Use of IVHM Systems for Airworthiness Credits

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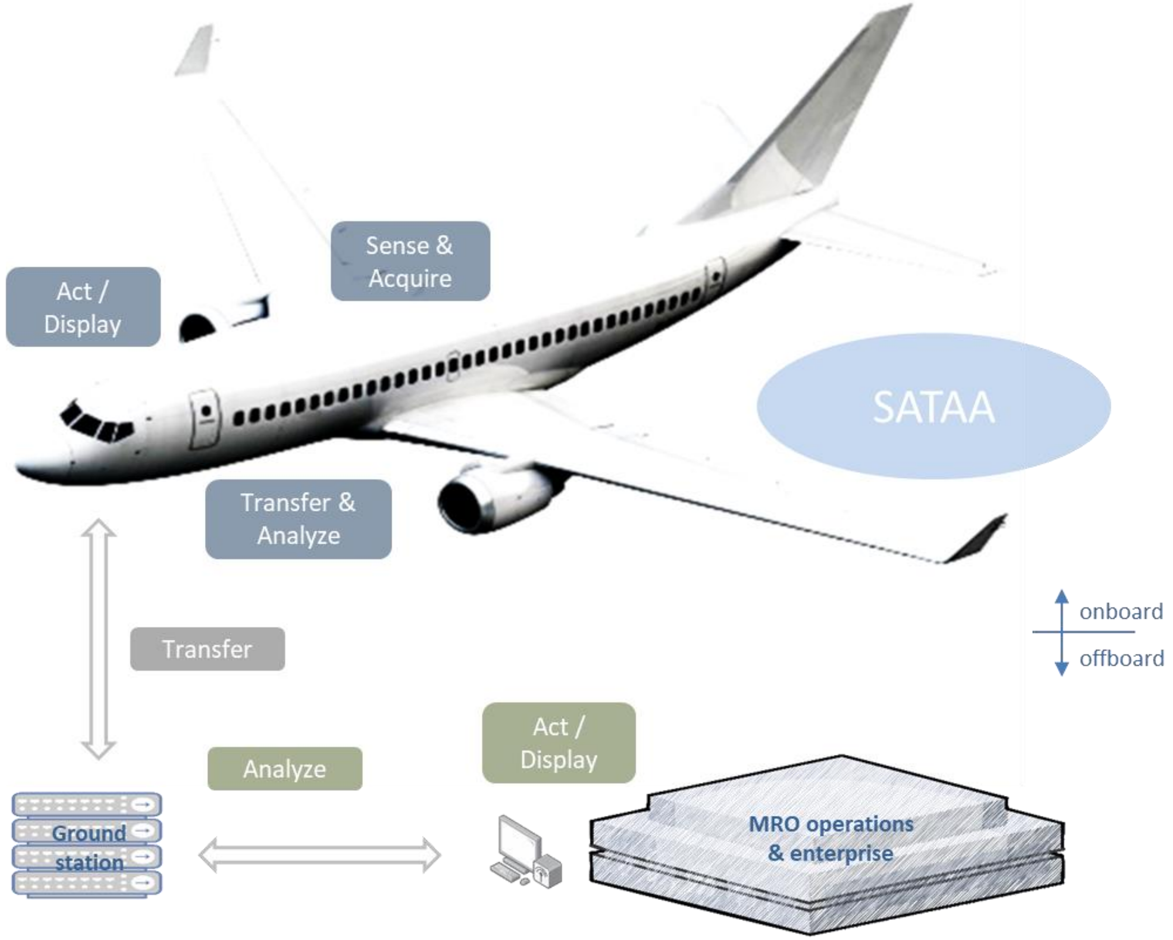
And inputs from: Bill Heliker, Marcus Labay

