



AEROSPACE INFORMATION REPORT

AIR6892™

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Structural Health Monitoring Considerations and Guidance Specific to Rotorcraft

RATIONALE

Rotorcraft manufacturers, operators, and regulatory agencies will be able to utilize this AIR to link existing resources, including ARP6461, to Structural Health Monitoring (SHM) applications in rotorcraft. Operating environment and subsystem architecture common for rotorcraft will be in the forefront of the enclosed guidance with intention of bridging any existing gaps between generic documentation and rotorcraft.

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1. SCOPE

This SAE Aerospace Information Report (AIR) provides guidance on the definition, development, integration, qualification/certification, and deployment of Structural Health Monitoring (SHM) technologies applied to commercial and military rotorcraft. Increased implementation of SHM is believed to have numerous potential benefits, including enhanced operational safety and reduced maintenance burden. The focus is on augmenting ARP6461 to address specific unique aspects of implementing SHM on rotorcraft without unnecessarily duplicating guidance already contained in the ARP that is generally applicable to both fixed-wing and rotary-wing aircraft.

For the purpose of this document, SHM is defined as “the process of acquiring and analyzing data from on-board sensors in order to determine the health of a structure”. Note that this is irrespective of whether the on-board sensors are a permanent or temporary installation. On-board sensors could include any presently installed aircraft sensors as well as new sensors to be defined in the future. Interrogation of these sensors could be done on-board during flight or off-board using ground support equipment during maintenance activities. It is assumed that the primary user of SHM in the near term will be the maintenance and operations crew. This document does not include guidance on SHM business case analysis nor display of health state or recommendations to the flight crew in real-time.

1.1 Purpose

This document has the following major purposes:

- Define key elements of rotorcraft SHM system functionality, including key similarities and differences compared to fixed wing SHM as defined in ARP6461.
- Provide guidance on the implementation of SHM in rotorcraft applications aligned with different application scenarios (e.g., temporary mitigation of fleet structural integrity issue, Condition Based Intervention (CBI) for proactive maintenance versus published schedule, deferment or SHM triggering of traditional visual or NDI inspections or condition-based maintenance for fault-tolerant structures and maintenance practices).
- Establish lessons learned from the development, integration, qualification, certification, and deployment of rotorcraft Health and Usage Monitoring Systems (HUMS) functionality as they relate to SHM.
- Provide guidance on controlled introduction into service and validation of SHM efficacy through combined validation testing and fleet experience.
- Provide guidance on known regulatory requirements and approaches for using SHM to obtain Condition-Based Maintenance (CBM) credits (hereafter referred to as either CBM credits or maintenance credits).
- Provide guidance on how SHM can be incorporated within or as modifications to current maintenance and airworthiness documents.
- Provide input for consideration by airworthiness authorities and regulatory agencies for refinement of guidance related to SHM-based maintenance credits.

2. REFERENCES

2.1 Applicable Publications

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 International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), 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
ARP5987	A Process for Utilizing Aerospace Propulsion Health Management Systems for Maintenance Credit
ARP6461	Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft

2.1.2 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

14 CFR Part 21	Certification Procedures for Products and Parts
14 CFR Part 23	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
14 CFR Part 25	Airworthiness Standards: Transport Category Airplanes
14 CFR Part 26	Continued Airworthiness and Safety Improvements for Transport Category Airplanes
14 CFR Part 27	Airworthiness Standards: Normal Category Rotorcraft
14 CFR Part 29	Airworthiness Standards: Transport Category Rotorcraft
14 CFR Part 33	Airworthiness Standards: Aircraft Engines
14 CFR Part 35	Airworthiness Standards: Propellers
14 CFR Part 121	Operating Requirements: Domestic, Flag, and Supplemental Operations
14 CFR Part 135	Operating Requirements: Commuter and On Demand Operations and Rules Governing Persons on Board Such Aircraft
14 FAR 27.1529	Instructions for Continued Airworthiness
14 FAR 29.1529	Instructions for Continued Airworthiness AC 20-115 Radio Technical Commission for Aeronautic, Inc. Document RTCA DO-178
AC 20-152	RTCA, Inc., Document RTCA DO-254, Design Assurance Guidance for Airborne Electronic Hardware
AC 20-156	Aviation Data Bus Assurance
AC 25-571-1	Damage Tolerance and Fatigue Evaluation of Structure
AC 25-19	Certification Maintenance Requirements

