CERTIFICATION PROCESS OF SHM SYSTEMS IN THE AERONAUTICAL SECTOR

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1 INTRODUCTION

Aerospace industry is one of the most regulated industrial sectors worldwide. Aircraft are made to fly from one place to another complying with takeoff and landing countries and their specific regulations. From the very early aviation, agreements between different countries on aviation standards have been made. In 1943, ICAO (International Civil Association Organization) was born with the aim of a sustainable and safe aerospace industry growth. Nowadays, FAA in the US and EASA in Europe lead the aerospace regulation standards and contribute to a more controlled and safer aviation.

Through the aircraft certification process, inspection and repair procedures, as well as maintenance programs are defined and approved by the aviation authorities. In order to keep the airworthiness of any aircraft, those maintenance tasks shall be complied on time, under a strict quality system and guaranteed by trained staff. The certification process may impose flight time limits for some components and assemblies and/or frequent inspections to be made. Consequently, maintenance tasks contribute in a great manner to the direct operating costs of any aircraft.

Those programmed aircraft inspections will keep the aircraft out of operation during the time needed for the completion of such activities, no matter if there is a defect in any component or not. Moreover, if the inspection needs to be conducted out of the operator headquarters, additional costs may apply. However, if a monitoring system is able to collect the necessary data and make the adequate analysis, those programmed inspections could be delayed and readjusted depending on real necessities so there would be no need to ground the aircraft for such reason.

Aircraft structures manufacturers determine based on design calculations and certification test results, the maintenance intervals. They analyze the defect appearance probability considering the implication of the component or structure in the aircraft safety, the materials used and the manufacturing processes, the operative environmental conditions, the planned operation demands, the expected working cycles and the influence of ageing.

In the next chart we may observe the growth of worldwide airlines maintenance, repair and overhaul (MRO) costs. There is also an estimation for the coming years, where a noticeable increase in those costs will appear in time:

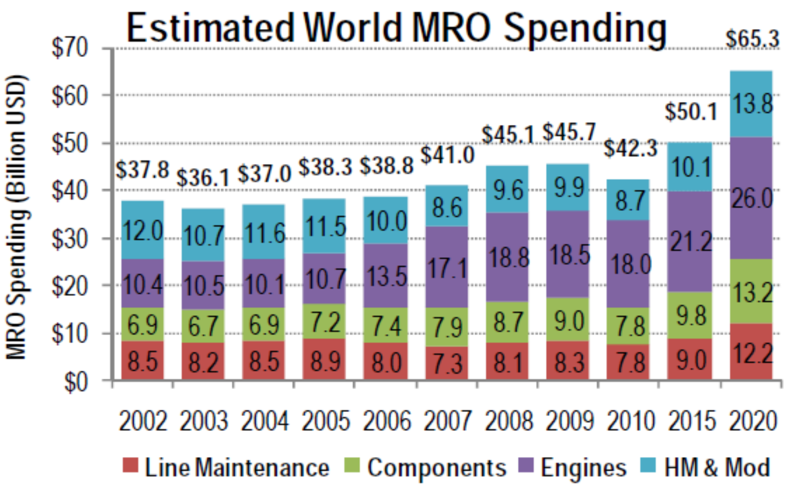

Figure 1: MRO costs and mid-term estimation [1].

Structural Health Monitoring was born to increase the safety of critical components such as helicopter main gearboxes and structures, flying in real demanding conditions. Nowadays, the main goal is to reduce operational costs and increase lifetime of structures [2]. SHM uses NDI principles joined to in-situ sensing so the system allows real-time condition assessments [3]. Such technology, used in standard flight conditions, means an operation cost reduction. If we focus on composite material structural components of an aircraft, the costs associated to the operation and maintenance may come up to 25% of the total cost of its life cycle; there is room for a great improvement, actually.

The characterization of damage before failure in structures is a crucial factor for the integrity of the aircraft and systems to be controlled. All the structural components of a commercial aircraft are inspected at regular time intervals by different evaluation techniques, making this process technically complicated and therefore costly. With a maintenance process based on SHM continuous monitoring we move from predictive maintenance methods to real conditions affecting the structure. Thus, maintenance tasks will be conducted only when they are really needed. This is possible due to the continuous monitoring, as damage existence and their severity level is known in real time.

