On-board SHM System Architecture and Operational Concept for Small Commuter Aircraft

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ABSTRACT

Significant R&D progress has been done in the area of SHM technologies in recent years. However real SHM application on aircraft board is still challenging and puts specific requirements on the SHM system design and operation. These challenges include assurance of reliable and provable damage detection capabilities, taking over decision-making responsibilities instead of a human inspector and other challenges related to on-board installation and operation during the flight. Further, minimal weight and dimension, and system reliability and durability should be considered. Due to these challenging requirements the SHM has not been widely implemented in aerospace industry yet.

The paper deals with system architecture and operational concept of SHM system for L-410 NG commuter aircraft. The SHM system is based on excitation, sensing and analysis of ultrasonic guided waves using PZT actuators / sensors. The SHM system is designed for monitoring of PSEs of metallic airframe that are hard to access or completely inaccessible for common inspection methods used in the aircraft maintenance. The design puts emphasis on integration of the SHM system within aircraft avionic system in order to achieve highly automated data acquisition and data transfer process to make the health data available for on-ground analysis. Finally, scenario of the SHM system operation in accordance to the L-410 NG maintenance plan is proposed in the paper. The scenario assumes replacement of common inspections that are done within regular maintenance checks by the automated inspections using SHM system. Challenges of the proposed scenario from the point of view of the aircraft certification and operation are discussed as well.

1. INTRODUCTION

Effort to utilize all aircraft parts and components efficiently leads to transition to on Condition Based Maintenance (CBM) philosophy with taking into account real operating conditions and load. In the area of aircraft structure, the CBM approach to aircraft maintenance is enabled by implementation of "Structure Health Monitoring" (SHM) system, which monitors actual state of aircraft structure parts. Maximum efficiency of SHM system application can be achieved if it is taken into consideration during aircraft design and development phase. This allows SHM system integration into avionics information systems, which is in compliance with current trends in the development of new aircraft and higher-order innovation in the elderly types.

This paper describes the architecture of on-board SHM and its concept of operation. The work aims to establish a precedent of using this perspective SHM system and its installation on a small commuter aircraft. In particular, SHM system for the L-410 NG is being developing as a part of the aircraft modernization efforts where the damage tolerant design philosophy is applied for specified Principal Structural Elements (PSEs), which are prone to fatigue damage. The damage tolerance design philosophy is based on the scheduled inspection plan for fatigue cracks detection. Analysis, which was done in connection with the aircraft design under Damage tolerance philosophy, revealed advantageousness of the SHM methods application for PSEs with short inspection interval, PSEs with limited life or for PSEs prone to Multi-Site Damage (MSD), i.e. parts with multi-focal cracks growth, typically riveted lap joints in aircraft fuselages or wings.

2. ON-BOARD SHM REQUIREMENTS

The main function of the SHM is the aircraft structure monitoring during the whole aircraft life. This puts several requirements on the on-board SHM system design and installation:

- **Minimal impact on the aircraft design and manufacturing.** Optimization of the sensor layout and sensor wiring to minimize need for modifications of the adjacent structure has to be assured. The sensor installation process should be as simple as possible to minimize influence on the aircraft manufacturing and assembly. Optimally, it should be possible to install sensors on aircraft, which is already in operation. This requirement should be taken into account in design of sensor network distribution, connections, wiring and sensor bonding technology.

- **Low weight and small dimensions** are the most important requirements on the SHM system design from the point of view of ecomonical utilization of the aircraft. Practical applicability of the SHM system and benefits of the application are strongly dependent on these parameters. Evaluation of SHM benefits against its weight influence on the aircraft payload has to be taken into account.
- **System modularity and installation versatility** has to be assured due to a variety and high number of monitored aircraft structural areas. These system properties would minimize SHM design and installation costs.
- **Long-term system operation** without maintenance need is required. The SHM system life has to exceed the life of the monitored structure in case of inaccessible areas monitoring. The system has to be designed with respect to all adverse environmental service conditions and safety requirements. Thus, reliable solution or functional system backup is required.
- **Automated operation and integration** with overall avionics system is the key factor of its effective and advantageous deployment with regards to all system capabilities and benefits utilization. It includes high frequency/continuous monitoring on the individual aircraft. It results in an increase of safety of the aircraft operation in comparison to current approach. The current scheduled inspection plan is based on the assumed crack growth behavior dependent on supposed typical loading. On the other hand, the SHM provides information about the real state of the monitored structure. Further, high level of automation minimizes impact of human factor on the results of the inspection.