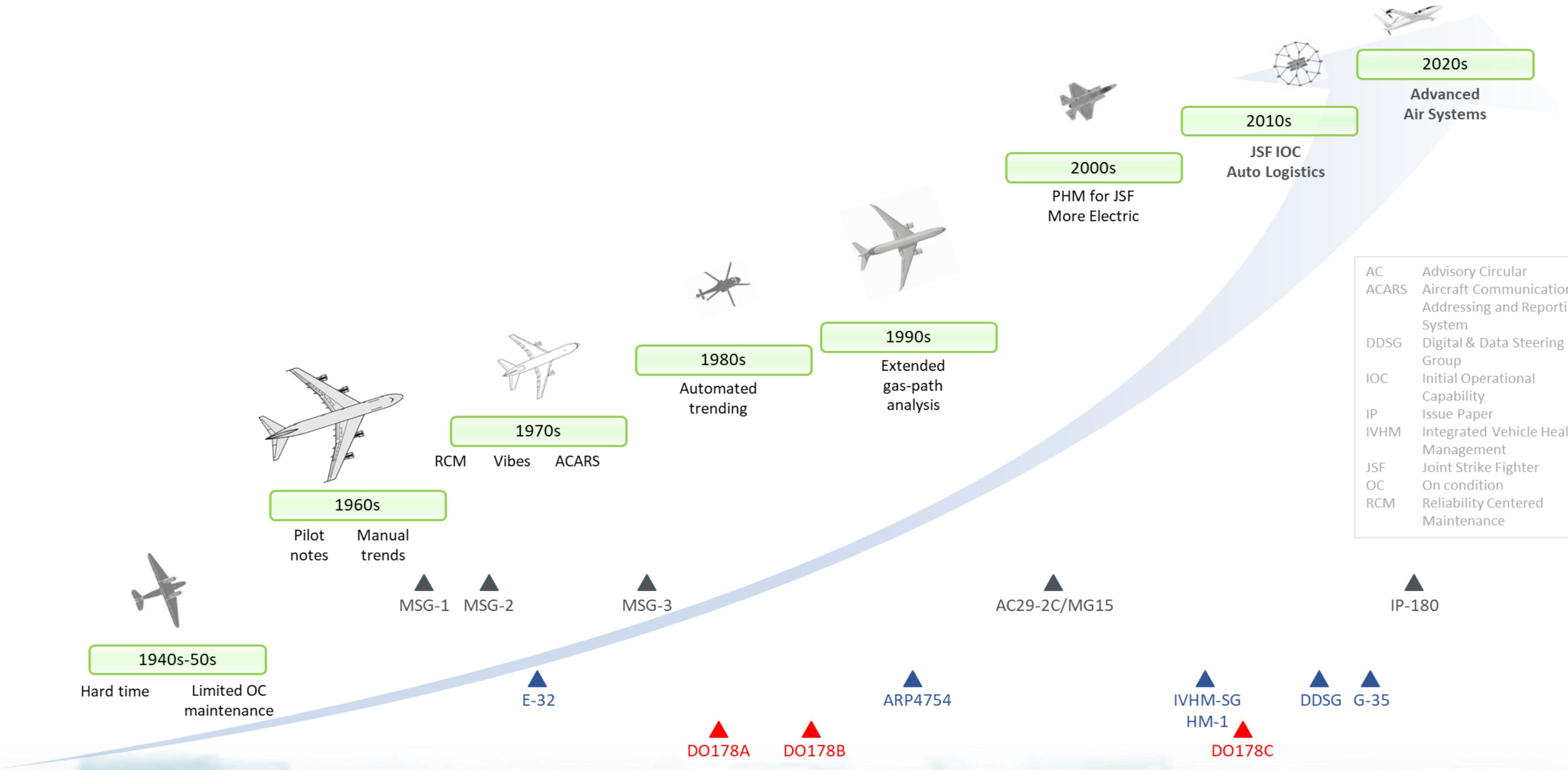
June 2022

Outline

- A Brief History of Health Management in Aerospace
- Introduction to IVHM and SAE's Involvement in its Development
- Current Status of ARP5987A and ARP7122
- Relationship to IP-180
- Next steps

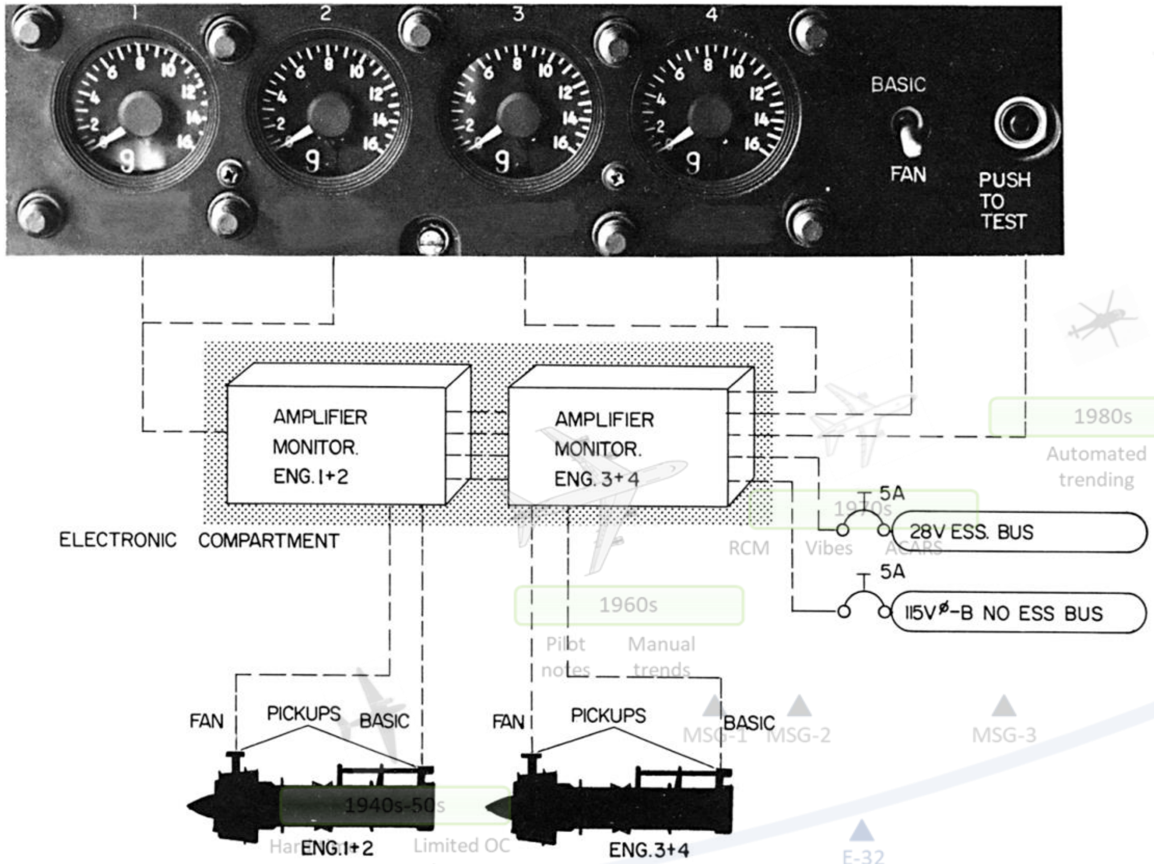


Health Management in Aerospace – A Rich History



AC	Advisory Circular
ACARS	Aircraft Communications Addressing and Reporting System
DDSG	Digital & Data Steering Group
IOC	Initial Operational Capability
IP	Issue Paper
IVHM	Integrated Vehicle Health Management
JSF	Joint Strike Fighter
OC	On condition
RCM	Reliability Centered Maintenance