This type of maintenance reduces inspections to the critical ones and saves labor and aircraft on ground time. Moreover as this system include sensors located at not easy access places, it allows the detection of structural flaws that would be hardly found without disassembling the whole structure to access the zone of failure.

Furthermore, the use of such continuous inspection system during all manufacturing and assembly processes will permit an advanced quality control of the manufacturing process itself, reducing the amount of discarded elements and its tolerances.

In summary, the development and application of SHM technology in aircrafts provides important advantages.

Safety:

- Increase of safety: Constant monitoring of the aircraft allows a better knowledge of the structural state and guarantees the best conditions for flight.
- On-line structural state: In case of an impact or crack growth event, the aircrew will

be able to better evaluate the circumstances and to apply the most appropriate procedure and protocols.
- Operation type associated risks: those high demanding aerial operations such as cargo, emergency or frequent flight on turbulent conditions will benefit from information of any component fatigue incident.

Cost reduction:
- Maintenance on-condition (CBM): CBM is based on using real-time data obtained from the SHM system to prioritize and optimize maintenance resources. Design concept changes to “maintenance on-condition” [4].
- Operation type associated costs: those low demanding aerial operations may benefit from a longer component life. Such a system shall demonstrate to the aviation authorities the healthy state of a life limited component and thus the possibility to safely extend its on service time.
- Inspection costs and time reduction: As real-time information of the structural state of the aircraft is available, some inspections could be substituted by a condition monitoring report after each flight. This report may indicate a pass/fail status or the need of a deeper inspection.
- Weight reduction: There is no need to design structures with higher thickness. This weigh reduction consequently generates reduction in fuel consumption.
- Certification tests: Instrumentation and data collection is a big issue during aircraft and component certification tests. SHM will allow to reduce those costs as well as to reduce the test lead-time.

2 DEVELOPMENT AND VALIDATION OF NEW SHM TECHNOLOGIES

Significant developments in SHM have been achieved lately. We may include the validation tests as one of the drivers for that success: SHM systems under investigation have been exposed to loads, movements and environment flight operating conditions.

CTA leads a R&D consortium focused on SHM systems called AIRHEM, consisting on several universities and technological centers of the Basque Country: UPV-EHU, MONDRAGON UNIBERTSITATEA, TECNALIA, BCMATERIALS and LEARTIKER. AIRHEM consortium has been working since 2008 granted by the Basque Government. This stable group of research in SHM does not only apply to operation and maintenance activities but also to the whole lifecycle of airborne components; from manufacturing to transport, assembly and testing.

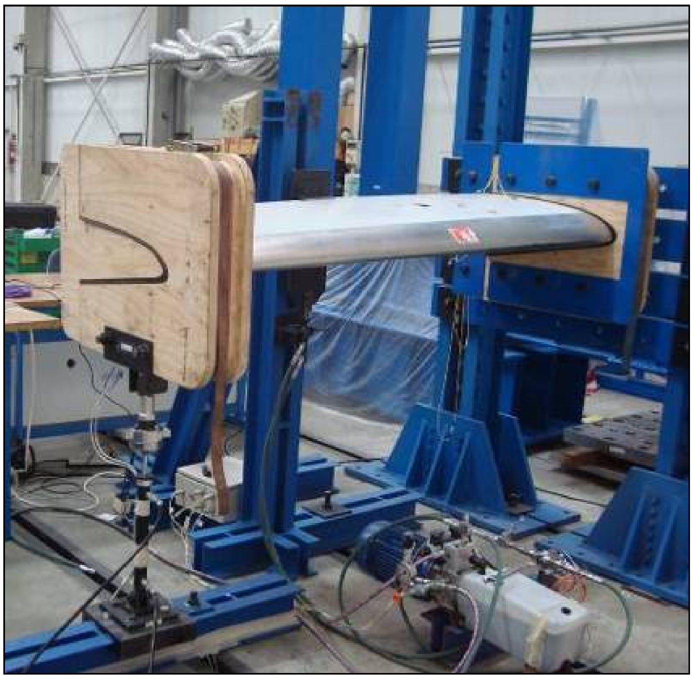

Figure 2: Demonstrator developed in AIRHEM-08. Leading edge of a wing instrumented with SHM.

