Guidance for the Certification and Continued Airworthiness of IVHM Functions for Aviation

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ABSTRACT

The need for certification has proved to be a barrier for the wider use of Integrated Vehicle Health Management (IVHM) functions in commercial aviation. By its very nature, such a function involves the use of multiple systems on an aircraft and often on the ground, and hence it is distinct from other functions associated with the aircraft. Hence, there is a paucity of guidance available on the development, certification, and the maintenance of IVHM systems in aviation. Recently, however, three events of significance have occurred that bode well for the development and deployment of such systems for commercial aircraft. In this paper, these events have been described and their significance for the future discussed.

The Maintenance Programs Industry Group, which develops the MSG-3 maintenance guidance for commercial aircraft recently published guidance on how an IVHM task can replace an approved scheduled maintenance task. Secondly, the Federal Aviation Administration published an advisory circular laying out the requirements for what an end-to-end IVHM function needs to comply with to be deployed on any aircraft certified in the US. But even more critically, SAE's Propulsion Health Management technical committee published a short guidance on how to certify an IVHM system – and any required ground support equipment – on an engine. The sister Integrated Vehicle Health Management committee recently updated this guidance to include the entire vehicle. With these three recent developments, one piece of the puzzle has been solved. Many other challenges still remain, of course, but it will be harder to argue now that regulators are opposed to the inclusion of IVHM systems in commercial aviation. This paper looks at these developments in the historic context of aircraft maintenance so that the reader gets a holistic view of the current situation and where it is headed.

1. INTRODUCTION

Aircraft maintenance is one of the most critical aspects of aviation, commercial or military. To ensure that maintenance practices can be codified, taught, and audited, the industry has developed fairly rigorous standards with regards to their implementation. Beginning in the late 1960s, to ensure that a complex machine such as the Boeing 747 jumbo jet could be maintained in a safe but relatively cost-effective manner, industry stakeholders formed a consortium under the erstwhile Air Transport Association, called the Maintenance Steering Group, to develop guidance for scheduled maintenance (ATA, 1968). This maintenance group is now called the Maintenance Programs Industry Group (MPIG) and is part of Airlines for America (A4A). Prior to the publication of the MSG guidance document, maintenance practices were not standardized across the industry. (MSG is now used only as a designator for the published documents, as in MSG-3, and not as an abbreviation.) These non-standard practices gave rise to many inefficiencies in the way regular scheduled maintenance was conducted across the industry and often resulted in costly over-maintenance. For example, Nowlan and Heap (1978) – the pioneers in the application of Reliability Centered Maintenance (RCM) techniques to aviation – reported that the Douglas DC-8 that first flew in 1958 employed 4 million maintenance person hours for a major structural inspection, while a Boeing 747 from 1969 used only 66 thousand for a similar inspection. This is astounding, considering that the DC-8 is small compared to the jumbo jet, which could seat twice as many passengers. The publication of the MSG guidance in 1969 was a big factor in this increase in maintenance efficiency.

The Prognostics and Health Management (PHM) community is trying to bring about another major evolution of maintenance philosophy by promoting a more *condition-based* approach to diagnostics and prognostics when it comes to aircraft maintenance. The goal is to further increase efficiency and reduce associated costs. According to the International Air Transport Association (IATA, 2025), the global MRO (Maintenance Repair and Overhaul) spend by airlines in 2023 was $94B, representing about 11% of total expenses; any reduction in this would have a direct and profound effect on the bottom line of any operator. Anecdotal evidence from industry insiders suggests that this number may be even higher – possibly as much as 15%. This would be true especially for airlines that operate older equipment requiring more maintenance. IATA (2025) also points out the interesting fact that engine maintenance is nearly 50% of the total cost of maintaining an aircraft!

This paper discusses the history of the PHM discipline as it relates to the aviation industry, with the emphasis being on the commercial sector. It describes some of the recent advances in standards and governance rules regarding the use of PHM, and presents some thoughts on the future of the use of these Health Management (HM) systems in aviation. A key development in recent times is the coordination that has happened between the MPIG and the PHM communities, which bodes well for the future of the use of these technologies in supporting aircraft maintenance, since much of regular maintenance of aircraft in the world is governed by the MSG guidance published by the MPIG.