AC 29-2C MG 15	Airworthiness Approval of Rotorcraft Health Usage Monitoring Systems
AC 121-22	Maintenance Review Board Report, Maintenance Type Board, and OEM/TCH Inspection EASA Publications
FAA CPI Guide	The FAA & Industry Guide to Product Certification, Sept. 2004
Order 8110.37E	Designated Engineering Representative (DER) Guidance Handbook
Order 8110.54	Instructions for Continued Airworthiness, Responsibilities, Requirements and Contents
Order 8100.8D	Designee Management Handbook

2.1.3 EASA Publications

Available from European Aviation Safety Agency, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

CS-23	Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes
CS-25	Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes
CS-29.1465	Certification Specifications for Large Rotorcraft-Vibration Health Monitoring
EC 748/2012	Annex Part 21: Certification of Aircraft and Related Products, Parts and Appliances, and of Design and Production Organizations

2.1.4 TCCA Publications

Available from Transport Canada, 330 Sparks Street, Ottawa, ON, Canada, K1A 0N5, Tel: 613-990-2309, www.tc.gc.ca.

CARs 2012-1	Part I - General Provisions, Subpart 1 - Interpretation (CARs 101.01).
CARs 2012-1	Part V - Airworthiness, Regulations, Subpart 21 - Approval of the Type Design or a Change to the Type Design of an Aeronautical Product (CARs 521.01 to 521.456), Division IV - Changes to a Type Design (CARs 521.151 to 521.161)
AC 521-004	Changes to the Type Design of an Aeronautical Product

2.1.5 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

2.1.6 A4A Publications

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

A4A MSG-3 Operator/Manufacturer Scheduled Maintenance Developments, Volume 2 - Rotorcraft

2.1.7 U.S. Government Publications

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

MIL-HDBK-1823 Nondestructive Evaluation System Reliability Assessment

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-1472 Design Criteria Standard: Human Engineering

MIL-STD-3063 Rotorcraft Structural Integrity Program (RSIP)

ADS-79E-HDBK Aeronautical Design Standard Handbook 79E, Condition Based Maintenance System for U.S. Army Aircraft, U.S. Army Research, Development, and Engineering Command, Aviation Engineering Directorate, 8 February 2016

2.1.8 Other Applicable Publications

CAP 753 Helicopter Vibration Health Monitoring (VHM): Guidance Material for Operators Utilising VHM in Rotor and Rotor Drive Systems of Helicopters

ENV13005 Guide to the expression of uncertainty in measurement

ISO 5725 Accuracy (Trueness and Precision) of Measurement Methods and Results

JAA JAR145 Aviation Maintenance Human Factors

2.2 Supplementary Publications

None.

2.3 Definitions

AIRWORTHINESS: The condition of an aircraft, aircraft system, or component in which it operates in a safe manner to accomplish its intended function (refer to ARP4754).

APPROVAL: The act of formal sanction of an implementation by a certification authority (refer to ARP4754).

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

CERTIFICATION: 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 (refer to ARP4754).

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

CONDITION BASED MAINTENANCE (CBM): The act of performing maintenance based on the condition or health of a component/system as opposed to schedule. Specifically, a maintenance action that is taken by the operator based upon HUMS data analysis which is addressed in the OEM Maintenance Program.

CRITICALITY: Indication of the hazard level associated with a function, hardware, software, etc., considering abnormal behavior (of this function, hardware, software, etc.) alone, in combination or in combination with external events (refer to ARP4761).

DAMAGE MONITORING: Any direct measurement methods that allow the detection of damages in the structure.

DAMAGE TOLERANCE: The attribute of the structure that permits it to retain its required residual strength for a period of use after the structure has sustained a given level of fatigue, corrosion, or accidental or discrete source damage (refer to AC 25 571-1).

FAILURE CONDITION: A condition caused or contributed to by one or more failures or errors that have either a direct or consequential effect on the airplane, its occupants, and/or other persons. In identifying failure conditions, the flight phase, relevant adverse operational or environmental conditions, and external events should be considered (refer to AC 25-19).

FAULT: Mechanical degradation has progressed to the point where a traditional, approved fault detection application has produced an alert indicating a corrective action is required by the OEM Maintenance Program to insure Continued Airworthiness.

FUNCTIONAL HAZARD ASSESSMENT: A systematic, comprehensive examination of functions to identify and classify failure conditions of those functions according to their severity (refer to ARP4754).

INCIPIENT DEFECT: The initial stage of degradation that typically leads to a fault.

INDEPENDENCE: (1) A concept that minimizes the likelihood of common mode errors and cascade failures between aircraft/system functions or items. (2) Separation of responsibilities that assures the accomplishment of objective evaluation (e.g., validation activities not performed solely by the developer of the requirement of a system or item). Refer to ARP4754.

