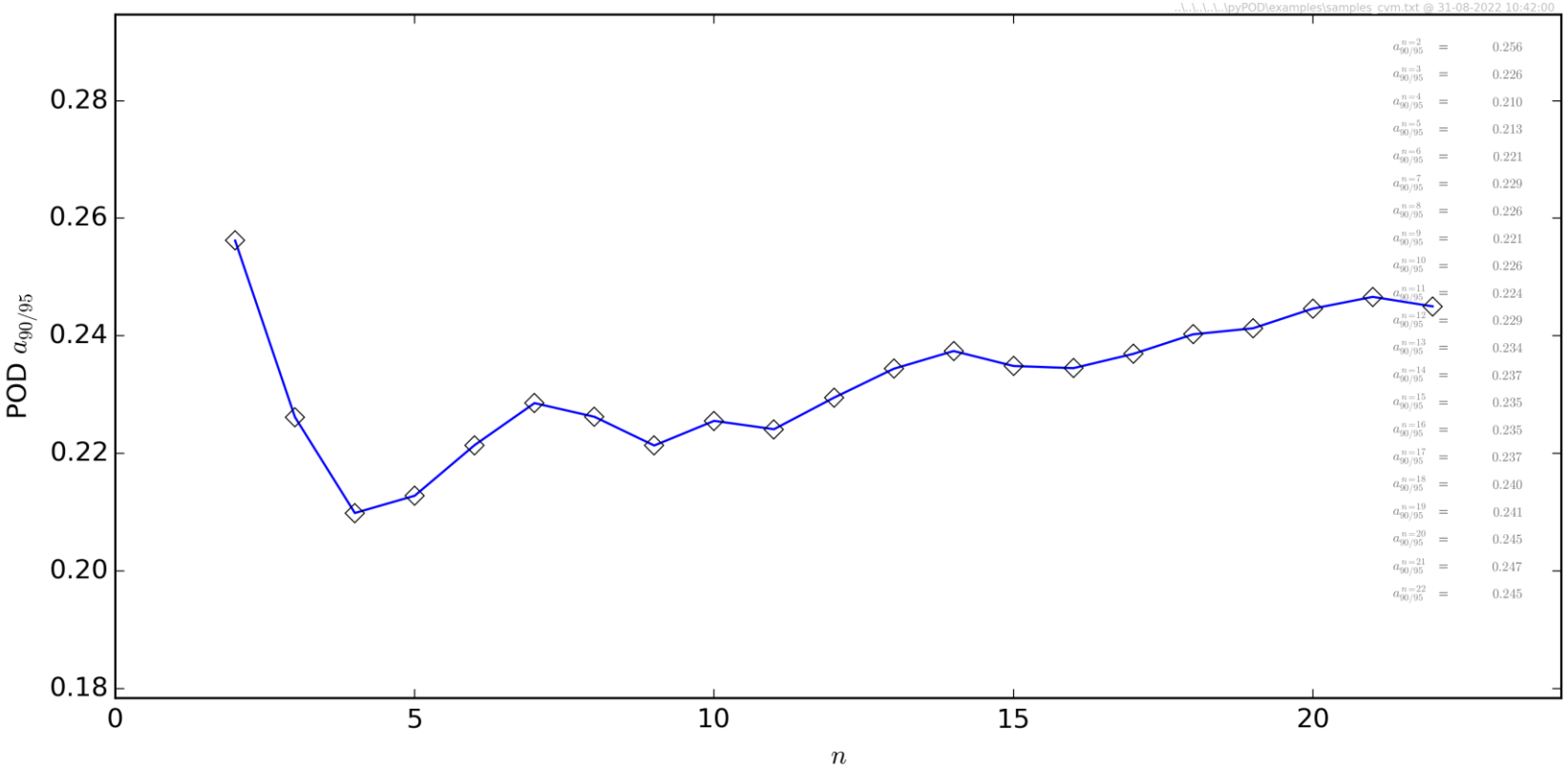
1- α = Detection level

POD CURVE / CVM



POD CONVERGENCE

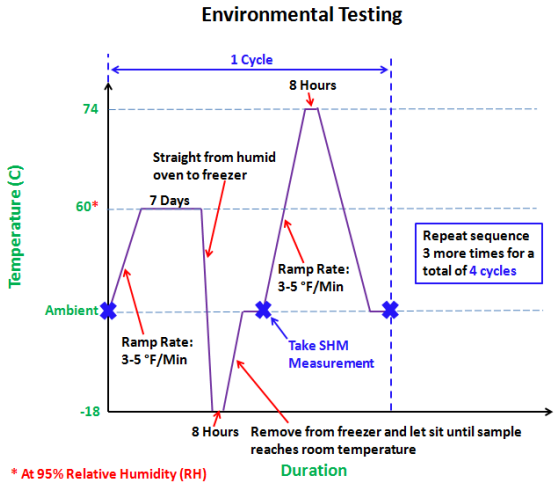
CVM

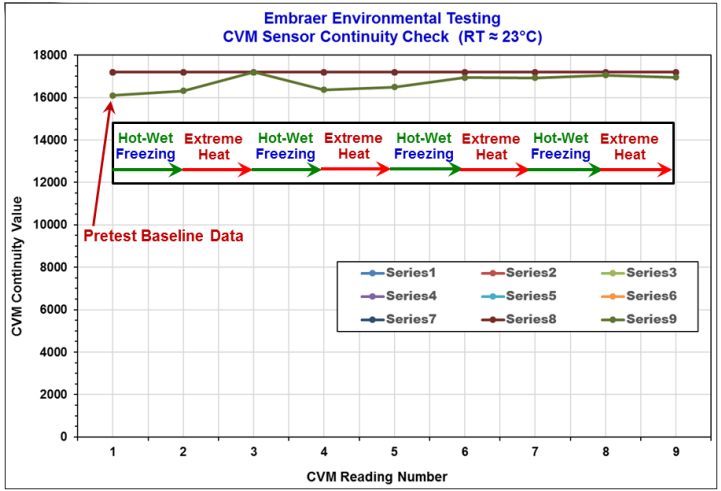


QUALIFICATION PROJECT

Laboratory Tests – Environmental

Environmental/Durability Tests





QUALIFICATION PROJECT

In-service Aircraft

- Service Bulletins for the installation of CVM and LW sensors and cables into **Azul Airlines** aircraft

