

New Guidelines for Implementation of Structural Health Monitoring in Aerospace Applications

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ABSTRACT

The first cross-industry guidelines for the implementation of structural health monitoring for aerospace applications have been created as a SAE International Aerospace Recommended Practices document: SAE ARP 6461 'Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft' [1]. These guidelines have brought together manufacturers, operators / users, systems integrators, regulators, technology providers and researchers to produce information on the integration of SHM into aircraft maintenance procedures, generic requirements and advice on validation, verification and airworthiness.

The take-up of SHM in the aerospace industry has been slow, in part due to the lack of accepted industry practices surrounding not just the technology itself (sensors and sensor systems) but also the associated issues arising from the introduction of new methods into aircraft maintenance. The SHM community responded by forming an Industry Steering Committee on the topic which then became a Technical Group within the SAE International standards organization (G-11 SHM). The initial task of this group was to produce guidelines to address some of the issues that currently prevent adoption of SHM in commercial and military aircraft operations.

This paper is a summary of the key content to the guidelines and the rationale behind their development. This is the first document of its type and as such is not concerned with details of the SHM technologies themselves but instead, focuses on the key steps needed to implement the technologies within the current regulatory environment and prevailing aircraft structural design and maintenance practices.

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INTRODUCTION

Structural Health Monitoring (SHM) is an emerging technology and has a long history of research and development [2]. The needs of the aerospace industry to maintain and assure the integrity of safety critical airframes have provided a driver for this development. The requirements for SHM are not primarily for improvements in safety but are more a means to achieve, maintain and possibly enhance the current maintenance practices by using more advanced and automated forms of technology, i.e. built-in sensors to perform structural usage monitoring and damage detection as an alternative or supplement to manual inspection methods.

In 2006 following the European Workshop on Structural Health Monitoring (held in Granada) industry representatives approached Prof Fu-Kuo Chang of Stanford University to create an industry group to mobilize consensus on approaches

to implementing SHM for commercial aircraft application. This followed, what were perceived by some, as missed opportunities to integrate SHM technologies onto new aircraft programmes such as Boeing 787 and Airbus A380. At the time, the technology supply chain for SHM systems (especially those capable of direct structural damage detection) was not sufficiently mature to provide suitably qualified and validated capability to the OEM (Original Equipment Manufacturers) integrators. Contributing to the immaturity of the technology was a complete absence of industry practices, guidelines and standards relating to the numerous types of systems and a clear rationale and framework for implementation in commercial aircraft operations.

The intention in forming an industry group was to draw together users, operators, technology providers, regulators and researchers to redress this inadequacy by creating

guidelines and eventually standards to enable the technology to mature.

The industry group is called the Aerospace Industry Steering Committee on SHM (AISC-SHM) comprising representatives from commercial aircraft OEMs: Airbus (EADS), Boeing, Bombardier and Embraer; system integrators: BAE Systems, Honeywell and Goodrich; Industry test and research: NASA and Sandia Labs; military user representatives: AFRL, and NAVAIR; regulators: EASA, FAA; universities: Stanford and Tokyo and Japanese industry suppliers, FHI.

Initially the AISC-SHM was an independent group but after agreeing that the main task was to prepare industry recognized guidelines, the group joined SAE International Aerospace Division in 2008 as a new technical committee now called G-11 SHM (AISC-SHM). Since that time the committee has prepared SAE ARP 6461: the first Aerospace Recommended Practices on SHM.

THE SCOPE AND MAJOR COMPONENTS OF SHM GUIDELINES ARP 6461

The ARP 6461: 'Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft' uses the following definition of Structural Health Monitoring (SHM): "the process of acquiring and analyzing data from on-board sensors to evaluate the health of a structure." Throughout the document the terms structural health monitoring and structural health management remain distinct. This is acknowledgment that structural health management is the current practice for ensuring aircraft structural integrity within aircraft maintenance programmes. SHM as defined, is a means of enabling health management in the same manner currently served by scheduled programmes of manual inspection (see Figure 1).