INSTRUCTIONS FOR CONTINUED AIRWORTHINESS (ICA): Documentation that sets forth instructions and requirements for the maintenance that is essential to the continued airworthiness of an aircraft, engine, or propeller (refer to AC 25-571-1).

INTEGRITY: Attribute of a system or an item indicating that it can be relied upon to work correctly on demand (refer to ARP4751)

PRELIMINARY SYSTEM SAFETY ASSESSMENT: A systematic evaluation of a proposed system architecture and its implementation, based on the Functional Hazard Assessment and Failure Condition classification, to determine safety requirements for systems and items (refer to ARP4754).

PRIMARY STRUCTURE: Structure which is intended to carry primary design loads or is necessary to maintain certified levels of structural integrity for the rotorcraft (refer to MIL-STD-3063).

PRODUCT: (1) Hardware, software, item or system generated in response to a defined set of requirements (refer to ARP4754). (2) Aircraft, aircraft engines, propellers, as well as appliances and components or parts (refer to FAA CPI Guide).

QUALIFICATION: The processes of verifying that a product (system, hardware, and software) complies with a specified set of performance and airworthiness requirements.

ROTORCRAFT STRUCTURE: Components that provide the strength, stiffness, and mechanical stability required for reacting, carrying, or transmitting loads or motions (refer to MIL-STD-3063).

SCHEDULED SHM (S-SHM): To use/run/read out a SHM device at an interval set at a fixed schedule (refer to MSG-3).

STRUCTURAL HEALTH MONITORING (SHM): The process of acquiring and analyzing data from on-board sensors in order to determine the health of a structure.

STRUCTURAL INTEGRITY: Attribute of a structural system or a component that can be relied upon to function as required by the criticality determined by the Functional Hazard Assessment (FHA).

SYSTEM SAFETY ASSESSMENT: A systematic, comprehensive evaluation of the implemented system to show that the relevant safety requirements are met (refer to ARP4754).

UNSCHEDULED MAINTENANCE: Unplanned maintenance actions that are required, in response to traditional alerts such as a chip light, metal debris in the strainers, high oil temperature, low oil pressures, crew reports of unusual noises, vibration, etc.

VALIDATION: The determination that the requirements for a product are correct and complete. (Are we building the right aircraft/system/function/item?). Refer to ARP4754.

VERIFICATION: The evaluation of an implementation of requirements to determine that they have been met. (Did we build the aircraft/system/function/item right?). Ref to ARP4754.

VM DATA: Vibration Monitoring data (CI or HI) available from a HUMS.

2.4 Acronyms and Abbreviations

A4A	Airlines for America, formerly known as Air Transport Association of America, Inc. (ATA)
AD	Accidental Damage
A-SHM	Automated SHM
AC	Advisory Circular (FAA) or Airworthiness Certificate
ACO	Aircraft Certification Office
AG	Advisory Generation
AIR	Aerospace Information Report (SAE)
AISC-SHM	SAE Aerospace Industry Steering Committee on Structural Health Monitoring
AL	Assurance Level
AMM	Aircraft Maintenance Manual
ARP	Aerospace Recommended Practice (SAE)
BIT	Built-In Test
CAA	Civil Aviation Authority of the UK
CAR	Canadian Aviation Regulations
CBI	Condition Based Intervention
CBM	Condition Based Maintenance
CCA	Common Cause Analysis
CFR	Code of Federal Regulations
CI	Condition Indicator
CIS	Controlled Introduction to Service

CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf
DAL	Design Assurance Level
DAR	Designated Airworthiness Representative
DER	Designated Engineering Representative
DET	Detailed Inspection
DOD	Department of Defense (U.S.)
DOM	Director of Maintenance
EASA	European Aviation Safety Agency
EC	European Commission
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FD	Fatigue Damage
FHA	Functional Hazard Assessment
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Assessment
FOD	Foreign Object Debris
FODD	Foreign Object Debris Damage
GAG	Ground-Air-Ground
GBS	Ground-Based System
GVI	General Visual Inspection
FOQA	Flight Operations Quality Assurance
FT	Flight Time
HA	Health Assessment
HARP	Helicopter Airworthiness Requirements Panel
HCF	High-Cycle Fatigue
HI	Health Indicator
HUMS	Health and Usage Monitoring System(s)
ICA	Instructions for Continued Airworthiness
IMV	Independent Means of Verification