- 5 Aircraft (installation from 4Q/2013 to 1Q/2016)
- Data acquisition: 18 months

Azul
Linhas Aéreas Brasileiras

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

EMBRAER

SERVICE BULLETIN

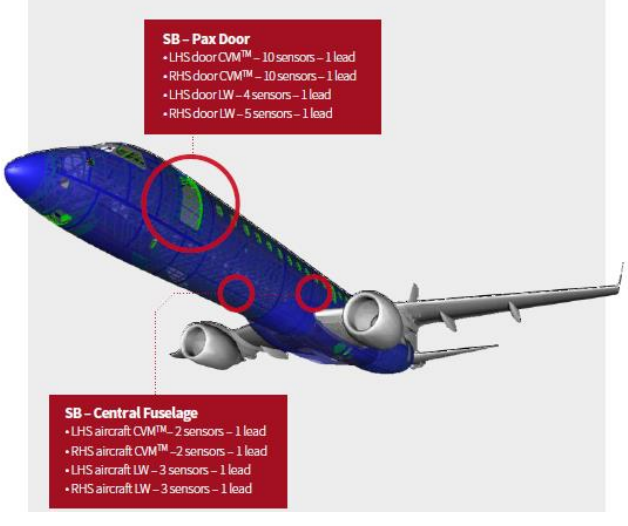
GENERAL - STRUCTURAL HEALTH MONITORING SYSTEM (BASED ON CVM AND LW TECHNOLOGY) INSTALLATION IN THE FORWARD FUSELAGE STRUCTURE