Health Management in Aerospace – A Rich History



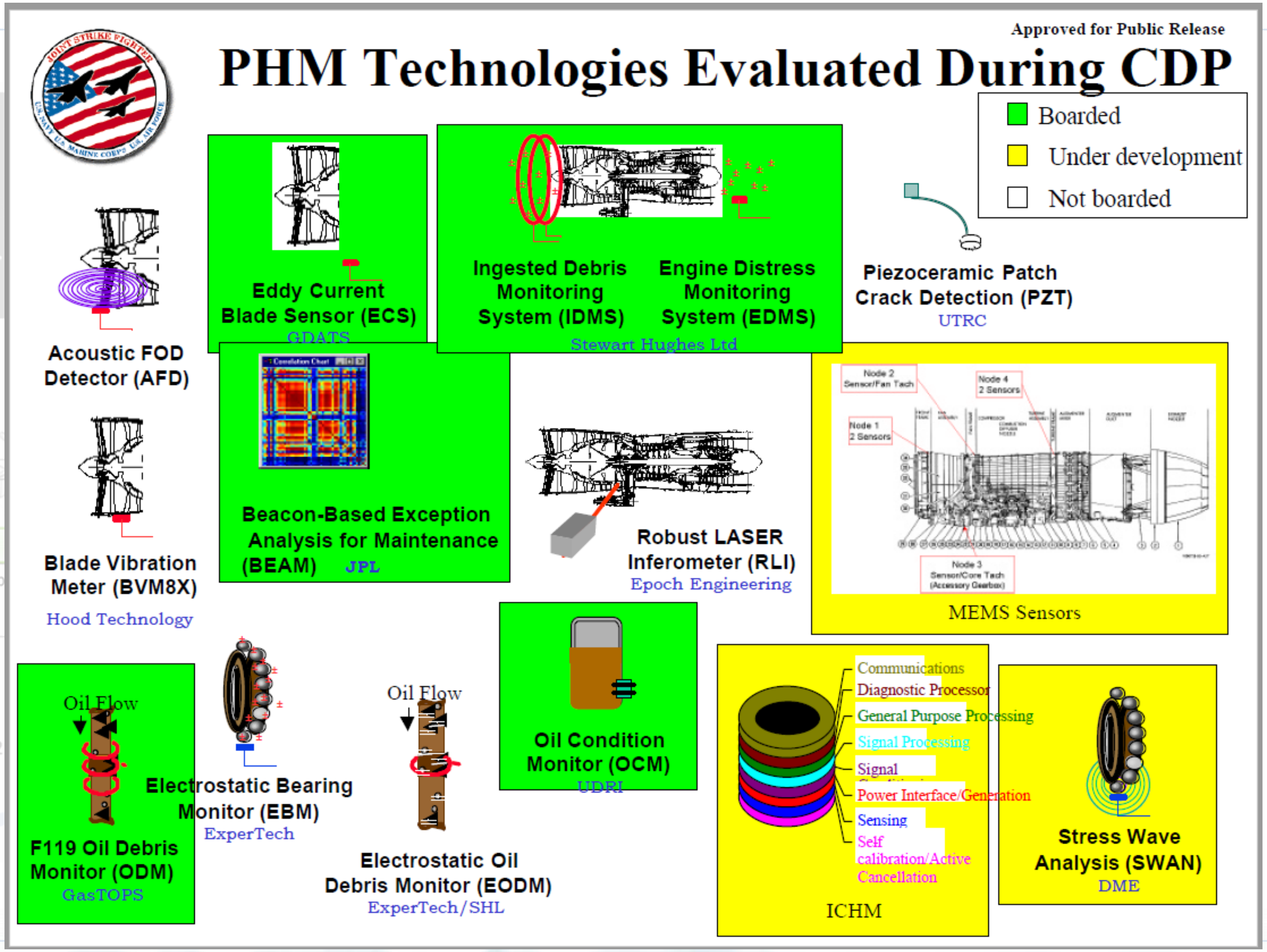
Analog vibration monitoring (accelerometers)

Mandated by the FAA 25.1305 (D) (3)
Early 1970s

Health Management in Aerospace – A Rich History

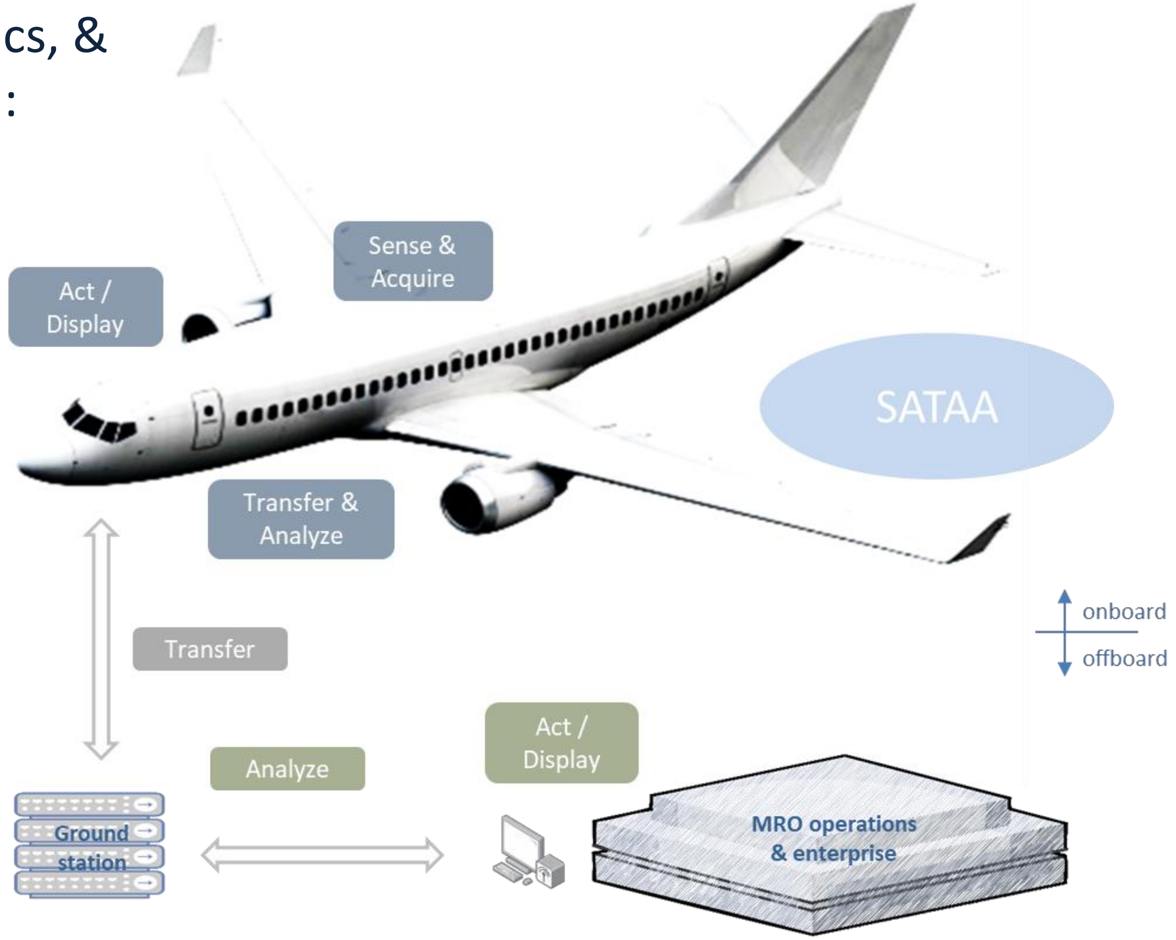
Advanced Military Prognostics and Health Management (PHM) Systems

