



AEROSPACE RECOMMENDED PRACTICE

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Utilizing Integrated Vehicle Health Management Systems for Airworthiness Credit

RATIONALE

Regulatory approval has been provided to some engine and aircraft Original Equipment Manufacturers (OEMs) to allow the use of health management functionality to comply with Airworthiness Directives (AD), extend inspection intervals, comply with MSG guidance, or more effectively utilize component lives to optimize “their service life.”

This document has been written to provide a consistent approach for obtaining approval to use aerospace Integrated Vehicle Health Management (IVHM) systems for airworthiness credit. The objective of this SAE Aerospace Recommended Practice (ARP) is to help applicants prepare the materials needed for regulators to carry out assessments of the merits of an airworthiness credit application with a view to provide approval. Given that many specifics related to this topic are still evolving, the initial version of this document provides high-level steps for ensuring adequate integrity of a health management function. The intent is to identify gaps in guidance in a companion “statement of concerns” document, which will then be used to inform future improvements to this document as industry consensus evolves.

This document was originally derived from ARP5987, which was published by the SAE E-32 (Propulsion Systems Health Management) standards committee. In response to a request from the Airlines for America (A4A) Maintenance Programs Industry Group (MPIG), SAE agreed that the HM-1 (Integrated Vehicle Health Management) standards committee would publish an equivalent document at the aircraft level rather than focus on the engine level. One of the objectives of this aircraft-level document is to provide the International Maintenance Review Board Policy Board (IMRBPB) with information on industry experience as the policy board works to harmonize guidance related to health management for airworthiness credit. HM-1 and E-32 then agreed to retire ARP5987 and establish joint ownership of the vehicle-level document: ARP7122. These two committees will maintain a joint working group to define the strategy and content for future revisions.

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TABLE OF CONTENTS

1.	SCOPE.....	3
2.	REFERENCES.....	3
2.1	Applicable Documents	3
2.1.1	SAE Publications	3
2.1.2	A4A Publications	4
2.1.3	EUROCAE Publications	4
2.1.4	FAA Publications	4
2.1.5	RTCA Publications	4
2.1.6	Other Publications	4
2.2	Related Publications	5
2.2.1	SAE Publications.....	5
2.2.2	RTCA Publications	5
2.2.3	IATA Publications	5
2.3	Definitions	5
2.4	Abbreviations	6
3.	INTRODUCTION.....	8
3.1	Consequence Versus Probability Concept Applied to an IVHM System	10
4.	HEALTH MANAGEMENT SOLUTIONS FOR AIRWORTHINESS CREDIT	10
4.1	New Designs	10
4.2	Fielded Designs	11
4.3	Relationship to the MSG Process	11
4.4	Process Questions	13
5.	NOTES	15
5.1	Revision Indicator.....	15
APPENDIX A	AIRWORTHINESS CREDIT CHECKLIST DETAILS	16
APPENDIX B	AIRWORTHINESS CREDIT EXAMPLES	19
Figure 1	Consequence versus probability (adapted from AC 25-1309).....	9
Figure 2	Process steps for IVHM function.....	14

1. SCOPE

The process detailed within this document is generic and applies to the entire end-to-end health management capability, covering both on-board and on-ground elements in both commercial and military applications throughout their life cycle. While some guidance related to usage of ground-based health management equipment for airworthiness credit exists in certain areas, this document provides a general mechanism to ensure a level of integrity commensurate with the potential aircraft-level consequences of the relevant failure conditions. The practical application of this standardized process is detailed in the form of a checklist. In order to provide some detailed guidance utilizing the process and checklist, some high-level examples of successful cases of approved “Maintenance Credit” applications for airworthiness credit (and one case where the approval is in process in 2024) are included.

This document does not teach how to design an IVHM function, how to do a safety or risk analysis, prescribe hardware or software assurance levels, or answer the question, “How much mitigation and evidence are enough?” The criticality level and mitigation methods will be determined between the applicant and the regulator, using existing guidance from SAE International and other sources. Note that the focus of this document is to ensure appropriate process integrity for the creation of a candidate IVHM function, but it may not address all the elements required to operationalize that function.

