

AEROSPACE INFORMATION REPORT

AIR6245™

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Perspectives on Integrating Structural Health Monitoring Systems into Fixed-Wing Military Aircraft

RATIONALE

A wide range of engineering disciplines are required to evolve Structural Health Monitoring (SHM) technologies, and to integrate these technologies into military aircraft. ARP6461 provides information about these disciplines in the form of guidance for implementation of SHM on civil transport airplanes. For military aircraft, SHM development activities will benefit from further information highlighting the perspectives of international military organizations in terms of their requirements, SHM use cases, and SHM challenges.

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1. SCOPE

This SAE Aerospace Information Report (AIR) is prepared for stakeholders seeking information about the evolution, integration, and approval of SHM technologies for military aircraft systems. The report provides this information in the form of (a) two military organizations' perspectives on requirements, and (b) general SHM challenges and industry perspectives. The report only provides information to generate awareness of perspectives for military aircraft and, hence, assists those who are involved in developing SHM systems understanding the broad range of regulations, requirements, and standards published by military organizations that are available in the public domain from the military organizations.

1.1 Purpose

A wide range of engineering disciplines are required to evolve SHM systems and integrate matured technologies into military aircraft. The disciplines are required from stakeholders with varying experiences: aircraft manufacturers, system suppliers, regulatory agencies, academia, etc. The stakeholders' SHM activities will benefit from information highlighting the perspectives of key international military organizations in terms of their requirements and identified SHM challenges. Therefore, the main purposes of this report are:

- Generate multi-discipline awareness of a wide range of SHM disciplines including perspectives on military requirements and main SHM challenges.
- Provide context and information where appropriate on the evolution and integration of SHM into military aircraft and maintenance support systems.

Whilst this report presents the perspectives of military organizations and include examples of identified challenges, the following imperative explanatory notes should be considered:

- This report does not promote or endorse a technology or a system. The report only provides references to information to assist in validating, verifying, and certifying SHM systems, and integrating matured systems into military aircraft by imperative considerations of the relevant military regulations and standards.
- The report contents do not constitute a policy or regulatory requirements of any of the military organizations considered in this report. For each military organization, the applicable regulations, requirements, and standards are those published and updated by the organization. Therefore, the information in this report must only be considered as guidance information.
- The information of Section 3 is collated from public domain papers, standards, and MOD publications by authors who do not represent the UK MOD.
- Whilst the information in this report is applicable to rotorcraft, considerations should be made to the specific structures, operations, and environments of the rotorcraft, along with the vibratory loads induced on the airframe structures by rotors and transmissions. Also, considerations should be made to the fact that a large number of military helicopters have been fitted with Health and Usage Monitoring Systems (HUMS). Therefore, an SHM AIR dedicated to rotorcraft application is being prepared by the AISC-SHM committee; the rotorcraft AIR would include the military perspective of the U.S. Army.

1.2 Field of Application

The information contained in this document can assist in the following:

- Maturing SHM systems for military applications,
- Deriving from the identified challenges approaches to exploit SHM technologies, and
- Integrating matured SHM technologies into military aircraft and associated maintenance support systems.

NOTE: This SAE document is not a policy or a regulatory document; therefore, the reader of this report is not compelled to follow the information presented in the report.

1.3 An Overview of This Document

Section 2 of this report lists the applicable documents that contain detailed information about the regulations, standards, and requirements of military organizations. The section also lists key non-military publications that are widely accepted by various military organizations. The section collates relevant definitions followed by the references from which they are quoted. Those definitions without references are either: (a) definitions introduced for the purpose of this report, or (b) definitions believed to agree with the generally accepted understanding of the terms.

The military regulations, standards, and processes required for designing, approving, and maintaining aircraft structures can vary between nations and between the military operators of one nation. However, the wide range of manufacturers within the defense industry implements similar best practice approaches to develop aircraft products that comply with the varying regulations and standards across the military organizations. For example, the common practices for developing an aircraft product include most of the main development activities and processes shown in Figure 1, with minor variations in the names of the activities/processes and their implementation details.