F-35 Joint Strike Fighter 2000s



Integrated Vehicle Health Management

- An end-to-end capability that uses sensors, electronics, & analytics both on-board and off-board to accomplish:
  - Diagnostics: Determining the ***current*** health condition
  - Prognostics: Predicting the ***future*** state
  - Health management: ***Managing*** the asset based on this (and related) information
- IVHM systems comprise of:
  - Sense, Acquire, Transfer, Analyze, Act/Display **(*The SATAA Model*)**
- IVHM systems manage assets while
  - Delivering guaranteed performance
  - Increasing availability
  - Lowering life-cycle costs
  - And without compromising system safety



SAE's History with Aerospace and Involvement in IVHM

1905

2022

- SAE established: 1905
- SAE charter expanded to incorporate aeronautics: 1916
- 1st SAE Aerospace Standard: 1917
- **SAE E-32 – EHM committee: 1975**
- **G-11 SHM (now AISC-SHM) formed and work on ARP6461 begun: 2008**
- **IVHM Steering Group and HM-1 committee: 2010**
- **SAE AeroTech with IVHM track and first SAE IVHM book: 2011**
- **ARP6461 Published: 2013**
- **Reliability Maintainability and Health Management Systems Group: 2016**
- DDSG and G31 committees. Standards for digital transactions: 2018
- **ARP5987 Published: 2018**
- G34 committee on AI in aviation: 2019
- G35 committee on modeling and simulation and training: 2021
- **More than 12 books on IVHM and related topics published to date**

- In addition to aerospace, SAE covers *spacecraft*, *automobiles*, *commercial vehicles*, and produces standards in diverse topics such as *multi-modality*, *infrastructure*, *power*, *data access, sharing, and ownership*.
- SAE has produced over **2,500 unique standards** for ground vehicles and over **7,800 unique standards** for aerospace.

"The work covered by the SAE is of such value that everybody identified with the industry should take out membership."
Orville Wright, 1918

Current Work Across Different SAE Committees

Related to the Broad Area of Continued Airworthiness

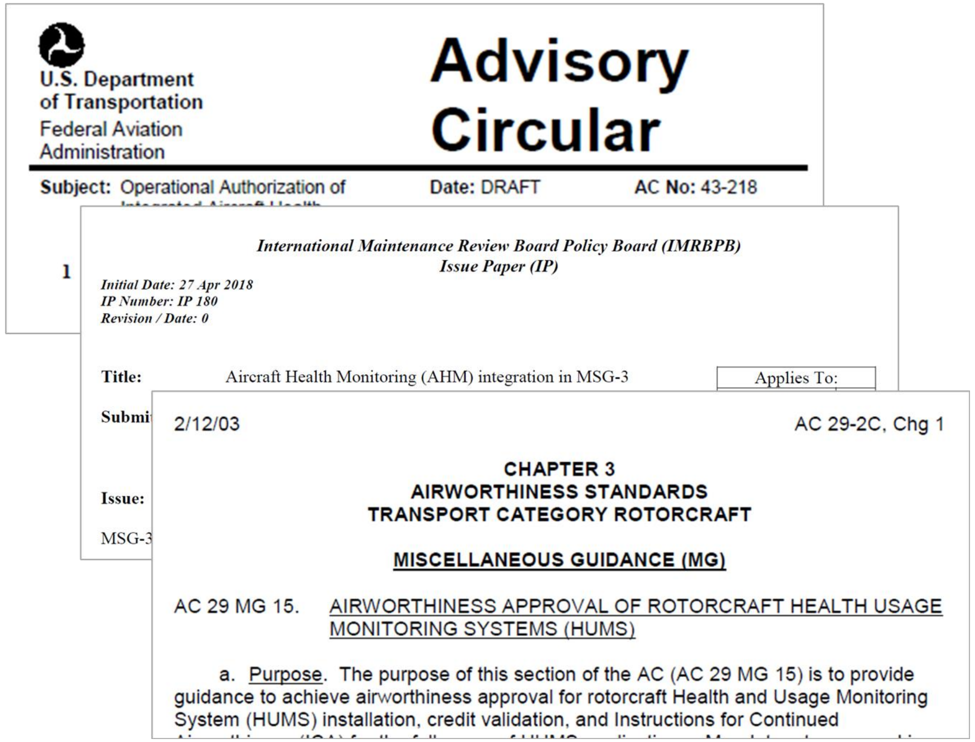
IVHM Steering Group	• Steering group initiative on Airworthiness Credits • Liaisons with FAA / EASA / MPIG / etc.
E-32: Propulsion Health Management	• ARP5987A: A Process for Utilizing Aerospace Propulsion Health Management Systems for Airworthiness Credit (being updated)
AISC-SHM: Aerospace Industry Steering Committee on Structural Health	• **ARP6461A: Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft**
HM-1: Integrated Vehicle Health Management	• **JA6268: Design & Run-Time Information Exchange for Health-Ready Components** • ARP7122: Utilizing Aircraft IVHM Systems for Airworthiness Credit • JA1013: Condition Based Maintenance (CBM) Recommended Practices
G11: Probabilistic Methods &Uncertainty Quantification / Maintainability	• **JA1010: Maintainability Program Standard** • **JA1011: Evaluation Criteria for RCM Processes** • **JA1012: A Guide to the RCM Standard**