At this point, the reader may be confused by the varying use of the two terms IVHM and PHM. In the opinion of this writer, PHM is the discipline that covers the technology of diagnostics, prognostics, and health management, whereas IVHM (or HM) is an instantiation of this discipline as it is implemented on the vehicle. This is akin to controls science or engineering being the discipline (or the subject area) and a control system being an implementation of the laws of that discipline to solve a specific problem. The field of PHM is new enough that these definitions are still evolving, so it is to be understood that the interpretation used here may be different than what the reader may have encountered elsewhere. If so, the reader is requested to confine this interpretation to the current manuscript.

Figure 1. The SATAA model

An IVHM system – or more generally, an IVHM function – is an implementation of PHM principles to achieve some specific requirements on a vehicle. Typically, the goal is to reduce the maintenance burden and overall cost and increase vehicle availability without compromising system safety. While the focus of this paper is on fixed wing aircraft, it should be noted that an important form of an IVHM system in the rotorcraft industry is the health and usage monitoring system (HUMS). The HUMS is primarily concerned with the monitoring and analysis associated with vibrations within the transmission system of a rotorcraft, but the essential elements of this system is no different from those of a generic HM system. This includes sensing, acquisition, transmission, analysis, and action/display (SATAA). A graphic depiction these elements is included in Figure 1. A big part of the operations of the IVHM system is its links to the maintenance, repair, and overhaul (MRO) infrastructure. This is often overlooked when implementing PHM, which is unfortunate, because the MRO part of airline operations is where much of the tangible action related to IVHM takes place. It is also where a lot of very useful data critical to the successful operation of an IVHM system resides. For example, the most direct way to validate whether the analysis from the IVHM system is correct is to get teardown data from the MRO side of the airline operations. The SATAA model has been adopted by SAE's technical committees working on HM topics, such as the IVHM technical committee, HM-1 (SAE, 2010A).

Note that Figure 1 depicts the Act (/Display) stage of the SATAA model as occurring both on board as well as on the ground. The key difference between an IVHM function and most other functions on an aircraft is that the former operates not only on board but on the ground as well; in fact it operates wherever relevant data is accessed and can be analyzed. IVHM functions might even use data from shop findings when the asset is being repaired to inform future maintenance actions. This is a clearly a strength for any IVHM function because the architecture can be optimized across many domains to make the best use of each of them, but it is also a weakness because the distributed nature of the function makes it a difficult system to codify and regulate. Add to this the fact that many ground-based system rely on commercial off-the-shelf (COTS) hardware and software elements, and the job of ensuring system safety becomes that much harder.

As can be expected in such a risk-averse industry as aviation, and more so in one that operates globally, National Aviation Authorities (NAA) form a crucial part of the equation. Moreover, coordination between NAAs around the world is critical. Standard methods of operations and maintenance are required so that safety can be assured regardless of where the aircraft are operating. Realizing this, a group of NAAs got together in the 1990s and set up a coordinating body called the International Maintenance Review Board Policy Board (IMRBPB). The IMRBPB currently has eleven members: Australia, Brazil, Canada, China, the European Union, China, Japan, Singapore, the UAE, the UK, and the USA. India and

Russia – with sizeable aircraft fleets – are two of the major players missing from this group.

An important task of the *Policy Board* (as the IMRBPB is known colloquially) is the approval and retention of documents associated with changes to MSG procedures. IT does this through its European partner, the European Union Aviation Safety Agency (EASA, 2025). The other major task of the Policy Board is the coordination of the Maintenance Review Board (MRB) that produces the MRB Report for any new aircraft. Section 3 discusses this in more detail.

The next section of the paper touches on the importance of certification in this safety-obsessed industry, which is handled by individual NAAs but harmonized globally. Certification establishes airworthiness when new. The second aspect of regulations is to ensure continued airworthiness via approved maintenance practices. This is covered in Section 3. Regulatory efforts in the areas of certifying or approving IVHM systems is covered in Section 4. Finally, in Section 5, the recently published aerospace recommended practices (ARP) from SAE International are discussed. Future outlook for the use of PHM in aerospace is covered in the final section (Section 6) before the paper concludes.

2. CERTIFICATION

One of the key regulatory innovations in commercial aviation was the institution of the certification system. The type certificate (TC) is design approval issued by a relevant authority that demonstrates that a product conforms to regulations. The TC includes the type design, the data sheet, operating limits, etc. (FAA, 2004).