As a result of the research and development activities carried out by this consortium, new sensors have been developed such as sensors adapted to airworthiness product (PZT, OF), optical particle detector (OPD), embedded central control system, Passive Wireless sensors in harsh conditions, ultrasound inspection of aircraft parts manufacturing generated by pulsed laser, a SHMUS system, a μSHM system and magnetostrictive and magnetoelectric sensors. Besides, there have been also developments of longitudinal ultrasound monitoring techniques, smart tooling, tests for the characterization and validation of sensors and SHM and energy harvesting integrated systems.

CTA also participated in European R&D projects. AISHA project was focused on the development of SHM technologies based on lamb waves, with the objective of evaluating the capability of this technique to detect damages in structures. A full-scale test was conducted in order to validate the results obtained in a real aeronautical structure. The selected structure was an Airbus Helicopters EC135 model tail-boom. Several damages were intentionally generated in this specimen by BVID (Barely Visible Impact Damage) tests, using different controlled impact energies. Validation of the Lamb Waves results were carried out by comparing them both with conventional ultrasonic inspections and with an innovative infrared thermography NDT technique.

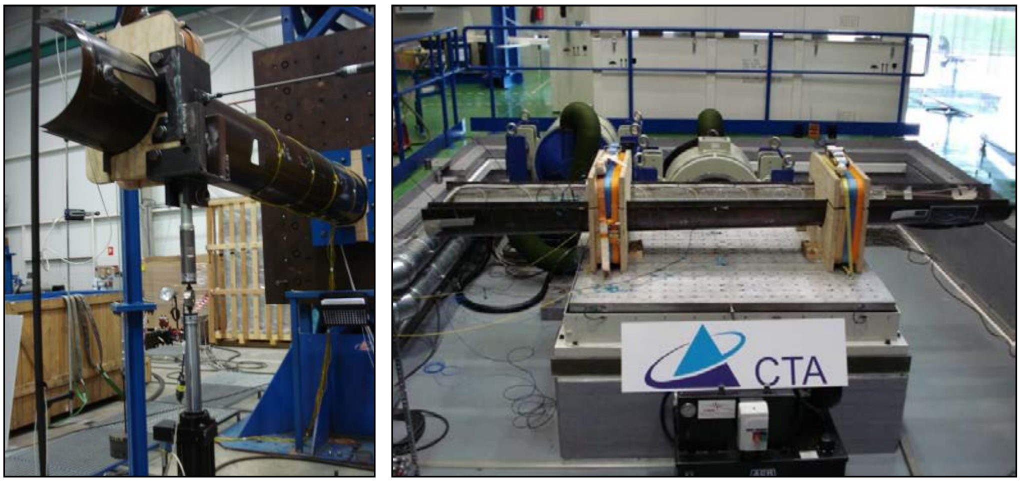

Figure 3: AISHA Test Set-up.

CTA is currently collaborating with TWI and the University of Patras in the development of a SHM platform applicable to real aircrafts (RPAs). We have been able to identify and locate failures in flight within the VIBRATION project (VII FP): “Global in flight health monitoring platform for composite aerostructures based on advanced vibration based methods”. In this project many different defects with different characteristics has been generated in a controlled manner in order to calibrate a new SHM system. The detailed characterization of these defects has been carried out by CTA by applying nondestructive inspection techniques based on infrared thermography as well as numeric modeling simulated by TWI. University of Patras finally proceeded with the calibration of the SHM system based on these previous inputs.

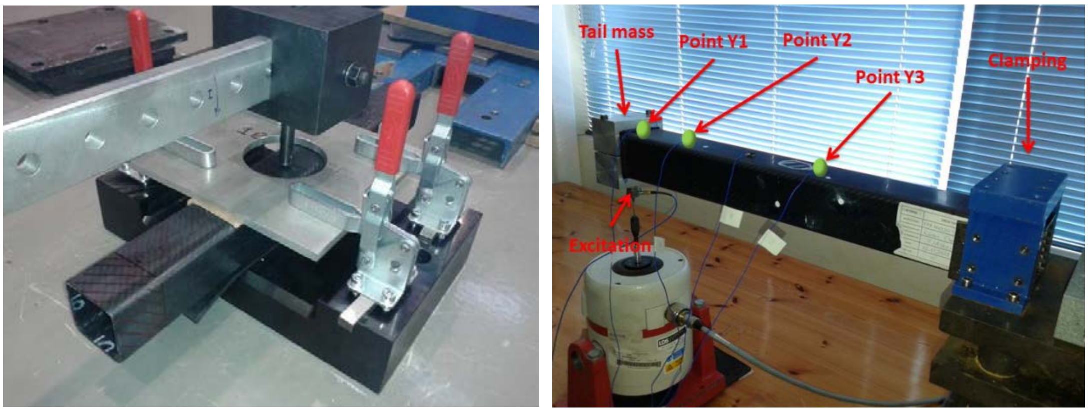

Figure 4: Defect generation and subsequent experimental characterization by SHM system.