Documents in bold already published

In addition, many documents discuss requirements, design, V&V, etc., related to IVHM systems

Regulatory Developments in the Recent Past Regarding IVHM

- FAA AC29-2C / MG15 (2003)
  - Related to rotorcraft health & usage monitoring systems (HUMS).
  - Restricted to DAL B or lower.
  - **Discusses COTS systems and how to verify them independently.**
- MPIG Modified MSG-3.2009
  - Mention of **scheduled structural health** management systems (S-SHM).
- MPIG IP-180 (2018)
  - Introduces the concept of **Level 3 analysis** (as a flowchart) which determines how AHM can be used.
  - Restricted to FEC 6 (Ev Op), FEC 7 (Ev Ec), FEC 9 (Hd Ec)
  - Will be incorporated into MSG guidance soon.
- FAA AC43-218
  - Guidance for the certification of IAHM systems for fixed wing.
  - Currently being reviewed by FAA legal.



U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Operational Authorization of Integrated Aircraft Health ... Date: DRAFT AC No: 43-218

International Maintenance Review Board Policy Board (IMRBPB)
Issue Paper (IP)

Initial Date: 27 Apr 2018
IP Number: IP 180
Revision / Date: 0

Title: Aircraft Health Monitoring (AHM) integration in MSG-3 Applies To:

2/12/03 AC 29-2C, Chg 1

CHAPTER 3
AIRWORTHINESS STANDARDS
TRANSPORT CATEGORY ROTORCRAFT

MISCELLANEOUS GUIDANCE (MG)

AC 29 MG 15. AIRWORTHINESS APPROVAL OF ROTORCRAFT HEALTH USAGE MONITORING SYSTEMS (HUMS)

a. Purpose. The purpose of this section of the AC (AC 29 MG 15) is to provide guidance to achieve airworthiness approval for rotorcraft Health and Usage Monitoring System (HUMS) installation, credit validation, and Instructions for Continued

ARP5987A

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

- First version published in 2018.
- New version incorporates major terminology change: *Airworthiness Credits* replacing *Maintenance Credits*, to emphasize both initial airworthiness and continued airworthiness.
- Has input from major engine OEMs and regulators.
- First ballot in Feb 2022; final ballot expected by end of Jul 2022.
- Basis for ARP7122.
- Emphasizes the end-to-end nature of the HM function involving onboard and offboard elements.
- Presents guidelines for HM systems that are certified during initial type certification and for systems that are approved for retrofit.

Health Management & Airworthiness Credits

Retrofit design (modify existing ICA)

Examples

- Replace a manual task with automated one.
- Reduce/remove a scheduled task.
- Make tasks condition-based.
- Support in-service issue with monitoring instead of mandated inspections.
- AMOC for an airworthiness directive (AD).

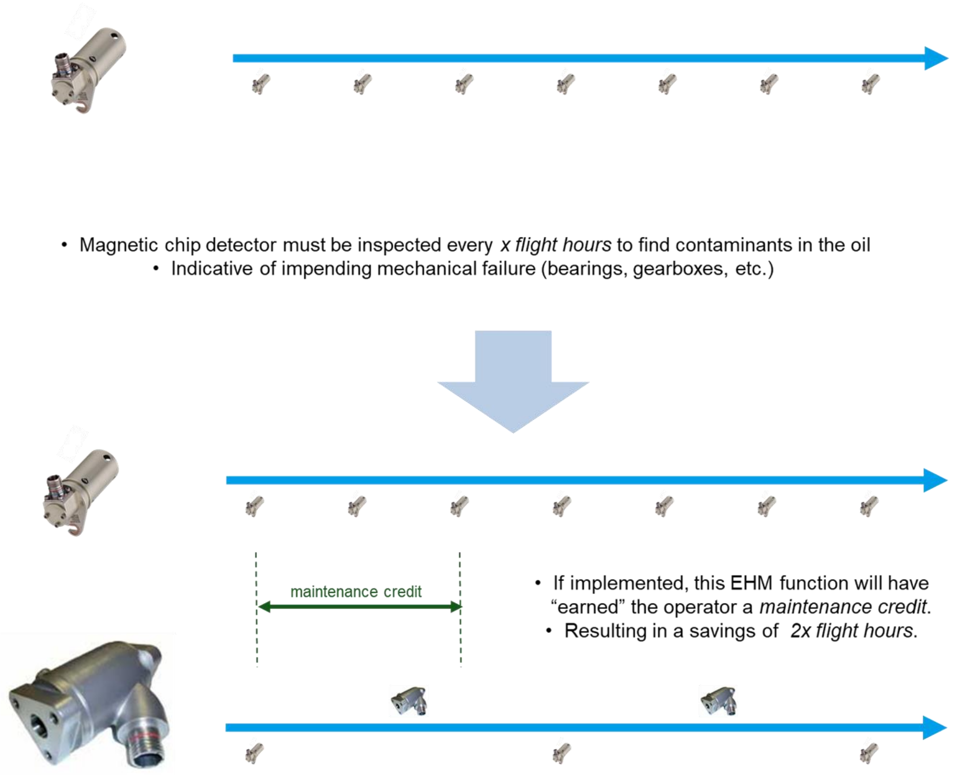
New design (develop novel ICA)

Examples

- Reduce design conservatism with health management.
- Use data to drive new maintenance procedures.