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

EMBRAER

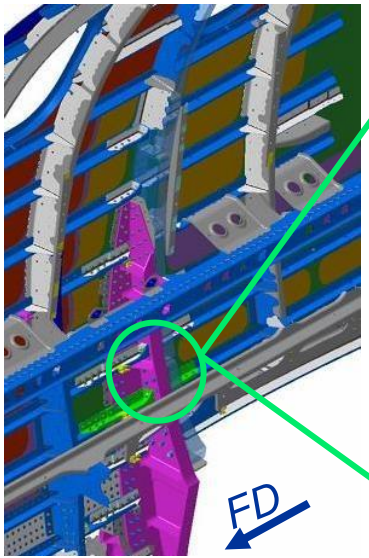
SERVICE BULLETIN

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



QUALIFICATION PROJECT

Installation into 3 of 5 Aircraft during Maintenance Checks

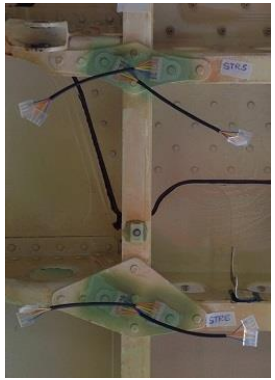


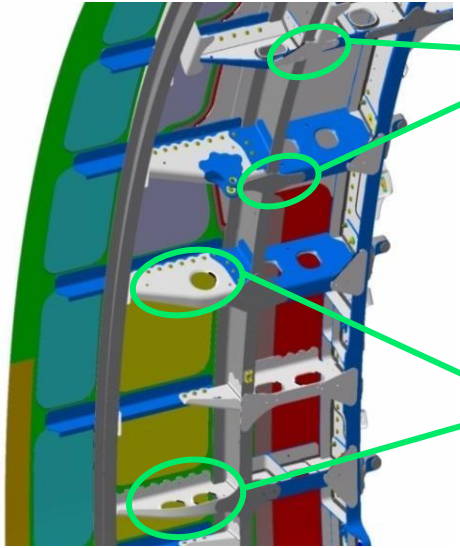
CVM
4 sensors
per a/c

LW
6 sensors
per a/c

QUALIFICATION PROJECT

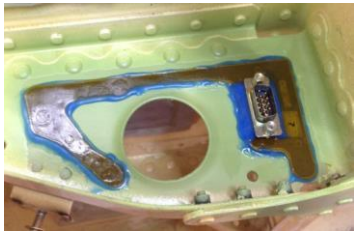
Installation into 2 of 5 Aircraft during Maintenance Checks