This document uses the term IVHM to refer to any health management function applied to an air vehicle. The SAE standards committees have been using this term for decades; however, other communities within this industry have used terms such as Aircraft Health Management or Monitoring (AHM), Integrated Aircraft Health Management (IAHM), Vehicle Health Management (VHM), and Rotorcraft Health and Usage Monitoring System (HUMS) to refer to the same concept. At the subsystem level, terms such as Structural Health Monitoring (SHM), Equipment Health Management (EHM), Engine Condition Monitoring (ECM), and Engine Health Management (EHM) are also commonly used. It should be understood that all these terms refer to the same function.

There are cases where this process is applicable but is not required because of historic precedents. For example, there is a historical precedent for using an off-board health management solution to achieve compliance with extended-range twin-engine operations performance standards (ETOPS) (refer to AC 120-42A).

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 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.

AIR7999	Diagnostic and Prognostic Metrics for Aerospace Propulsion Health Management Systems
ARP4761	Guidelines for Conducting the Safety Assessment Process on Civil Aircraft, Systems, and Equipment
ARP6275	Determination of Costs and Benefits from Implementing an Integrated Vehicle Health Management System
ARP6290	Guidelines for the Development of Architectures for Integrated Vehicle Health Management Systems
ARP6461A	Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft
ARP6803	IVHM Concepts, Technology and Implementation Overview
ARP6883	Guidelines for Writing IVHM Requirements for Aerospace Systems

ARP6887 Validation and Verification of Integrated Vehicle Health Management Systems

SAE JA1011 Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes

SAE JA6268 Design and Run-Time Information Exchange for Health-Ready Components

2.1.2 A4A Publications

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

MSG-3 Operator/Manufacturer Scheduled Maintenance Development (Volumes 1 and 2)

2.1.3 EUROCAE Publications

Available from EUROCAE Secretariat, 9-23 Rue Paul Lafargue, 93200 Saint-Denis, France, Tel: +33 1 40 92 79 30, <https://www.eurocae.net/>.

EUROCAE ED-12C Aviation Software Standards Training - Airborne

2.1.4 FAA Publications

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

AC 20-115 Airborne Software Development Assurance Using EUROCAE ED-12() and RTCA DO-178()

AC 25-1309 System Design and Analysis

AC 29-2C (MG-15) Airworthiness approval of rotorcraft health usage monitoring systems (HUMS)

AC 39-10 Alternative Methods of Compliance

AC 43-218 Operational Authorization of Integrated Aircraft Health Management Systems

FAA Order 8110.54A Instructions for Continued Airworthiness, Responsibilities, Requirements and Contents

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.

RTCA DO-178C Software Considerations in Airborne Systems and Equipment Certification

2.1.6 Other Publications

IP-170 International Maintenance Review Board Policy Board (IMRPBP) Issue Paper "HUMS for credit," April 2017

IP-180 International Maintenance Review Board Policy Board (IMRBPB) Issue Paper - Aircraft Health Monitoring (AHM) integration in MSG-3

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 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.

AIR4174 Guide to Aircraft Power Train Monitoring

ARP4754 Guidelines for Development of Civil Aircraft and Systems

ARP5120 Aircraft Gas Turbine Engine Health Management System Development and Integration Guide

ARP5783 Health and Usage Monitoring Metrics, Monitoring the Monitor

ARP5987 A Process for Utilizing Aerospace Propulsion Health Management Systems for Airworthiness Credit

2.2.2 RTCA Publications

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

RTCA DO-200 Standards for Processing Aeronautical Data (EUROCAE ED-76)

RTCA DO-254 Design Assurance Guidance for Airborne Electronic Hardware (EUROCAE ED-80)

2.2.3 IATA Publications

Available from International Air Transport Association, Publications Assistant, 800 Place Victoria, P.O. Box 113, Montreal, Quebec H4Z 1M1, Canada, Tel: 1-514-874-0202, www.iata.org.

From Aircraft Health Monitoring to Aircraft Health Management (White Paper on AHM), 2022.

2.3 Definitions

2.3.1 FOR AIRWORTHINESS CREDIT

When the results from a health management function, or a predefined backup activity, are required for the aircraft to be declared airworthy. This is distinct from health management functions supporting supplemental maintenance (i.e., economic benefit) only. This includes maintenance credits applicable when the health management function replaces or intervenes in accepted maintenance practices.