Airworthiness Credits

- To gain approval for a Health Management function that is designed to support continued airworthiness, or one that adds to, replaces, or intervenes in accepted maintenance practices required for continued airworthiness.
- This is distinct from health management functions supporting supplemental maintenance (i.e., economic benefit) only.
- The concept of *Airworthiness* Credits includes that of *Maintenance* Credits which has traditionally been used to define benefits that accrue when a traditional manual maintenance task is replaced with an automated one involving a health management function.



ARP7122: An Extension of ARP5987 to the Vehicle

- Complements IP-180 Level 3 analysis to add a Level 3A analysis that includes FEC 5 and FEC 8 failure effect categories.
- As a high-level guidance, walks the applicant through a series of process steps to determine applicability.
- Is not prescriptive in its approach. Refers the applicant to other documents for specific approval guidance (ARP4761, DO 178C, etc.).
- Covers the end-to-end system including on-board and off-board elements.
- Points to industry accepted processes for dealing with commercial off the shelf (COTS) elements in the IVHM system.
- Includes examples (target: 5) to help the applicant understand what steps are needed to get approval.

AEROSPACE RECOMMENDED PRACTICE	ARP7122™	
	Issued 2022-10-31	

A Process for Utilizing Integrated Vehicle Health Management Systems for Airworthiness Credit

RATIONALE

This document was written to provide a process to achieve airworthiness credit using Aerospace Integrated Vehicle Health Management Systems (IVHM) in a consistent way. The objective of this 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.

This document reflects the fact that regulatory approval has been provided to multiple engine and aircraft Original Equipment Manufacturers (OEMs), allowing the use of IVHM functionality in the mitigation of Airworthiness Directives (AD), extending inspection intervals, compliance with MSG guidance, and more effective utilization of component lives to optimize 'time on wing.'

In this document we mainly use the term IVHM to refer to any health management function applied to an air vehicle. The HM-1 community has been using this term for decades and we feel comfortable with it. However, other communities within this industry have used terms such as Aircraft Health Management or Monitoring (AHM), Integrated Aircraft Health Management (IAHM), Aircraft Condition Monitoring System (ACMS), 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. We do not want the reader to be confused by our use of terminology.

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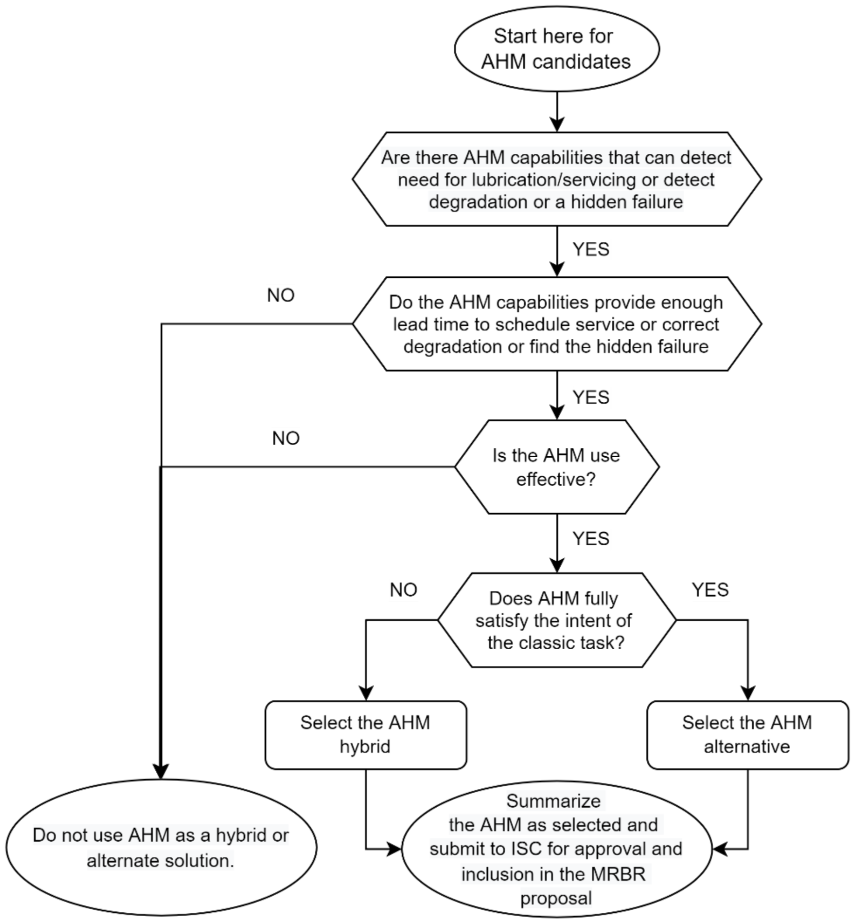
drR2 consulting