The rigorous process of getting certificated requires that aircraft Original Equipment Manufacturers (OEM) prove to the regulatory body that their designs are sound and airworthy when new and, additionally, that the OEMs have developed the procedures and processes to maintain the aircraft so that it continued to remain airworthy throughout its useful life. The concept of type certification in the US came about quite early, a little over two decades after the Wright brothers demonstrated sustained, controlled, heavier-than-air flight at Kitty Hawk in 1903. The first type certificate was issued by the FAA to a Buhl Airster biplane in March 1927. Progress in aviation was quite rapid after this; the chronology of aviation history available on the FAA website (FAA, 2025A and 2025B) notes that by January of 2030, 287 certificates had been issued. The rigor with which the applicants have to show how they are complying with regulations is one reason commercial flight is so safe. It is also one reason why the development of aircraft is so expensive compared to other modes of transportation.

There are two aspects to keeping aircraft operations safe: 1) Type certification, that ensures that the aircraft has been designed properly, and 2) Instructions for Continued Airworthiness (ICA), which are the inspection and maintenance procedures which ensure that it remain airworthy throughout its lifetime. However, this is not all. Before an aircraft is allowed to be manufactured and sold, two other areas need to be certified. Firstly, there are the facilities associated with manufacturing and maintaining an aircraft. These need to be inspected and certified to ensure that the design can reliably and safely be converted into a product; and that the operator has the means and resources to maintain the aircraft. And secondly, the personnel associated with operations and maintenance of the aircraft need to be certified. These include the pilots, the maintainers, and if zooming out further, other support personnel such as air traffic controllers, etc. Commercial air operations is a complex business which is why it is hard to get into and even harder to operate profitably. The financial statistics for global airlines are all over the map, so to speak. According to Bailey (2025), the most profitable airline in the past year was Emirates with a profit of 14.25% on revenues of $33B. While US airlines were far less profitable, they brought in more revenues, with the three largest – Delta, United, and American – accounting for more than $172B. China and India have rapidly growing airline markets, with varying profitability and revenue numbers. Indigo – India's biggest airline – for example, was very profitable (about 12%) with about $9B in revenues, but China Southern – China's biggest – is estimated to have just about broken even on nearly three times the revenue base. The bottom line is that this is an expensive business, and one reason for this is the high levels of regulations the OEMs, the operators, and the maintainers have to contend with. Having said that, it is also clear that the main reason commercial aviation is considered the safest form of transportation is this set of regulations.

The existence of these safety-related regulations is also one reason IVHM technologies have failed to make serious headway in commercial aviation until now. That does not mean there are no IVHM functions installed on aircraft. For the most part, these functions have made their way in because they deliver economic benefits, rather than enhance safety. Because a majority of existing IVHM functions have no affect on safety, this allowed them to be introduced without much regard to their regulatory impact. Additionally, many IVHM technologies were implemented on ground-based systems, which are not typically certified or form part of the ICA. These considerations are changing as it is becoming clear that well designed IVHM systems can have very favorable financial impact due to the fact that they can reduce costs and turn-around-times associated with MRO. And, these benefits are not limited to non-safety critical systems. In fact, it is increasingly clear that IVHM can achieve its cost-reduction goals while enhancing safety. Take, for example, the Oil Debris Monitoring System (ODMS) that is described in more detail in the next section. If integrated into the engine design from the very beginning, it can play a key role in catching potentially dangerous lubrication problems from escalating. Technologies such as the ODMS are now finding their way into many commercial and military programs. In general, this push to include PHM technologies in safety-critical areas has led to some key advancements specifically for the aerospace market. The intent of this paper is not to justify the use of IVHM functions in any aerospace application. There are a few published references that showcase real life examples of IVHM system that have demonstrated quantified economic and safety benefits; the reader may consult Malere and Santos (2013), SAE (2021), or the edited collection by Jennions (2012) for discussion on this topic. This paper is only concerned with how an IVHM function can be certified for use in an aviation product to get airworthiness credit, once the decision has been made to incorporate it into the product. This decision should be based on a sound cost-benefit analysis that must be conducted by the applicant before ever beginning this journey.