2.3.2 AIRWORTHY (Refer to FAA Order 8110.54A)

When a product conforms to its type design or properly altered condition and is in a condition for safe operation.

2.3.3 CONTINUED AIRWORTHINESS (Refer to FAA Order 8110.54A)

When certified aircraft, engines, propellers, and appliances, maintain a condition in which they can be operated safely for their intended purpose. They must maintain this condition safely throughout their service life. The product shows its continued airworthiness when it meets its type design and is in a condition for safe operation.

2.3.4 INSTRUCTIONS FOR CONTINUED AIRWORTHINESS (ICA) (Refer to FAA Order 8110.54A)

Documentation that gives instructions and requirements for the maintenance that is essential to the continued airworthiness of an aircraft, engine, or propeller.

This refers to the documentation that defines the required maintenance activities to maintain airworthiness. In the context of this document, the term ICA is considered to apply equally across the aerospace industry to both commercial and military applications.

2.3.5 MITIGATING MEASURE

A practical technique utilizing concepts such as redundancy, human-in-the-loop, field maturation, and backup systems to help manage the risk associated with system failure.

2.3.6 MEANS AND METHODS OF COMPLIANCE

Regulators generally publish acceptable means (the “what”) and methods (the “how”) of compliance to their regulations, either as part of the regulations themselves or in the form of Advisory Circulars (AC). Applicants have to demonstrate that their product or any novel function is properly designed, manufactured, operated, and maintained. They are not under any obligation to use the specified means or methods to show compliance; they can use a range of alternatives, as long as these are formally approved by the relevant regulatory authorities. Often, means of compliance are derived from industry standards developed by organizations such as SAE International.

Regulators such as FAA and EASA use very similar language to define these concepts, with the terms means and methods often used interchangeably. Terms in use include Acceptable Means of Compliance (AMC), Alternative Means of Compliance (AltMoC), and Alternative Method of Compliance (AMOC), etc. The military may use different terms than the ones listed, but the concepts are generally similar. When an in-service issue impacting safety arises during the operation of an aircraft, regulators will publish an Airworthiness Directive (AD) to manage it. Working with the manufacturer, the operator, and other relevant stakeholders, the authorities determine if the root cause of the problem can be corrected via a design change or a maintenance action. This is then documented in the AD, along with specified means of complying with it. The affected party may come up with an alternative method to comply with the directive. If they can prove that this alternate method will satisfy the intent of the AD, it would generally be approved by the relevant authority. This method will then form an approved AMOC to the AD; for reference, the details are spelled out in AC 39-10.

2.4 Abbreviations

AC	Advisory Circular
AD	Airworthiness Directive
AltMoC	Alternative Means of Compliance (EASA)
AMC	Accepted or Acceptable Means of Compliance (EASA)
AMOC	Alternative Method of Compliance (for an AD)
ARP	Aerospace Recommended Practice
CFAR	Code of Federal Aviation Regulations
CIP	Candidate Issue Papers
COTS	Commercial-off-the-shelf
DAH	Design Approval Holder

FAA	Federal Aviation Authority
FEC	Failure Effects Category
FHA	Functional Hazard Assessment
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects, and Criticality Analysis
HPT	High Pressure Turbine
HUMS	Health and Usage Monitoring System
IAHM	Integrated Aircraft Health Management
ICA	Instructions for Continued Airworthiness
IFSD	In-flight Shutdown
IMRBPB	International Maintenance Review Board Policy Board
IP	Issue Paper
ISC	Industry Steering Committee
IVHM	Integrated Vehicle Health Management
LLP	Life Limited Part
MAE	Mean Absolute Error
MCD	Magnetic Chip Detector
MG	Miscellaneous Guidance
MEL	Minimum Equipment List
MMEL	Master Minimum Equipment List
MPIG	Maintenance Programs Industry Group
MRBR	Maintenance Review Board Report
MSG-3	Maintenance Steering Group 3
MSI	Maintenance Significant Items
OEM	Original Equipment Manufacturer
ODM	Oil Debris Monitor
PC	Personal Computer
PPH	Policy and Procedures Handbook
RCM	Reliability Centered Maintenance