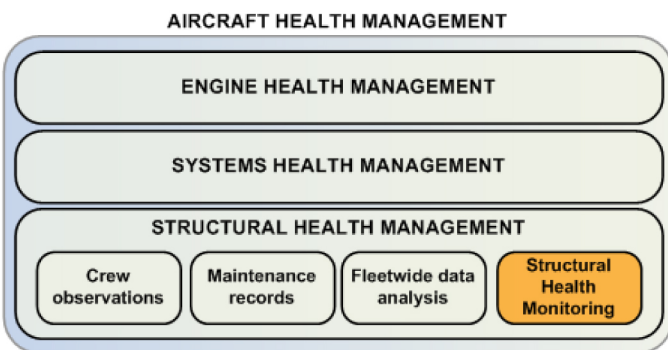


Figure 1. The context of structural health monitoring (SHM) as defined in the SAE ARP 6461 SHM guidelines.

The document is organized into seven main sections or chapters with an appendix relating to military aviation implementation.

The main section headings are:

1. Scope. This includes purpose and field of application
2. References. This includes applicable documents, related publications definitions, and acronyms.
3. Introduction to aircraft design and structures maintenance. This includes design principles, current maintenance principles, MSG-3 (the Airlines For America Maintenance Steering Group document and practices) and a description of the maintenance review board principles.)
4. Essential aspects of SHM. This includes architecture, operational considerations and options such as Scheduled SHM (S-SHM) and Automated SHM (A-SHM).
5. SHM requirements. This includes on-board and ground based requirements.
6. Validation and verification. This includes guidance on the development rigor, use and approval of SHM systems and also example approaches to general evaluation of SHM systems.
7. Certification. This section describes where SHM fits into the current certification processes for commercial aircraft. The emphasis is on compliance with current certification requirements.

Scope

The SAE ARP 6461 guidelines are intended to provide information for stakeholders in SHM who are concerned with the procedural and practical steps necessary for implementing the technology in commercial aircraft operations in a compliant manner. There are no assumptions made on the specific types of SHM techniques employed other than their generic classifications as for operational monitoring (e.g. operational loads monitoring and environment monitoring) or damage detection and monitoring. As such the guidelines describe how SHM aligns with the current Maintenance Review Board process used by the industry to develop maintenance programmes. It also describes the principal benefits accrued by use of SHM but does not explore individual business cases.

The guidelines should be read by:

- Aircraft OEMs who wish to know how to incorporate physical SHM systems into their products to provide benefits to operators and users via more efficient maintenance planning and also from use of SHM system data for future design improvements or upgrades.
- MROs (Maintenance, Repair and Overhaul) who wish to incorporate new techniques into the current structural inspection and maintenance tasks that can potentially mitigate time and cost.
- Operators who wish to remain informed on new developments in capability that can enhance operational availability via streamlined maintenance

• SHM technology providers who wish to understand the pathways and technology maturation requirements from research and development of sensor systems through to implementation in aircraft products and programmes.

An important development parallel to the creation of these guidelines was the revision made in the MSG-3 document owned by Airlines For America (A4A, formerly known as Air Transport Association of America, Inc. : ATA). The MSG-3 document [3] is a result of combining more than 40 years of aircraft manufacturers', airlines' and regulatory authorities' experience to create a minimum list of scheduled maintenance tasks for aircraft models under a given type certificate. The document describes the analysis necessary for understanding the maintenance needs for aircraft structures. It is based on a Reliability Centered Maintenance philosophy. Its evolution from the original Handbook MSG-1, "Maintenance Evaluation and Program Development," produced in July 1968 has underpinned a steady decline in structures related aviation safety incidents over the same period. The MSG-3 analysis is a pre-requisite to the development and revision of the initial minimum scheduled maintenance/inspection requirements for derivative or newly type-certificated transport category aircraft and power plants. These requirements constitute the Maintenance Review Board Report (MRBR) which after approval by the regulatory authorities; become a base or framework around which each airline develops its own individual maintenance program.