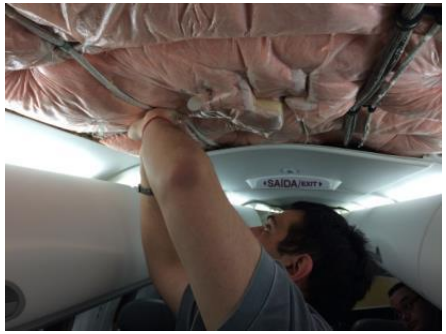
CVM
10
sensors
per a/c

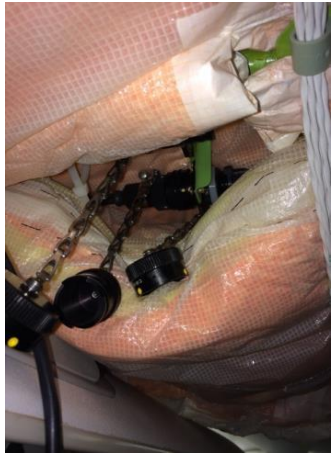
LW
4
sensors
per a/c

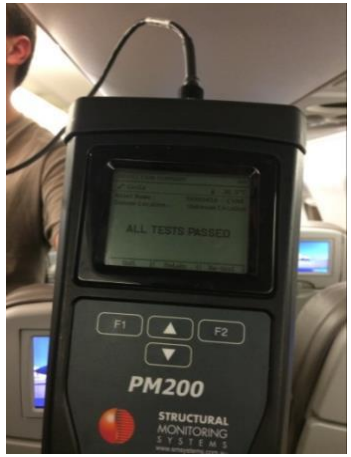


QUALIFICATION PROJECT

Periodic Data Acquisition during overnight interventions



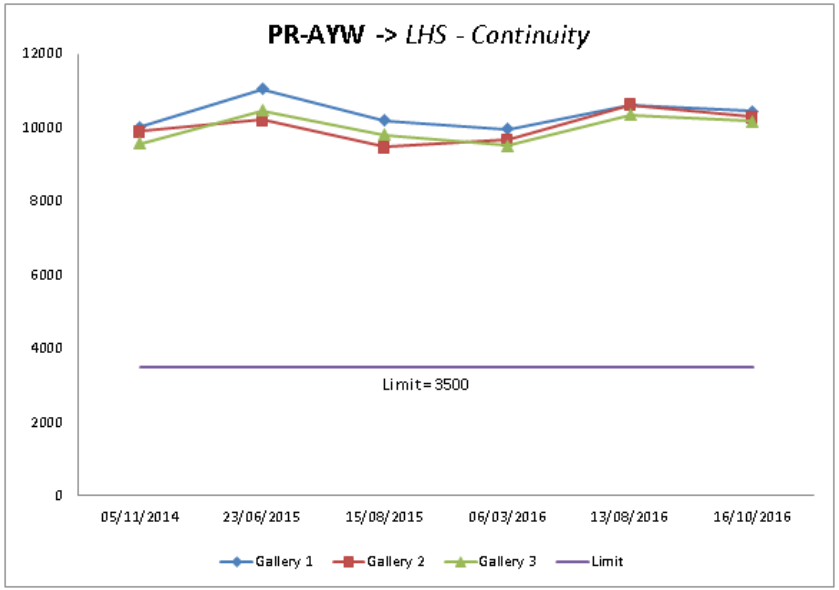


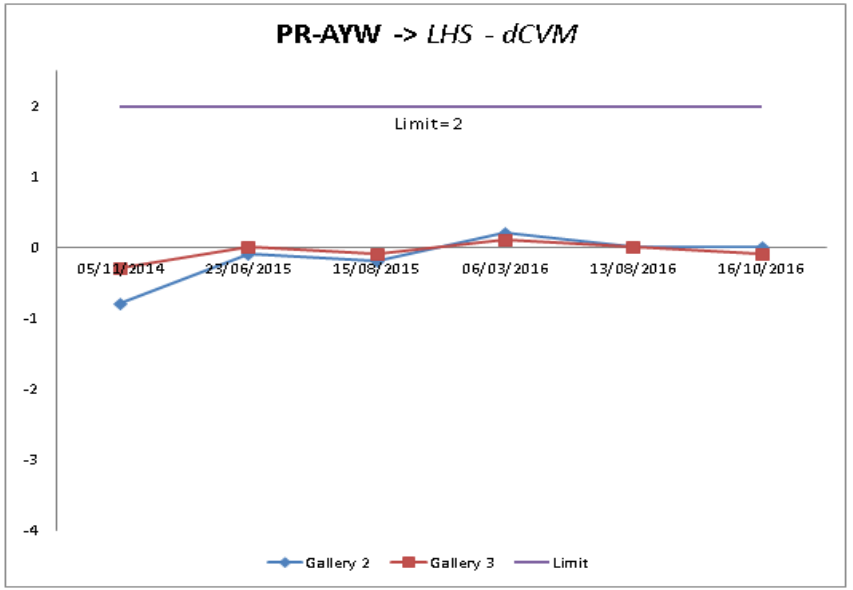


QUALIFICATION PROJECT

In-service Aircraft Results

Comparative Vacuum Monitoring (CVM)





QUALIFICATION PROJECT

How can S-SHM replace traditional inspection procedures?