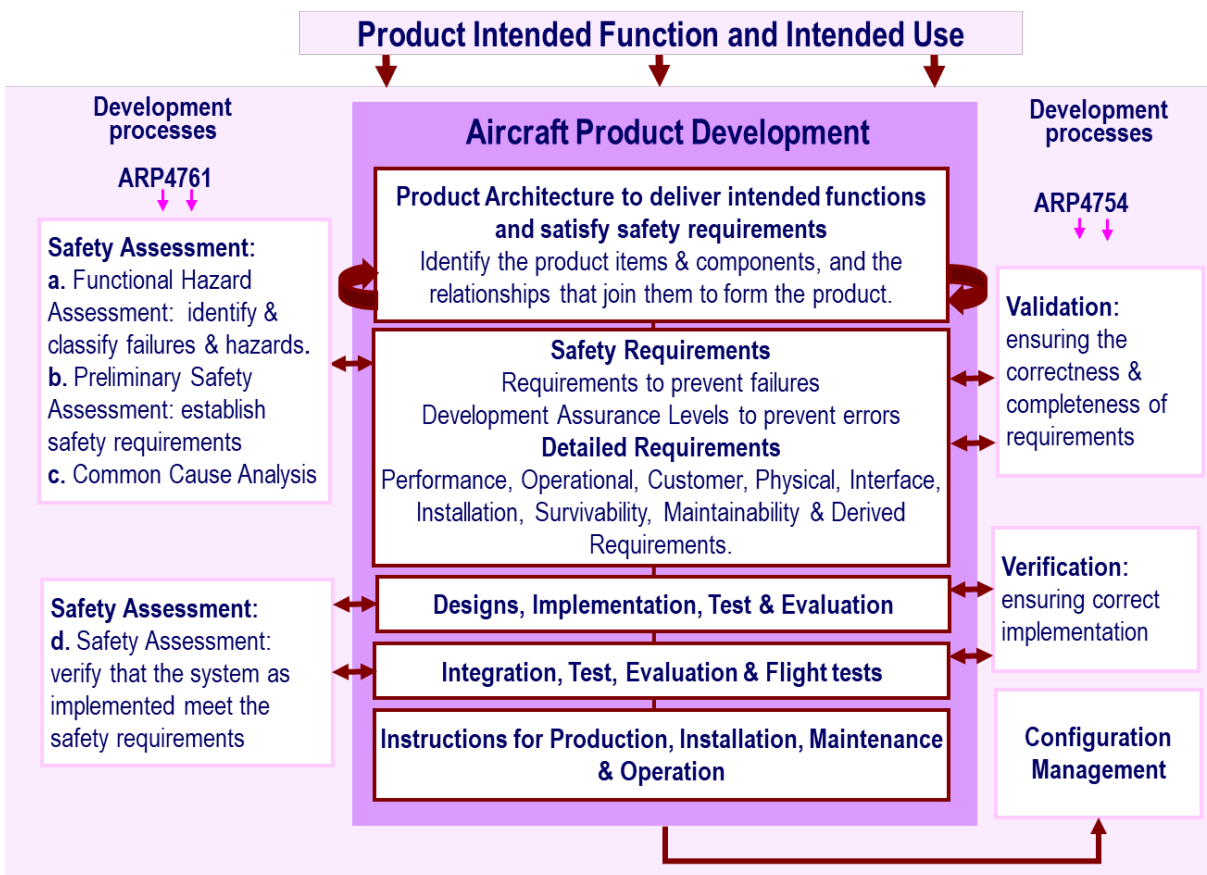


Figure 1 - Key system development and process activities



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In other words, the perspectives of military operators are expected to show the following:

- **Significant Differences:** The military perspectives on the design and maintenance approaches can show significant differences between various military organizations; for example, some of these approaches are based on safe-life methodologies and others based on damage tolerance methodologies.
- **Process Differences:** Differences are expected in the details of the approval and certification processes, including variations in the interaction mechanisms between the military authorities and the developers, as well as differences in the names of the approval/certification outputs and the sequence of events leading to the product approval.
- **Insignificant Differences:** Often, the above differences do not have any significant influence on the common development practices of aircraft products. The manufacturers within the defense industry implement similar best practice approaches to develop aircraft products; generally, the documents of these approaches call for or include parts similar to international standards such as ARP4754, ARP4761, DO-178, and DO-160.