All those described requirements have been considered during the on-board concept development including requirements resulting from standards and regulations related to the commuter category: EASA CS-23, RTCA DO-160, RTCA DO-178 and RTCA-DO 254. Further, the Guidance on Structural Health Monitoring for Aerospace (ARP6461) has been considered and appropriet recommendations have been applied during the SHM concept preparation.

3. SHM SYSTEM ARCHITECTURE

Scheme of the conceptual SHM system architecture is shown in the Figure 1. The system consists of on-board and on-ground parts. Each PSE selected for monitoring of its health is equipped with permanently installed sensor network, which is particularly designed and optimized for the PSE. The sensor network is controlled by SHM hardware (HW). The SHM HW is connected to Central Maintenance Computed (CMC), which controls the SHM system operation, i.e. initiates collection of the data for particular PSE, stores the data, provides indication of correct functionality of the monitoring system for individual PSE and allows transfer of the data to the ground unit for further processing and evaluation. The ground unit consists of a computational device with installed software for the signal processing and evaluation of the health of individual PSE, which includes defect indication, localization, and estimation of severity / size of the defect alternatively PSE Remaining Usage Life (RUL) estimation.

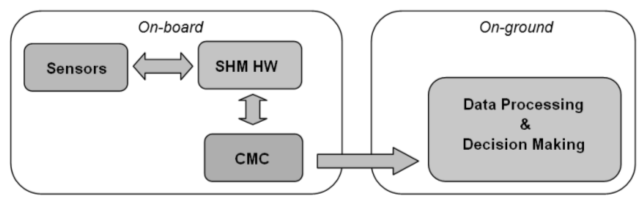

Figure 1. General Concept of SHM system

4. ON-BOARD SHM SYSTEM ARCHITECTURE

The on-board part of the SHM system (Figure 2) can be described as a distributed modular system respecting structural design and PSEs selected for the monitoring. The modularity of the SHM system design allows various numbers of sensors connection in different net configurations. The redesign of elementary system modulus is not necessary in case of its application on different structural parts. The SHM system, for which the architecture is designed, is based on technology of generation / registration of ultrasonic surface waves using simple PZT actuators. However, the architecture is general enough to be implemented with other SHM technologies or their combinations.

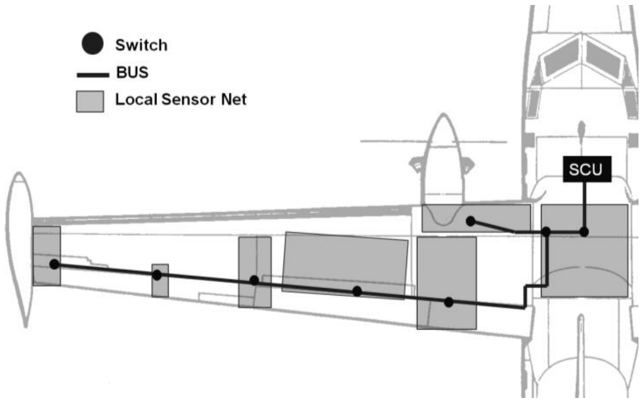

Figure 2. On-board SHM System Architecture

Particular application of the SHM on-board architecture consists of local PZT sensor nets, sensor switches and sensor control unit (SCU). Local sensor nets are attached on monitored structural parts and controlled by small lightweight switches localized in the vicinity of sensor nets. A BUS topology is used for the switches connection to the SCU. This topology allows connection of various numbers of sensor switches and sensor network complexity optimization.

The SCU provides several functions. First group of functions relates to sensors signals generation, sensor signal responses registration, temperature measurement and sensor control. The measuring period and other required settings for different PSEs are individually set in dependance on the particular structural element criticality and localization. Further, the SCU performs data pre-processing, temporary storing and transfer/communication to the CMC with usage of a standard communication protocol (e.g. ARINC 429). The SCU is designed for the independent operation (data collection in defined intervals). This operational independence minimizes burdening of the CMC modulus, which main function is initiation and termination of the measurement by the SCU and transfer of measured data from SCU to the on-ground processing. .