MSG-3 Revision 2009.1 included for the first time a reference to SHM described as Scheduled SHM (S-SHM) which the document describes as "the act of using/running/reading out a SHM device at an interval set at a fixed schedule". The structure section of the A4A MSG-3 document was revised to select S-SHM tasks and interval in lieu of classic (manual) inspections. Structure inspection tasks for Accidental Damage (AD), Environmental Damage (ED) and/or Fatigue Damage (FD) can be replaced by a scheduled interaction with a SHM device demonstrated to be applicable and effective.

The SAE ARP 6461 guidelines may be regarded as the next level down of information from the MSG-3 document intended to expand and elaborate on the nature and use of SHM.

ESSENTIAL ASPECTS OF SHM

Although there are numerous potential benefits from SHM the current motivation for its development is the reduction of maintenance costs and increased operational availability through reduced labour and downtime respectively. In the long term, SHM can offer benefits for aircraft design where, for example, damage tolerant design allowables can be influenced by the inclusion of diagnostics and prognostic sensing as a design parameter.

The essential features including benefits of SHM are illustrated in [Figure 2](#).

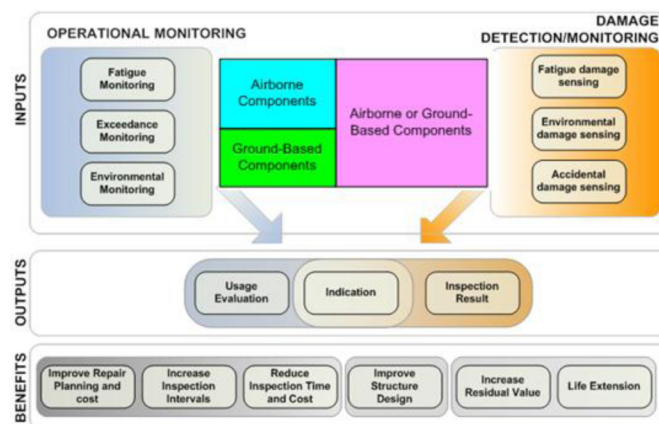


Figure 2. Essential elements of SHM showing the main types of monitoring, the information they provide and the benefits gained (after SAE ARP 6461)

The technologies are not described in detail in the guidelines but are differentiated by their functional uses: operational monitoring (fatigue, load exceedance, environment) and damage detection and monitoring (fatigue damage, environmental damage, accidental damage).

All SHM systems will comprise airborne components such as durable sensors attached to aircraft structural items on a long term, operational basis. Depending on the type of technology there may be associated airborne and ground based equipment such as data processing systems and energy sources. All SHM systems will interface with ground based operations at the level of airport and/or maintenance depot.

The definition of S-SHM was carefully chosen to describe a concept of operation where the SHM system provides an inspection result on demand as part of a prescribed, scheduled maintenance action. It would be stated as part of the MRBR structural and/or corrosion prevention and control program sections in the same way as a traditional inspection and so would require special certification as a process. In MSG-3 Revision 2009.1 it is listed alongside but distinguished from current inspection methods such as

- General Visual Inspection (GVI)
- Detailed Inspection (DET)
- Special Detailed Inspection (SDI)

As an example, S-SHM may be used as an alternative means of compliance for a specific maintenance task involving inspection of structural regions that are accessible to manual inspection only after removal and dismantlement of other aircraft components. Once performed without indication of structural failure, the correspondent aircraft structure is considered airworthy until the next scheduled check by definition (as with any other traditional inspection).

Ideally the task can be carried out by a mechanic with aircraft type rating without additional training hence avoiding the costs associated with training and accreditation of expert