Therefore, only in Section 3 of this document, the common development practices of aircraft products are briefly discussed based on such above international standards because the UK defense standards explicitly quote them as applicable documents. Section 3 also presents the UK military perspective by providing information derived through the following activities: (a) discussing the Damage Tolerance and Safe Life approaches used to design and maintain aircraft structures; the Safe Life approach is the standard approach in the UK, (b) reviewing the UK military regulations that govern the design and maintenance of structures, (c) summarizing regulations and processes required to overcome the threats to structural integrity, (d) discussing the evolution and acquisition phases of UK military aircraft products including SHM systems, (e) presenting the architectural ingredients and choices that can deliver required SHM intended functions, (f) establishing the requirements of SHM systems that are essential for compliance with airworthiness regulations and industry-accepted standards, (g) presenting the methods required to validate and verify aircraft products with interpretations and extensions specific to SHM systems, and (h) presenting the certification phases, their outputs, and associated approval forms of the UK Military Aviation Authority (MAA).

Section 4 presents two key documents that describe the U.S. Air Force perspective. By following the guidance of these documents, SHM systems can be matured, developed, and integrated into the U.S. Air Force aircraft and its support systems.

Section 5 highlights some of the main challenges facing SHM and presents general industrial perspectives indicating the progress made to address these challenges. Regarding the implementation of SHM NDI inspection tasks, two key aerospace documents (MIL-STD-1530 and A4A MSG-3) have added SHM to their contents.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Telephone: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), <http://www.sae.org>.

ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP5150	Safety Assessment of Transport Airplanes in Commercial Service
ARP6461	Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft

2.1.2 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
DO-178	Software Considerations in Airborne Systems and Equipment Certification
DO-200	Standards for Processing Aeronautical Data
DO-201	Industry Requirements for Aeronautical Information
DO-254	Design Assurance Guidance for Airborne Electronic Hardware
DO-278	Guidelines for Communication, Navigation, Surveillance and Air Traffic Management (CNS/ATM) System Software Integrity Assurance

2.1.3 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

DI-MGMT-81915	Condition-Based Maintenance Plus (CBM+) Program Plan
JSSG-2006	Joint Service Specification Guide, Aircraft Structures
NAVAIR 00-25-403	Guidelines for the Naval Aviation Reliability-Centered Maintenance Process
MIL-HDBK-1823	Nondestructive Evaluation System Reliability Assessment
MIL-HDBK-2173	Reliability-Centered Maintenance Requirements for Naval Aircraft, Weapons Systems and Support Equipment
MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-1530	Aircraft Structural Integrity Program (ASIP)
MIL-STD-1553	Digital Time Division Command/Response Multiplex Data Bus
MIL-STD-3034	Reliability-Centered Maintenance (RCM) Process

2.1.4 UK Ministry of Defence (MOD) Publications

2.1.4.1 Military Aviation Authority (MAA) Publications

Available through <https://www.gov.uk/government/collections/maa-regulatory-publications>.

MAA01	Military Aviation Authority Regulatory Policy
MAA02	Military Aviation Authority Master Glossary
MAA03	Military Aviation Authority Regulatory Processes
MAA 1000 Series	GEN 1000 Series Regulatory Articles,
MAA 4000 Series	Continuing Airworthiness Engineering Regulations (CAE) 4000 Series Regulatory Articles

MAA 5000 Series Design and Modification Engineering (DME) 5000 Series Regulatory Articles

CAE 4000 - MAP 01 Manual of Maintenance and Airworthiness Processes

CAE 4000 - MAP 02 Manual of Maintenance and Airworthiness Processes Supplement - MOD Form 700 Series of Form

2.1.4.2 Defence Standards (Def Stan)

Available through <https://sts.defencegateway.mod.uk/Login.aspx>.

Def Stan 00-45 Using Reliability Centred Maintenance to Manage Engineering Failures

Def Stan 00-56 Safety Management Requirements for Defence Systems

Def Stan 00-970 Design and Airworthiness Requirements for Service Aircraft, Part 0, Part 1, Part 7 & Part 9

2.1.4.3 Joint Services Publications

Available through <https://www.gov.uk/government/publications>.

JSP 815 Defence Environment and Safety Management, Joint Services Publication (JSP).

JSP 886 Defence Logistics Support Chain Manual

Available through <https://www.gov.uk/government/publications/military-aircraft-structural-airworthiness-advisory-group-masaag-documents>.

MASAAG Paper 123 Development, Validation, Verification and Certification of Structural Health Monitoring Systems for Military Aircraft

2.1.5 NATO Publications

Available through <http://nso.nato.int/nso/nsdd/listpromulg.html>.