SHM applications in composite materials have been typically based on sensors that measure the state and integrity of the structure locally, resulting in a large number of sensors necessary to cover the entire structure. The consequent installation and operation cost is high, hindering the in-flight application of the local SHM method.

One of the main objectives of the VIBRATION project is to reduce the number of sensors needed to monitor an aircraft. Thus it is necessary to manage signals that carry information about the global state of the structure. The vibratory behavior of the structure is definitely a global characteristic of its health state, so a SHM platform based on in-flight vibratory system is under development.

Along these cooperation projects, CTA has actively participated in validation tests for sensors and technologies under research and development. The development of testing technologies capable to validating the new SHM systems in flight operation simulated conditions is necessary to mature the systems and to get them ready for the certification stages and the final introduction to the market.

3 SHM CERTIFICATION PROCESS

3.1 Current Regulations

Certification processes include design, durability and environmental specifications that any aircraft component or system must comply with. Those specifications are defined by the OEM (Original Equipment Manufacturer) following the regulations issued by Aviation Authorities. There was no consensus for SHM among all agents involved so far. Therefore, the AISC–SHM working group was created with the aim of giving an answer to this truly inconvenient issue.

The AISC–SHM is “an international team comprising industry, government and academic participants with a collective vision to efficiently and effectively implement structural health monitoring for a wide variety of commercial and military aerospace applications through the development of guidelines, procedures, processes and standards for implementation and certification of the technologies” [5]. This committee focuses on the development of aerospace industry guidelines for structural health monitoring systems in order to achieve an industry consensus on SHM implementation and to draw the basis for certification. The issued guidelines recognize the different international standards on certification, manufacturing, operation and maintenance. Those standards are mainly issued by EASA (European Aviation Safety Agency) and the FAA (Federal Aviation Administration) of the United States. Nevertheless, the committee bears in mind those issued by the RTCA as well as the Military Standards inputs.

In Europe, aircraft certification regulations are issued by the EASA Aviation Authority and enforced by national Aeronautical Authorities such as the Spanish AESA (Aviation Safety State Agency). All applicable FAA regulations are included in the "Title 14: Aeronautics and Space" of the Code of Federal Regulations (CFR) belonging to "Title 49: Transportation". This Title 14 is divided into 5 volumes [6]. For avionics equipment, including SHM equipment, the regulation specified by the RTCA (Radio Technical Commission for Aeronautics) is followed. This organism advises technically to FAA since 1991 and its regulations are based on those issued by the FAA regarding avionics and communications equipment. Documents issued by the RTCA are called DO. Among those standards the most important one is DO-160G [7], which refers to the tests required to certify, among others, electronic equipment.

There is a specific legislation for military aircraft, which is used as guidance for the certification of aircraft, components and systems. American regulation of DoD (Department of Defense) Military Standards or MIL-STD is used as guidance material [8] [9].

3.2 Test identification and definition

After reviewing the different regulations a SHM system should comply with, it is necessary to define the area, system or component where it will be attached to in order to define the test campaign that applies for its particular case. Any certification must be performed taking into account the type of system that is going to be certified just like any other actual element such as radars, altitude sensor or communication antenna. If the SHM sensor is to be embedded inside the structure, this structure should pass all the standardized required certification tests with this sensor already installed as part of the structure itself.

SHM systems typically consist of several components, which involve different locations within the aircraft. All those SHM components must remain functional throughout the useful life of an aircraft. In order to guarantee such operational functionality, tests should be performed according to their field of application [10].

We find, within the CS 25, Certification Standards of EASA dedicated to large aircraft, the SUBPART H - ELECTRICAL WIRING INTERCONNECTION SYSTEM where requirements on any cable, wiring, or combination of both, including terminals, installed in any area of the aircraft and whose objective is the transmission of electricity, including data and signals between two or more points are defined [11].