Many of the technical advancements related to PHM were first developed for military applications first, and then got incorporated into commercial aviation products. The F-35 Joint Strike Fighter played a pivotal role in the development of PHM technologies for aerospace. The F-35, Lightning II, is a single-engine aircraft that succeeded the twin-engine F-22 Raptor, and the Joint Program Office wanted it to be as reliable as the latter. One way of ensuring the enhanced reliability was to incorporate PHM technologies in the F-135 engine (McCollom & Brown, 2011). The PHM design philosophy and some advanced technologies developed for the F-35 have migrated to modern commercial aircraft and engines. One reason such technologies have an easier path to implementation in military aircraft is that they do not have as high a safety barrier to cross when demonstrating their applicability. While human or operator safety is a key consideration for military aircraft design as well, it is not as predominantly a part of the design as it is with a civil aircraft, where it is not just the fate of a single operator that is being considered, but instead the fate of many passengers. It might for this very reason that modern military transport aircraft such as the Airbus A400M or the Boeing's C-17 are certificated under the same commercial criteria as a normal transport category aircraft.

3. Maintenance Practices

Maintenance practices are as old as the industry itself. In the beginning, much of it was based on fixing what was broken. Realizing that this would not be as safe as regularly scheduled maintenance, the industry evolved to a more "hard-time" approach where inspections and repairs were undertaken on set intervals. This, coupled with opportunistic maintenance, was the norm until well into the 1960s. Around this time, researchers at United Airlines – Matteson, Nowlan, and Heap – developed a way of characterizing system failures called Reliability Centered Maintenance. The US DoD soon got into the act and supported this work, which finally resulted in more systematic inspection and repair guidance for the entire aerospace industry.

A4A publishes the MSG guidance through the MPIG for fixed wing aircraft, and through the Rotorcraft MPIG (RMPIG) for rotorcraft. This paper is only concerned with Volume 1 of the MSG-3 guidance for fixed wing aircraft (A4A, 2022), which deals with fixed wing aircraft. This is the bible for scheduled maintenance that the industry follows. Figure 2 shows how this, along with a number of other documents such as industry consensus standards and regulatory advisories, is systematically transformed into the detailed maintenance manuals that each airline uses to maintain its aircraft. The details of this process are too complex to be covered here. The reader may consult various documents available freely on the internet, such as FAA (2012), for more details. The book by Barrera (2022) gives a very comprehensive treatment of the subject.

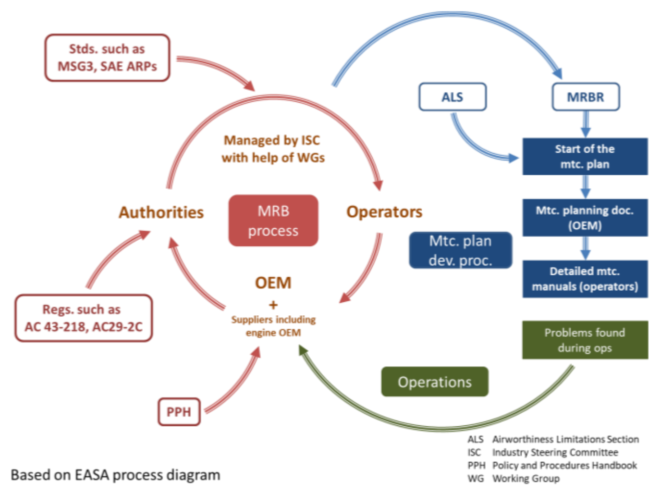

Figure 2. Maintenance program development process

In brief, the process begins when a new aircraft is ready to be certificated. The Type Certificate Holder (TCH), the aircraft OEM, initiates the process. The MRB is constituted with the TCH, key suppliers, certification authorities via the Policy Board, and other industry experts as necessary. The Industry Steering Committee (ISC) is set up to coordinate the work of developing the MRB Report (MRBR) which is the main product of the MRB. This is developed with guidance from MSG-3 and lists all the maintenance tasks that need regular maintenance. In addition to this, there are some mandatory tasks that the TCH lists under the Airworthiness Limitations Section (ALS). The ALS includes items such as life limited parts that must be replaced after a certain amount of usage, and maintenance of other structural components that are fatigue limited, for example. The MRBR and ALS are used to determine the Maintenance Planning Document (MPD) that the TCH produces and hands over to the operators (typically the airlines). The operators then build the detailed maintenance manuals that govern the day-to-day operations that allow them to maintain continued airworthiness of the assets. The MRB is reconvened from time to time to respond to issues found in the field.