Decision Logic in IP-180 and Checklist in 5987 / 7122

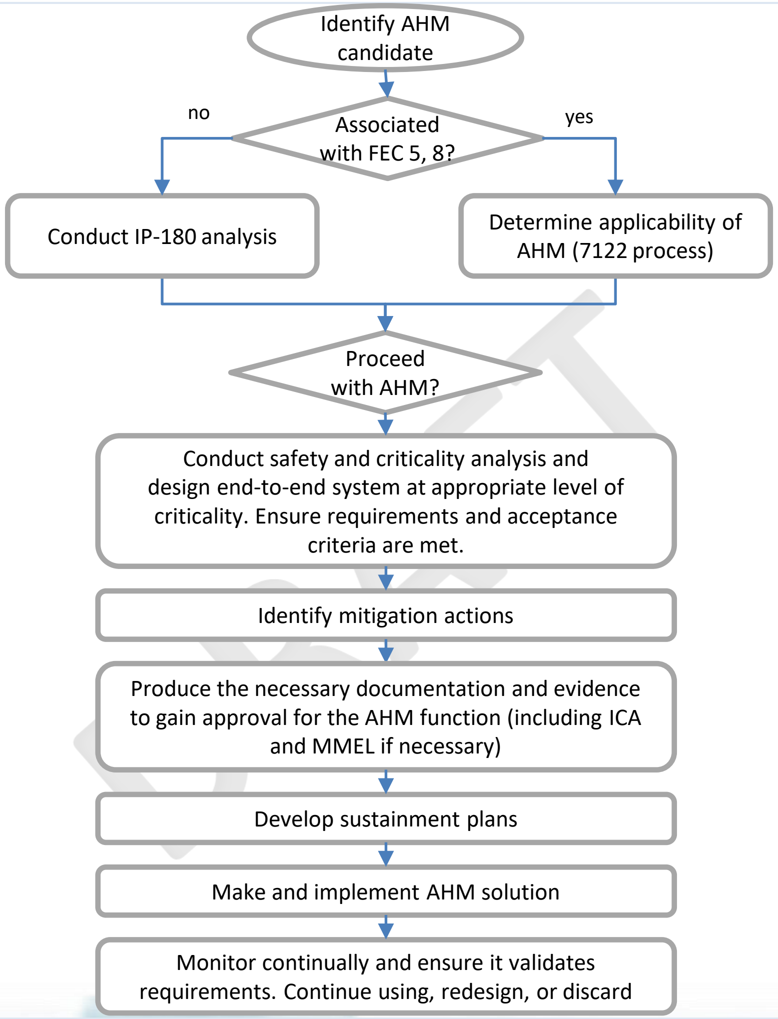


IP-180 Level 3 Analysis (simplified)

1. What improvement(s) will the health management solution provide?
2. What is the criticality of the failure condition associated with the improvement?
3. How is the impending failure detected, and is there sufficient time to mitigate it?
4. What are the success criteria?
5. Can any existing checks, constraints, and/or actions be removed?
6. Have all necessary mitigating measures (protections, redundancies, backups, etc) to support the heath management approach been evaluated?
7. What frequency of automated checks and data delivery rate are needed to ensure the required success rate?
8. Has the health management system approach been included in the appropriate airworthiness documentation?
9. Is there a plan to ensure that the process is improved and updated for technology and/or system configuration changes?

5987 / 7122 Checklist

ARP7122 is Working on a Complementing IP-180 Analysis



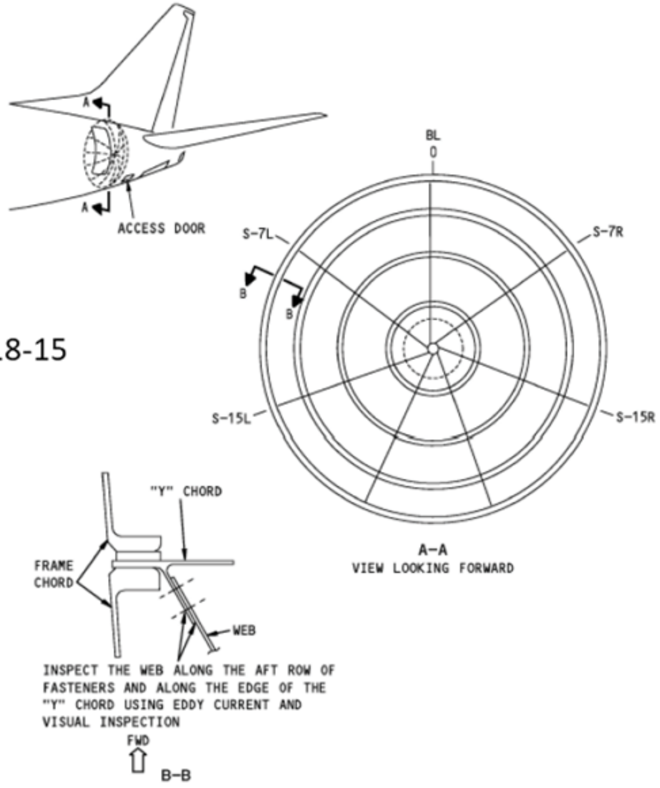
- IP-180's Level 3 logic applies to maintenance items associated with FEC 6, 7, 9 failure effects (non-safety related).
- ARP5987 / ARP7122's focuses on FEC 5, 8 items.
- Analysis output is a go/no-go decision on including an AHM/IVHM item in the MRBR.
- Once the decision is made, the rest of the ARP7122 process deals with high-level guidance about the design, the safety analysis, and the sustainment steps associated with the AHM solution.
- It is not prescriptive in its approach.