S-SHM procedure replacing a SDI

without SHM

with SHM

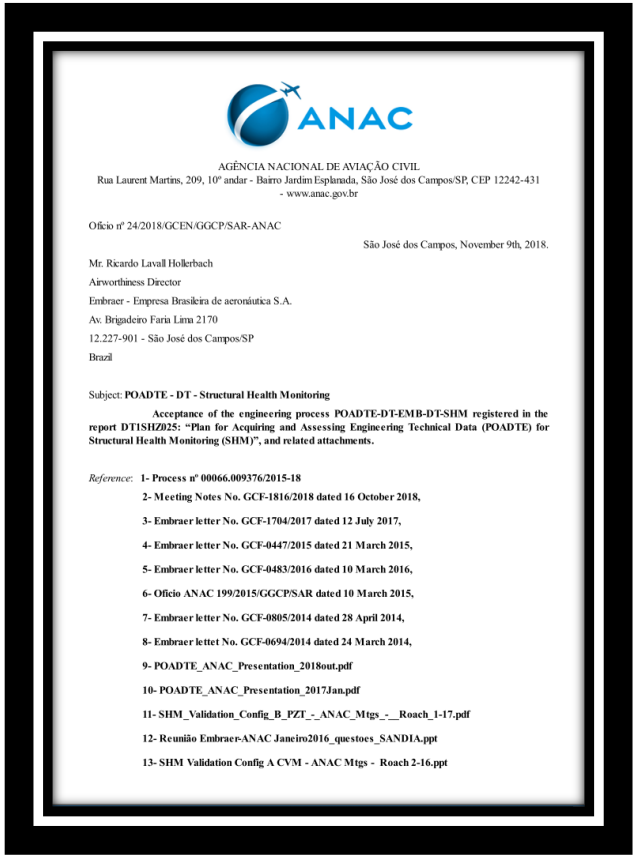
Just an alternative means of compliance (AMOC)

- High downtime due to assembly/disassembly
- Complex/Time Consuming Inspections
- High probability of induced damage during inspections

- Minimal downtime/simple access panel removals
- Simple/quick inspection procedures ('plug in play')
- No induced damage in the inspection areas

***SDI**: Special Detailed Inspection
A traditional type of inspection according to the A4A MSG-3 methodology

ANAC ACCEPTANCE LETTER



AGÊNCIA NACIONAL DE AVIAÇÃO CIVIL
Rua Laurent Martins, 209, 10º andar - Bairro Jardim Esplanada, São José dos Campos/SP, CEP 12242-431
- www.anac.gov.br

Ofício nº 24/2018/GCEN/GGCP/SAR-ANAC

São José dos Campos, November 9th, 2018.

Mr. Ricardo Lavall Hollerbach
Airworthiness Director
Embraer - Empresa Brasileira de aeronáutica S.A.
Av. Brigadeiro Faria Lima 2170
12.227-901 - São José dos Campos/SP
Brazil

Subject: **POADTE - DT - Structural Health Monitoring**

Acceptance of the engineering process POADTE-DT-EMB-DT-SHM registered in the report DT1SHZ025: "Plan for Acquiring and Assessing Engineering Technical Data (POADTE) for Structural Health Monitoring (SHM)", and related attachments.