STANAG 4671 Unmanned Aerial Vehicles System Airworthiness Requirements (USAR)

2.1.6 A4A Publications

Available from Airlines for America (A4A), 1301 Pennsylvania Avenue, NW, Suite 1100, Washington, DC 20004-1707, Tel: 202-626-4000, www.airlines.org/.

A4A MSG-3 Operator/Manufacturer Scheduled Maintenance Development

2.1.7 Standard Specifications Cited in the AIR for Communications Between Avionics

AFDX Avionics Full-Duplex Switched Ethernet: An Airbus-patented implementation of ARINC 664 Part 7 to achieve deterministic behavior and high reliability by duplicating virtual links between end-systems (avionics) and duplicating switches that direct the data traffic of the virtual links and police their bandwidth.

ARINC 429 Digital Information Transfer System (DITS): Specifications that define the physical and electrical interfaces of a two-wire data bus and a point-to-point data protocol for transferring digital data between avionics systems.

ARINC 664 Aircraft Data Network (ADN) specifications.

Bluetooth Industry specifications for short-range radio frequency (RF)-based connectivity for portable personal devices.

IEEE 802.11	A standard for Wireless Local Area Network (WLAN) providing the basis for wireless network products using the WiFi brand.
IEEE 802.15.1	An IEEE standard for a Wireless Personal Area Network (WPAN) based on the Bluetooth specifications.
IEEE 802.15.4	A standard defining the operation of low-rate WPAN (LR-WPANs).
Zigbee	An IEEE 802.15.4-based specification for LR-WPANs with low-power, low data rate, and close proximity network.

2.2 Related Publications

A list of publications is provided in Appendix A. These publications are provided for information purposes only and are not a required part of this SAE Aerospace Information Report.

2.3 Definitions

Most of the definitions in this section are followed by the references from which they are quoted. Those definitions without references are either: (a) definitions introduced for the purpose of this paper, or (b) definitions believed to agree with the generally accepted understanding of the terms.

AIRCRAFT DOCUMENT SET (ADS): The documents that have a prime airworthiness function for each aircraft type. They include the Release to Service (RTS), Aircraft Safety Case, Aircraft Maintenance Manual (AMM), Operating Data Manual (ODM), Flight Reference Cards (FRCs), Support Policy Statement, Engineering Air Publications (including the Flight Test Schedule (FTS)), and the Statement of Operating Intent and Usage (SOIU). The documents comprising the ADS may be held electronically. (MAA02.)

AIRWORTHINESS: The ability of an aircraft or other airborne equipment or system to be operated in flight or on the ground without significant hazard to aircrew, ground-crew, passengers, or to third parties; it is a technical attribute of materiel throughout its lifecycle. (MAA02.) The civil document ARP4754 defines airworthiness as, "The condition of an aircraft, aircraft system, or component in which it operates in a safe manner to accomplish its intended function."

APPROVAL: That which permits something to be done. Note: Approval may be granted to an individual or an organization verbally, or in writing by an appropriately authorized person or authority. (MAA02.) The civil document ARP4754 defines approval as, "The act of formal sanction of an implementation by a certification authority."

ASSURANCE: The planned and systematic actions necessary to provide adequate confidence and evidence that a product or process satisfies given requirements. (DO-178.)

AUTOMATED SHM (A-SHM): Automated SHM is any SHM technology which does not have a pre-determined interval at which maintenance action must take place, but instead relies on the system to inform maintenance personnel that action must take place. (CIP 2009-1 rev2nov09-MSG-3 proposed amendment.)

CERTIFICATION: A procedure by which a third party gives written assurance that a product, process, or service conforms to a specified requirement. (MAA02.) The civil document ARP4754 defines certification as, "The legal recognition that a product, service, organization, or person complies with the applicable requirements. Such certification comprises the activity of technically checking the product, service, organization, or person, and the formal recognition of compliance with the applicable requirements by issue of a certificate, license, approval, or other document, as required by national laws and procedures."

CERTIFICATION AUTHORITY: Organization or person responsible for granting approval in accordance with applicable regulations. (ARP4754.)

CONDITION-BASED MAINTENANCE: Maintenance performed as governed by condition monitoring programs. (ISO 13372.)