5. OPERATIONAL CONCEPT

Nowadays, maintenance of the aircraft using damage tolerance philosophy for the structure design is characterized by scheduled structural inspections. General Visual Inspections (GVI) are done and Non-Destructive Testing (NDT) methods are used by maintenance staff to inspect structure in details. Threshold interval of the inspection introduction, interval of inspection recurrence and particular inspection method is defined for all PSEs. Any structural damage has to be detected before its critical level is reached causing aircraft failure.

Certification and operation of the SHM system with deployment of its full capabilities is challenging nowadays. It is caused by no-existence of legislative allowing certification and operation of SHM for continuous on-board monitoring of aircraft structure damage, e.g. aircraft operation with known structure damage is not allowed. Therefore, we choose following strategy for the SHM system transition to real operation on the aircraft.

An operational concept of the parallel periodical maintenance checks related to damage tolerance and SHM system measurements is used in the first phase of SHM implementation into L-410 NG maintenance manual (Figure 3). SHM structural checks are carried out during the aircraft service in the automatic way. Data from sensors are automatically measured and stored on-board for further processing on the ground. The process of data transfer and evaluation is not fully automated. The pilot or maintenance crew assistance is needed for data transfer initialization and execution. The data processing and evaluation is done by maintenance or structure specialist on the ground and results are provided to maintenance staff.

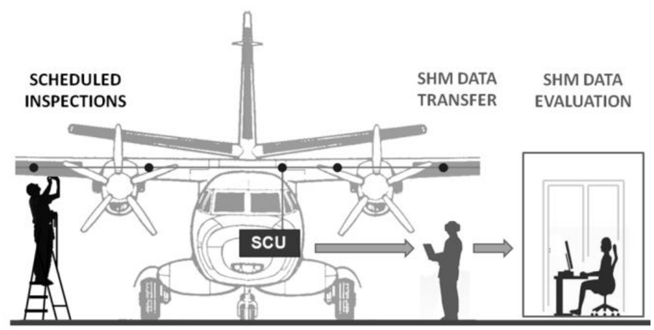

Figure 3. Operational Concept of SHM System in the first phase.

Running SHM system as a parallel / alternative means of inspection to the standard inspection procedures allows for long term data collection and comparison of results provided by SHM to the standard inspection methods. This will allow building confidence in reliability, accuracy and durability of the SHM solution, which is critical from the point of view of qualification of the SHM technology for commercial application. The SHM system has to fulfill same certification requirements and regulations as NDT methods for the damage monitoring, (probability of detection - 90 percent with confidence level of 95 percent). The SHM system on-board installation brings additional requirements on high level of technical durability and functionality (e.g. durability of sensors and wiring > 30 years, environmental resistance – meeting RTCA DO-160 standard).

The operational concept of fully automated & integrated SHM system will be implemented in the second phase. Schematic drawing of the concept is shown in the Figure 4.

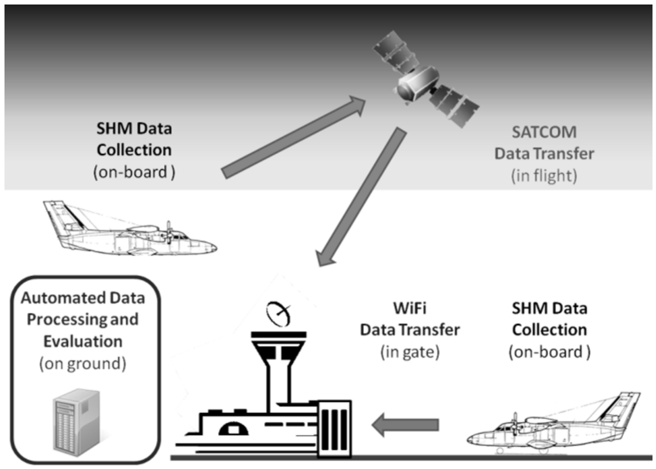

Figure 4. Operational Concept of Fully Automated & Integrated SHM System

Now the SHM system takes over the full responsibility in the area of the structural damage monitoring. All structural damage related inspections are fully covered by SHM system monitoring. It results in decrease of the burdening structural maintenance time. The life limitation of particular PSE is determined by the instant when a structural damage is detected by the SHM system. The structural health is monitored by the automated SHM system with arbitrary periodicity during all phases of the aircraft service. The periodicity of inspections can be very high resulting almost into continuous monitoring. In this case, the CMC provides automated and seamless data transfer to the ground for the following data processing and evaluation. There are several ways of the data dispatching from the aircraft to the ground: SATCOM (during flight) or WiFi (at the gate).