RM&T	Reliability, Maintainability, and Testability
ROC	Receiver Operating Characteristic
RMSE	Root Mean Squared Error
RUL	Remaining Useful Life
SB	Service Bulletin
SHM	Structural Health Monitoring
SSA	System Safety Analysis
SSI	Structural Significant Items
STC	Supplemental Type Certificate/Certification
TC	Type Certificate/Certification
TCH	Type Certificate Holder
TLD	Time-Limited Dispatch
WG	Working Group

3. INTRODUCTION

Historically, health management capability has been employed to ensure system reliability by reducing unplanned maintenance and optimizing scheduled maintenance tasks for economic benefit. The evolution of health management solutions in conjunction with improvements in computing capability, data storage, data transmission rates, and analytical techniques now offers the potential to enable much wider use of these systems. The assessment of benefit should be considered alongside the wider aspects of supportability, namely reliability, maintainability, and testability (RM&T), all of which deal with the associated impact of operational safety and cost. Often, especially where the health management approach is being implemented for economic benefit, it is preferable to other means of ensuring aircraft health. For a retrofit application or a modification, a key barrier to implementation of health management, apart from cost, is the potential impact on safety of aircraft operations. In cases where this potential exists, the health management system may be classified as “required for airworthiness” instead of for “economic benefit only.”

When a health management function is required for airworthiness, the primary objective of the development and sustainment activities is to ensure that it will perform in a sufficiently robust manner to maintain an acceptably low probability of failure during operation. As discussed in AC 25-1309 and illustrated in Figure 1, the level of acceptable probability is inversely proportional to the consequence of that failure condition.

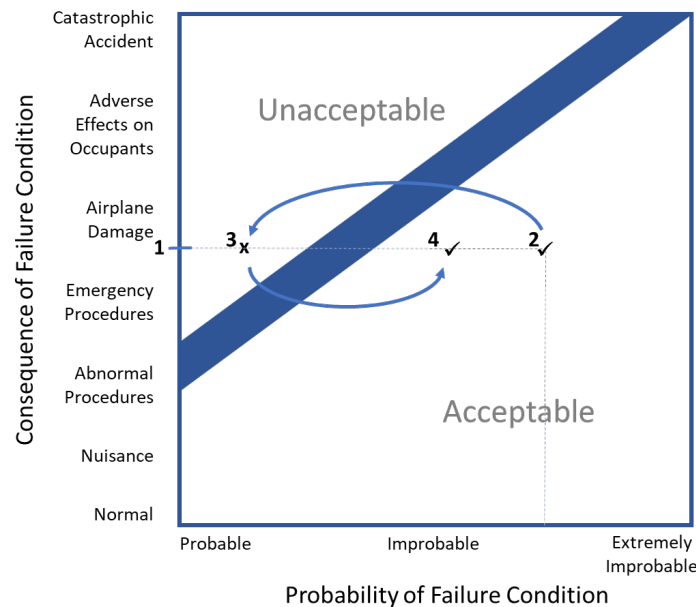


Figure 1 - Consequence versus probability (adapted from AC 25-1309)

For airborne hardware, an acceptable probability of a failure condition at the aircraft level is demonstrated quantitatively, typically through fault tree analysis of hardware reliability or by equivalent analytical or even simulation methods. This is achieved qualitatively for airborne software by requiring more thorough development and test processes (such as those defined in DO-178 and recognized in AC 20-115). Since these methods are typically not directly applicable to ground equipment, an alternative approach is used when such solutions are required for airworthiness to maintain an acceptable probability of a failure condition. This approach involves defining mitigating measures such as periodic manual checks, added “robustness” capabilities built into the system, initial development and test activities, etc. As the severity of the potential consequence increases, more mitigating measures are needed to minimize the qualitative probability of failure.

For ground-based software involved in supporting maintenance decisions, there are commercial practices in existence that will bring a level of rigor to any development. Adherence to these commercial software development practices preclude the need for special assurance requirements. This is justified on the basis that if the health management system fails to perform its intended function, the process and checklist will ensure that there is time to check, detect, and correct the problem within the context of an organization’s quality management processes. A similar situation exists with engineering models employed to determine component cyclic release lives, performance margin, vibration behavior, etc. The code that supports these models is not subject to the same integrity requirements as flight or engine control software, even though the results they generate can have a safety impact. Historically, this robust approach has been successful in maintaining safety. However, extra care should be taken to ensure that COTS elements in an IVHM function behave reliably. Refer to AC 29-2C (MG-15) for a more detailed discussion on the use of COTS elements in a health and usage monitoring (HUMS) system; the discussion there is equally relevant to the IVHM context. For example, the use of dissimilar hardware might be considered in rare cases where the reliability of the ground-based COTS elements needs to be assured to a high degree. The FAA’s AC 43-218 is a relevant reference in this context.