ISO	International Organization for Standardization
IVHM	Integrated Vehicle Health Management
JAR	Joint Aviation Requirements
LCF	Low-Cycle Fatigue
LOV	Limit of Validity
LRU	Line Replaceable Unit
MFOP	Maintenance Free Operating Period
MG	Miscellaneous Guidance
MIL-HDBK	Military Handbook
MOD	Ministry Of Defence (UK)
MRB	Maintenance Review Board
NDI	Non-Destructive Inspection
OBS	On-Board System
OEM	Original Equipment Manufacturer
PoD	Probability of Detection
RTB	Rotor Track and Balance
SD	State Detection
SHM	Structural Health Monitoring
TBO	Time Between Overhaul
TCH	Type Certificate Holder
TRL	Technology Readiness Level
VHM	Vibration Health Monitoring
VM	Vibration Monitoring

3. SAFETY AND MAINTENANCE APPLICATIONS

Practical applications of SHM to rotorcraft in the context of rotorcraft HUMS experience are covered in this section, with an emphasis on the likely differences in application of SHM between fixed-wing and rotorcraft. More differences than similarities can be drawn between rotorcraft and fixed-wing aircraft, which is why rotorcraft are more often manufactured by dedicated OEMs. While they share several components and subsystems by name and function, the unique mission profiles, operating conditions and dynamic loading environments pertaining to rotorcraft yield elements that are differentiated from their fixed-wing counterparts. This section provides an overview of these differences and sets the context for the detailed discussions given subsequently on systems integration (Section 5) and airworthiness (Section 6).

3.1 HUMS Background

Many rotorcraft are now fielded with HUMS integrated within the baseline aircraft configuration. In principle a HUMS is used by the maintainer and crew to assess aircraft integrity, determine mission risk, and plan aircraft maintenance. While HUMS is a general descriptor, to date, the rotorcraft community has prioritized vibration monitoring of dynamic systems such as rotors and drive systems over “static” airframe monitoring due to the fact that dynamic systems represent both a higher maintenance burden and a higher proportion of the causes of rotorcraft accidents/incidents. While the initial driver for rotorcraft HUMS may have been operational safety associated with dynamics systems, economic exploitation in terms of reduced life-cycle costs and aircraft availability is now being sought.

Current HUMS include some or all the following capabilities:

Rotor Track and Balance (RTB)

Rotorcraft inherently vibrate due to the aerodynamic operation of the rotors and out of balance conditions of primary rotating sub-systems, which leads to fatigue damage of rotating and static elements of the rotorcraft and adverse effects on the crew and passengers. One element readily controllable by maintenance is rotor out-of-balance and out-of-track. HUMS provides the capability to compute trim tab, pitch link, and balance weight adjustments from vibration measurements, phase information (e.g., tachometer), and track height information from a blade tracker.

Vibration Monitoring (VM)

A rotorcraft includes many different dynamic rotating components, including engines, transmissions, bearings, pumps, fans, etc. A primary function of a HUMS is the collection and analysis of higher frequency vibration signatures (typically 50 Hz to several 10s of kHz) from rotating components to diagnose or predict degradation or faults. For on-board HUMS, vibration signatures can be monitored during every flight, and component condition monitoring can be a continuous process.

Regime Recognition

Regime recognition is a capability provided by some on-board HUMS systems to control the acquisition of vibration data and to support usage monitoring. Often regime recognition is achieved by monitoring bus traffic containing flight parameters. Alternatively, some HUMS systems have an interface allowing the crew to alert the HUMS system when they are flying in a certain regime.

Structural Usage Monitoring

Regime recognition capabilities provided by HUMS are often used for the purposes of structural usage monitoring. ARP6461 refers broadly to structural usage monitoring with the term “Operational Monitoring”.

Exceedance Monitoring

HUMS systems also monitor bus and analog sensor data to detect exceedances of acceptable ranges of operation. This concept is also discussed under the category of “Operational Monitoring” in ARP6461.

3.2 The Application of SHM to Rotorcraft

SHM comprises monitoring the condition of structural components in order to determine component health and assess structural integrity.

Now that usage monitoring and vibration monitoring of dynamic systems are mature and in widespread use, there is renewed interest in improving the monitoring of rotor and airframe structural elements of the rotorcraft being driven by continuous improvement in operational safety and the desire for reduction of the maintenance burden. The driver for rotorcraft airframe SHM is mainly economic from the outset due to the significant burden associated with scheduled inspections; however, there will be other benefits including both operational durability and safety. It is expected that some level of SHM will be required to affordably reduce the risk of fully implementing a damage tolerant design, qualification, and life management philosophy on the next generation of rotorcraft.