Reference: **1- Process nº 00066.009376/2015-18**

2- Meeting Notes No. GCF-1816/2018 dated 16 October 2018,

3- Embraer letter No. GCF-1704/2017 dated 12 July 2017,

4- Embraer letter No. GCF-0447/2015 dated 21 March 2015,

5- Embraer letter No. GCF-0483/2016 dated 10 March 2016,

6- Oficio ANAC 199/2015/GGCP/SAR dated 10 March 2015,

7- Embraer letter No. GCF-0805/2014 dated 28 April 2014,

8- Embraer lettet No. GCF-0694/2014 dated 24 March 2014,

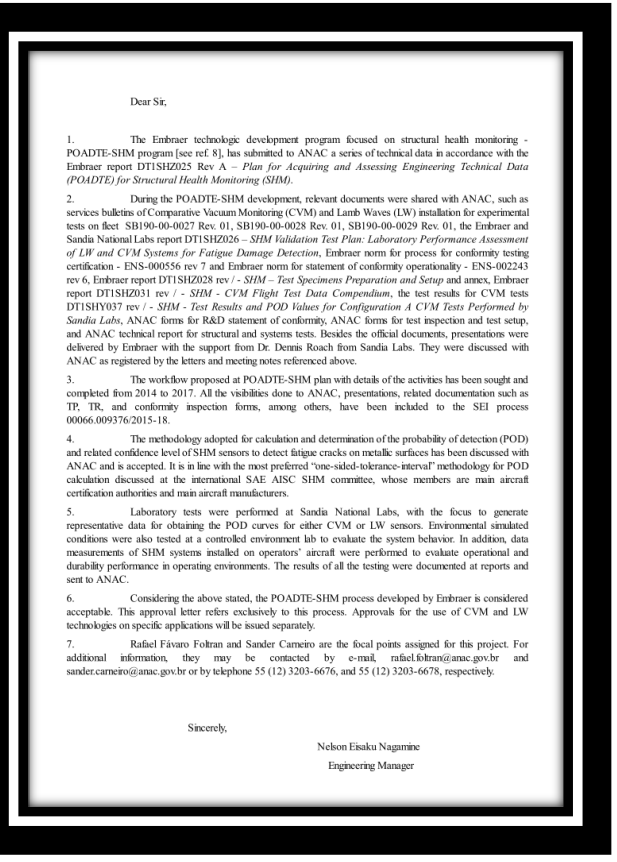
9- POADTE_ANAC_Presentation_2018out.pdf

10- POADTE_ANAC_Presentation_2017Jan.pdf

11- SHM_Validation_Config_B_PZT_-_ANAC_Mtgs_-__Roach_1-17.pdf

12- Reunião Embraer-ANAC Janeiro2016_questoes_SANDIA.ppt

13- SHM Validation Config A CVM - ANAC Mtgs - Roach 2-16.ppt



Dear Sir,

1. The Embraer technologic development program focused on structural health monitoring - POADTE-SHM program [see ref. 8], has submitted to ANAC a series of technical data in accordance with the Embraer report DT1SHZ025 Rev A – *Plan for Acquiring and Assessing Engineering Technical Data (POADTE) for Structural Health Monitoring (SHM)*.

2. During the POADTE-SHM development, relevant documents were shared with ANAC, such as services bulletins of Comparative Vacuum Monitoring (CVM) and Lamb Waves (LW) installation for experimental tests on fleet SB190-00-0027 Rev. 01, SB190-00-0028 Rev. 01, SB190-00-0029 Rev. 01, the Embraer and Sandia National Labs report DT1SHZ026 – *SHM Validation Test Plan: Laboratory Performance Assessment of LW and CVM Systems for Fatigue Damage Detection*, Embraer norm for process for conformity testing certification - ENS-000556 rev 7 and Embraer norm for statement of conformity operationality - ENS-002243 rev 6, Embraer report DT1SHZ028 rev / - *SHM – Test Specimens Preparation and Setup* and annex, Embraer report DT1SHZ031 rev / - *SHM - CVM Flight Test Data Compendium*, the test results for CVM tests DT1SHY037 rev / - *SHM - Test Results and POD Values for Configuration A CVM Tests Performed by Sandia Labs*, ANAC forms for R&D statement of conformity, ANAC forms for test inspection and test setup, and ANAC technical report for structural and systems tests. Besides the official documents, presentations were delivered by Embraer with the support from Dr. Dennis Roach from Sandia Labs. They were discussed with ANAC as registered by the letters and meeting notes referenced above.

3. The workflow proposed at POADTE-SHM plan with details of the activities has been sought and completed from 2014 to 2017. All the visibilities done to ANAC, presentations, related documentation such as TP, TR, and conformity inspection forms, among others, have been included to the SEI process 00066.009376/2015-18.

4. The methodology adopted for calculation and determination of the probability of detection (POD) and related confidence level of SHM sensors to detect fatigue cracks on metallic surfaces has been discussed with ANAC and is accepted. It is in line with the most preferred "one-sided-tolerance-interval" methodology for POD calculation discussed at the international SAE AISC SHM committee, whose members are main aircraft certification authorities and main aircraft manufacturers.