A recommended mechanism for establishing the relevant failure conditions and their associated severity levels is the Functional Hazard Assessment (FHA) described in ARP4761. Capturing the outputs of the FHA and the corresponding mitigating measures following the structure defined in Appendix A of this document can be helpful in discussions with the regulator. When modifying an existing approach, whether for economic benefit or for airworthiness, the minimal threshold to demonstrate is that the implementation of the new solution makes the safety “no worse than” it was without it.

If ground-based elements are necessary to keep the probability in the acceptable range, then the ICA should indicate that the ground-based system is required for airworthiness credit. In terms of mitigating measures to justify the solution is robust, there are a variety of options available. With regard to ensuring data quality, capabilities such as automated data integrity checks (e.g., parameter range checks, checksums or cyclic redundancy checks, output trending, and independent validation analyses) are available. The extent to which the health management capability is automated and whether there is still a human in the decision-making loop will also influence not only the process integrity but ultimately the likelihood of gaining approval. The reader is again directed to AC 29-2C (MG-15) for additional discussions on how such process integrity can be maintained.

3.1 Consequence Versus Probability Concept Applied to an IVHM System

Figure 1 illustrates how the consequence versus probability concept would apply to a health management system used to address an unexpected failure condition in a fielded system. Initially, the consequence of the failure condition was assessed (1), and it was determined that the design and required maintenance actions would keep the probability of the failure condition acceptably low (2). When field experience revealed that the original assumptions were inaccurate and the probability was unacceptable (3), an Airworthiness Directive was issued to address the unsafe condition by implementing a more stringent inspection schedule intended to reduce the probability of occurrence to an acceptable level (4). The operator determined that an AMOC to this AD in the form of an IVHM system could have been implemented to achieve the acceptable probability of failure condition (4) in a more cost-effective manner. If the operator had wanted to implement the AMOC, the process outlined in this document could be utilized to obtain approval to use the IVHM system for airworthiness credit for managing that failure condition.

4. HEALTH MANAGEMENT SOLUTIONS FOR AIRWORTHINESS CREDIT

4.1 New Designs

The process detailed herein is applicable to new designs. If product design margins leverage a health management capability or if the health management capability is provided as an alternative in the initial maintenance plan, it must be clearly defined in the ICA.

Throughout the inception of a new product, health management capabilities may be integrated alongside other engineering disciplines. The objective being to provide an optimized solution, reducing various forms of design conservatism while minimizing maintenance and support costs. Health management should be considered alongside RM&T, as these disciplines share similar objectives. There are well-established systems engineering/robust design tools and techniques available to support the evaluation of design concepts.

When new product design concept options are being evaluated, consideration needs to be given to health management to achieve a solution compliant with the specification. Although there are many other customer and regulatory requirements to consider, early integration of health management capability into a product should provide a means to reduce various forms of design conservatism.

For example, if it can be demonstrated that the usage of a critical part can be accurately calculated, this may reduce or remove expected operational uncertainty, which would otherwise need to be accounted for in the design. Therefore, use of a health management solution to perform this critical part usage function should allow the design team to reduce material and, hence, weight. On product developments where this concept is adopted, health management offers the potential to reduce the overall cost, weight, and complexity of systems, subsystems, and components.

Other examples of introducing health management sensors into a new design to replace historic manual methods also exist. This includes integrating a delta pressure switch or sensor to provide an indication of oil level instead of a dipstick or sight glass. Incorporating an oil debris monitoring system provides a couple of benefits, such as allowing inspection intervals for magnetic chip detectors to be extended or carried out "on-condition." Although these capabilities could all be introduced via retrofit, this is likely to be prohibitively expensive due to the level of product redesign required. Another useful addition to a new design could be one or more vibration or acoustic sensors possibly focused on a particular piece of hardware, such as a gearbox, providing a much better and targeted analytical capability.