Boeing B737 application – Aft Pressure Bulkhead (APB)

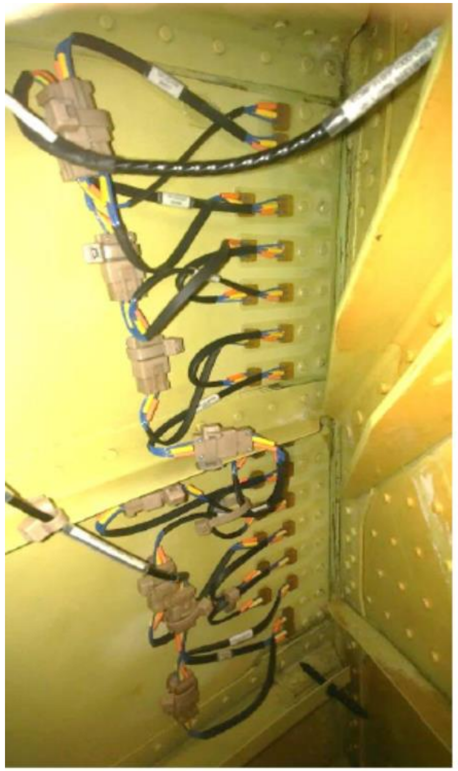
Inspection complicated due to aft galley covering inspection area

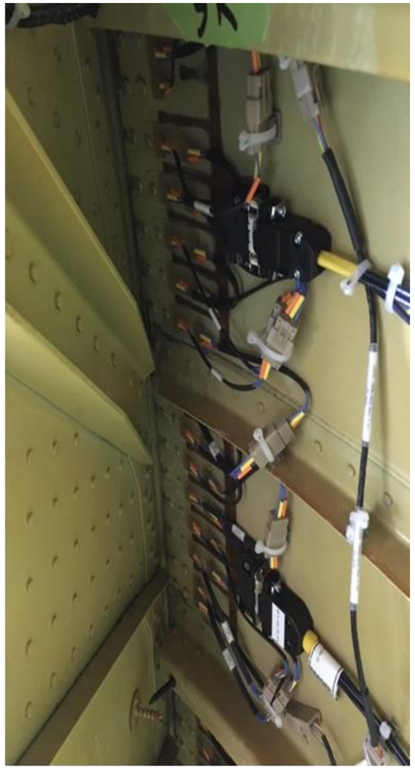
Courtesy: **David Piotrowski** DELTA TechOps

- SB 737-53A1248
  - Threshold 25,000 FC
  - Repeat Intervals
    - LFEC 1,200 FC
    - HFEC 3,800 FC
- Airworthiness Directive AD2016-18-15
- Airplane Models: 737-600, 737-700, 737-700C, 737-800, 737-900



- 20 aircraft equipped with Structural Monitoring Systems' CVM sensors SMS.
- AMOC, which is in progress at Boeing.
- Two aircraft have Acellent PZT Sensors installed in addition.
- Two technologies can be compared.
- CVM is specific, but PZT is widespread.





Airworthiness Directive (AD) requires crack inspections which the operator is replacing with S-SHM systems: Comparative Vacuum Monitoring (CVM) and Piezoelectric Transducers (PZT)-based.

Applying 7122 Process to Delta's B737 APB Application

Answers to the checklist items

1. What improvement(s) will the health management solution provide?

Will provide crack detection without onerous access requirements (3-5 days out of service Special Schedule reduced down to ~1 hour).

2. What is the criticality of the failure condition associated with the improvement?

AD 2016-18-15 (SB 737-53A1248) is mandated for crack detection via eddy current on certain fasteners of the APB; Structural Health Monitoring will be an AMOC to the required inspections. Therefore, this is classified as FEC -8 Hidden Safety.

3. How is the impending failure detected, and is there sufficient time to mitigate it?

Sensor is designed (ring around fastener) and placed to intercept crack with the same (or better) probability of detection (POD) crack length as Eddy Current.

4 What is the success criteria?

Same (or better) probability of detection (POD) crack length as High Frequency Eddy Current. This is validated with a testing program to confirm Probability of Detection equivalency. Other parameters in FAA's AIR-621 SHM Issue Paper titled "Qualification of a Structural Health Monitoring System for Detection of Damage in Structure" must also be satisfied.

5. Can any existing checks, constraints, and/or actions be removed?

SHM will be used to replace the eddy current inspection; access requirements (and possible associated damage) avoided.

6. Have all necessary mitigating measures (protections, redundancies, backups, etc) to support the heath management approach been evaluated?

Yes. The new procedure will be implemented into Boeing 737 NDT manual and Service Bulletin revision. Incorporation into a previous economic service bulletin by Boeing adds confidence to the approach. The back-up is the conventional eddy current inspections.

7. What frequency of automated checks and data delivery rate are needed to ensure the required success rate?

Same as the scheduled task; Threshold and repetitive intervals were determined by OEM service bulletin. Note: this is not an automated check; instead it is a passive S-SHM task. This means the sensors are not interrogated until ground equipment is plugged in, at the same interval. The frequent interval (1200 cycles) of the conventional inspections mean special scheduling of aircraft to the hangar since it falls outside the operator's scheduled maintenance visits.

8. Has the health management system approach been included in the appropriate airworthiness documentation?

It requires the approval of an alternate means of compliance (AMOC) to AD 2016-18-15, then an update of the Boeing Service Bulletin 737-53A1248.

9 Is there a plan to ensure that the credit is improved and updated for technology and/or system configuration changes?

Yes, fully supported by Structural Monitoring Systems, the sensor vendor. Currently, the AMOC request is for a passive, S-SHM program, i.e., the sensors are not interrogated until ground equipment is plugged in, at the same interval. Improving the credit (i.e., increasing intervals) is unlikely near-term, but possible with additional acceptance into fatigue & damage tolerance community. Future iterations of the monitoring processing equipment could lead to Automated SHM (A-SHM), i.e., a hybrid AHM solution that could be installed on-board and the maintenance action display automated. Further approvals would also be required for this step.

Courtesy: **David Piotrowski** DELTA TechOps

Next Steps for ARP7122

- Solicit examples from the IVHM community and incorporate into draft.
- Finish the ARP7122 draft and circulate it within HM-1 (Aug 2022).
- Incorporate feedback and ballot (Sep 2022).
- In parallel, develop CIP (with suggested changes to MSG) for IMRBPB review.
- Reconcile ballot comments and re-ballot (Jan 2022).
- Assuming favorable outcome, get Aerospace Council approval to publish (Mar 2023).
- Present CIP for review by IMRBPB and MPIG (Mar 2023).

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