The EUROCAE ED-14D / DO-160G RTCA regulation is accepted by EASA for the environmental tests development aimed at this type of equipment. In fact, there are 24 types of tests applicable for avionics equipment. For each test procedure, the specimen is classified in one of the categories, depending on its position in the aircraft and the characteristics of its mission.

Since all tests may not apply to all electric elements, it is necessary to define which of them apply to our specific case of a SHM system [12]. We shall always keep in mind the main objective of the certification process: safety. Therefore the way to define which test should apply is to study where or when the system may affect flight safety. Besides the definition of the requirements due to aircraft type or field of application and the specific location of the SHM equipment within the aircraft will affect the performance of the SHM system. It has to be distinguished between those elements installed in a controlled temperature and pressure area and those ones exposed to the outside environment. Furthermore, they could be affected by other elements such as de-icing fluids, hydraulics or jet fuel.

4 INDUSTRY EFFORTS THROUGH THE SHM: SOME EXAMPLES

The aeronautical sector poses the next major challenges for 2020:

- Accelerate the development of smart, environment-friendly and energy-efficient aircraft which shall operate worldwide, thereby meeting environmental and societal targets for more efficient, safer and greener air transport.
- Achieve its strategic social priorities of sustainable growth, wealth creation and stable employment in fields of high technology.
- Win global leadership for European aeronautics with a competitive supply chain, which includes academia, research bodies and SMEs.

European initiative JTI (CleanSky2), for which CTA has been named core partner, includes in its strategic agenda the development of SHM technologies to achieve the already mentioned objectives. For instance, the project SHERLOC, with the objective of combining advanced Structural Health Monitoring (SHM) and smart repair technologies. This combination is planned under a probabilistic design philosophy aimed to the development of new maintenance concepts that shall reduce the aircraft direct operation costs without lowering the operational safety of a composite fuselage.

Other notable examples of recent developments in SHM and the efforts to be introduced to real aerial conditions are described in the following paragraphs:

Delta TechOps has worked together with Sandia National Labs, the FAA, Boeing, Anodyne Electronics Manufacturing Corp. and Structural Measurement Systems in a SHM technology implementation [13]. The main purpose has been to test, validate and integrate into an aircraft a comparative vacuum monitoring (CVM) sensor. The function of this sensor is to provide crack detection real-time information and also structural data information to be used for maintenance program improvement. The CVM sensor has been tested in components of some aircraft like DC-9, 757 and 767.

Embraer, meanwhile, has spent some time studying the SHM systems and its application areas within their aircrafts. Some tests have been performed in E-Jets flight test aircraft with two different SHM technologies: CVM technology and Lamb Waves (LW) [14]. The aim of Embraer is to study these technologies in “real conditions” and obtain useful data in order to follow a self-imposed SHM certification roadmap.

Airbus has also joined the efforts to achieving a certified SHM system installed into an aircraft. There are several SHM projects running in Airbus Group: Tail Strike indicating system, now deployed on the A380 full-scale fatigue test; A350 SHM system used during structure certification and flight testing; A400M Life-Time Monitoring System (LTMS), optionally installed,; and integration of Onboard SHM system as part of the Integrated Vehicle Health Management System and Health and Usage Monitoring Systems (HUMS) in helicopters [15].

RPAs industry, currently under a meaningful growth rate will surely apply SHM systems due to their kind of operation. Those type of aircraft are expected to be operated in unfavorable conditions where structure condition monitoring may be most valuable.

5 CONCLUSIONS

The next future of aviation SHM will take advantage of more efficient and lighter new sensors, reliable wireless communications, big-data crunching methods and faster and more powerful computers.

Those advantages together with the efforts of SHM agents in the achievement of a common regulation for health monitoring systems and the Aviation Authorities contribution will lead us to a safer and cost saving aviation maintenance.

Besides, the efforts of the RPAs (remote piloted aircrafts) sector in miniaturization of airborne equipment and the expected regulations for their operation will benefit aviation real-time health monitoring field as a whole: high rate production of SHM systems may be expected and therefore, cost savings as well.

Also Test Laboratories involved in aircraft certification will benefit of the SHM advantage lowering the test lead times and improving data collection. Among CTA research lines we find the SHM application to the development of aerospace components certification tests.

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