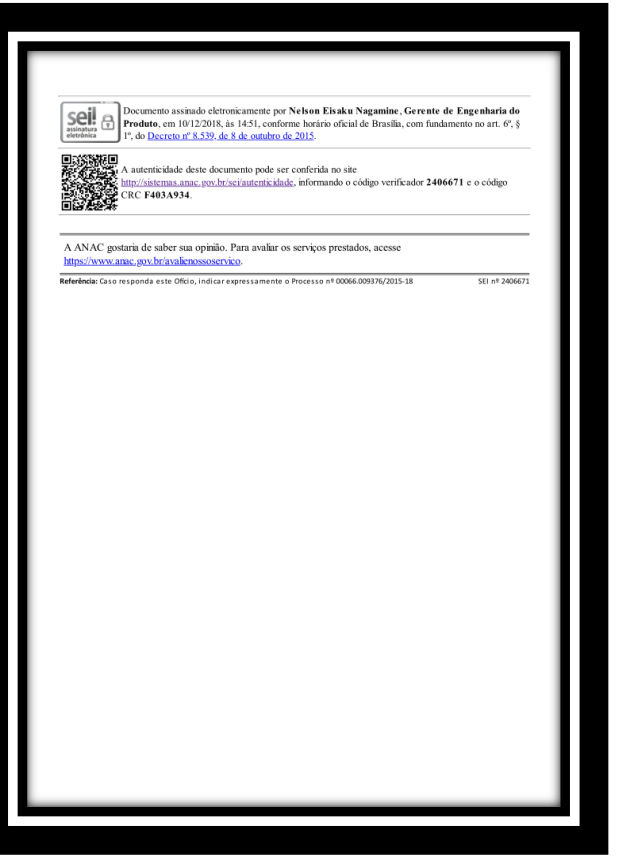
5. Laboratory tests were performed at Sandia National Labs, with the focus to generate representative data for obtaining the POD curves for either CVM or LW sensors. Environmental simulated conditions were also tested at a controlled environment lab to evaluate the system behavior. In addition, data measurements of SHM systems installed on operators' aircraft were performed to evaluate operational and durability performance in operating environments. The results of all the testing were documented at reports and sent to ANAC.

6. Considering the above stated, the POADTE-SHM process developed by Embraer is considered acceptable. This approval letter refers exclusively to this process. Approvals for the use of CVM and LW technologies on specific applications will be issued separately.

7. Rafael Fávaro Foltran and Sander Carneiro are the focal points assigned for this project. For additional information, they may be contacted by e-mail, rafael.foltran@anac.gov.br and sander.carneiro@anac.gov.br or by telephone 55 (12) 3203-6676, and 55 (12) 3203-6678, respectively.

Sincerely,

Nelson Eisaku Nagamine
Engineering Manager



Documento assinado eletronicamente por **Nelson Eisaku Nagamine**, **Gerente de Engenharia do Produto**, em 10/12/2018, às 14:51, conforme horário oficial de Brasília, com fundamento no art. 6º, § 1º, do Decreto nº 8.539, de 8 de outubro de 2015.

A autenticidade deste documento pode ser conferida no site http://sistemas.anac.gov.br/sei/autenticidade, informando o código verificador **2406671** e o código CRC **F403A934**.

A ANAC gostaria de saber sua opinião. Para avaliar os serviços prestados, acesse https://www.anac.gov.br/avaliemossoservico.

Referência: Caso responda este Ofício, indicar expressamente o Processo nº 00066.009376/2015-18 SEI nº 2406671

CONCLUDING REMARKS

- In the short-term S-SHM has the potential to become a reality, as Special detail Inspection (SDI) in a robust Aircraft's maintenance program;
- S-SHM can accomplishment of scheduled inspection tasks, providing an alternative to traditional NDI;
- CVM demonstrates a high level of maturity;
- LW 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 will be the proper tool for a CBM application;


THANK YOU!