The on-ground data processing is fully automated. Responsibility for correctness of diagnostic results is on the integrated SHM system, which significantly degrease requirements on expertise of the maintenance staff. This concept opens door for implementation of wide range of various maintenance and logistic support services including deployment of Remaining Usage Life (RUL) estimation for predictive maintenance usage, advanced maintenance and logistic planning, wide-fleet management and others. These services will be used not only by the maintenance organizations but they can be also advantageously used by operators and manufactures of aircraft.

6. CONCLUSIONS

The paper describes an approach to the SHM system application on the small commuter aircraft. Two main topics are discussed: SHM architecture and SHM operational concept.

The most important feature of the proposed on-board SHM system architecture is its modularity. This allows for monitoring arbitrary PSE on the airframe, minimization of the SHM system weight, optimization of the SHM system architecture and facilitation of its installation and integration with structure. Further, the modular architecture provides scalability of the SHM solution even for large aircraft platforms.

Two operation concept of the SHM system for implementation into the aircraft maintenance plan are discussed in the paper. In the first phase, the parallel SHM system operation to regular structural inspections is utilized for SHM system on-board introduction, installation issues fixing and its operation capabilities testing and verification. All SHM functions are not fully automated in this phase. The data transfer, data processing and heath status assessment requires involvement of the maintenance staff and structural specialist.

The SHM system takes over the full responsibility in the second phase. All structural damage related inspections are replaced by the automated SHM system. Applied automation and integration level increases the SHM application potential. Besides minimization of maintenance tasks done by maintenance staff, it enables other services as fleet-wide maintenance management, advanced maintenance and logistic planning and implementation of predictive maintenance strategies.

The SHM system development is still in progress. It is expected that results of current work will open way to the SHM system operational deployment in serial aircraft production.

ACKNOWLEDGEMENT

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NOMENCLATURE

ARINC	Standard communication protocol
ATA	Air Transport Asociation
CMC	Central maintenance computer
EASA	European agency for civil aviation
FAA	Federal Aviation Administration
FH	Flight hour
FPC	Flexible printed circuit
GVI	General visual inspection
MSD	Multiple side damage
NDT	Non- Destructive Testing
PSE	Principle Structure Element
PZT	Lead Zirconate Titanate
RUL	Remaining Usage Life
SCU	Sensor Control Unit
SHM	Structure Health Monitoring

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RTCA DO-254 - Design Assurance Guidance for Airborne Electronic Hardware

SAE ARP6461 - Guidance on Structural Health Monitoring for Aerospace

BIOGRAPHIES

Jindrich Finda (March 28th, 1980) earned his Master of Science in Aircraft Design from Brno University of Technology, Faculty of Mechanical Engineering, Institute of Aerospace Engineering in 2003 and his PhD. in Methods for Determination of Maintenance Cycles and Procedures for Airplanes/ Airplane Assemblies from Institute of Aerospace Engineering in 2009. Jindrich Finda works as a Scientist II R&D. His work is aimed on the SHM system development, (developing algorithms for advanced ultrasonic signal / image processing, and algorithms for automated defect detection, localization, size evaluation and prognosis of the defect growth, SHM integration into aircraft maintenance plan).

Radek Hedl (November 19th, 1973) has got his PhD. in Cybernetics and Computer Science from Department of Biomedical Engineering, Faculty of Electrical Engineering and Computer Science, Brno University of Technology. He works as a Technical Supervisor leading CBM/SHM group in Brno. His responsibilities include development of the resource and technology capabilities of the CBM/SHM group, involvement in definition of long term strategy technology roadmaps in the CBM/SHM area, and leading R&D projects.