Since PHM technology directly affects continued airworthiness, it was decided that the PHM community should engage more closely with the Policy Board and the MPIG. This initiative was taken by PHM engineers working at aerospace companies such as Collins and Honeywell, at airlines such as Delta, at organizations like IATA, and significantly by the leadership within SAE International's technical committees (TC) that were developing standards related to health management in aerospace. This involvement helped increase the awareness of the work that standards development organizations (SDO) had been doing in the PHM area for years.

The history of standards development within the PHM community, actually goes back many decades. SAE's Propulsion Health Management TC – E-32 – had been operational since 1975. It was established soon after the FAA mandated – in 1973 – that airlines should monitor engine rotor unbalance in transport category aircraft (FAA, 1973). Engine vibration monitoring was one of the first applications of IVHM in an aviation setting. Two other TCs that deal with HM topics were established in 2008 and 2010 respectively: The Aerospace Industry Steering Committee on Structural Health Monitoring (AISC-SHM) and the Integrated Vehicle Health Management (HM-1) (SAE, 2008, SAE, 2010A). In addition, the IVHM Steering Group was established in 2020 to coordinate the activities within SAE of all TCs working on HM topics (SAE, 2010B).

With respect to fixed-wing aircraft, MPIG had been working on a key issue paper related to the use of HM systems for maintenance. IP-180 dealt with how a maintenance program can substitute a PHM derived maintenance task for a classic one. For example, the classic task for a lubrication system check might be a periodic inspection of the magnetic chip detectors (MCD) every 100 engine flight hours (EFH). If the engine were to get an automated oil debris monitoring system (ODMS) then the PHM-derived hybrid HM task might be monitoring the ODMS debris counter for alerts and a 500-EFH inspection of the MCDs. If the MCD inspection were to be eliminated entirely, then the monitoring of the ODMS would be a fully self-contained alternative to the MCD inspections.

During system design, a Functional Hazard Analysis (FHA) is conducted that determines what can fail in the aircraft, and how to mitigate this via maintenance. The existing MSG process consists of a detailed decision logic diagram having two levels. In Level 1, each functional failure is analyzed to determine what is its severity, and in Level 2, the identified failure causes are used to assign specific scheduled maintenance tasks for each functional failure. For example, engines are subject to high temperatures and pressures, and this results in slow degradation of the bearings. A Level 2 analysis for the bearing system would require the lubrication system to be inspected every so many EFH, as described earlier. Scheduled tasks listed in the MSG guidance include: Lubrication/Servicing, Operational/Visual Checks, Inspection/Functional Checks (i.e., General Visual Inspections, Detailed Inspections, Special Detailed Inspections, and Scheduled Structural Health Monitoring, which is relatively new), Restorations, and Discards. The Level 2 analysis also recommends a redesign of a system if none of these maintenance tasks can keep the aircraft safe.

After the Policy Board approved IP-180 (and modifications suggested by IP-197 and IP-211) the MSG guidance now includes a Level 3 analysis that determines if the substitution of an IVHM task for a classic task is justified. The suggested IVHM task can be a fully self-contained alternative to a classical maintenance task or it could be a hybrid solution that contains elements of both. The classic task refers to the maintenance task that has been developed via the Level 1 and 2 process before the application of the IVHM candidate task analysis via Level 3. According to the accepted issue paper, the selection of the new IVHM function must be carried out by the OEM in accordance with their Policy and Procedures Handbook (PPH). Today, the only forms of IVHM functionality allowed by MSG guidance are alternatives and hybrids, i.e., replacements for classic tasks. That was one of the motivations for developing ARP7122, so that IVHM can be incorporated without a classic backup function. To do this, the ARP lays out the process by which the IVHM function is designed appropriately, the safety of the end-to-end capability has been analyzed, and appropriate mitigating measures incorporated (SAE, 2025). Section 5 presents details of this ARP.

4. Regulatory Antecedents to the SAE Documents

Regulators have not been unaware of the importance of health management to enhance safety. Some of the first attempts at regulating HM were carried out by the FAA in the late 1990s and early 2000s, albeit related to HUMS for helicopters. The FAA published their guidance in the form of an appendix to Advisory Circular (AC) AC29-2C called Miscellaneous Guidance 15 (FAA, 2003).

Two topics that were tackled in MG15 are still key to the implementation and certification of IVHM functions. The first was treating health management as an end-to-end function that could have elements on board and on the ground. And the second was an early attempt at handling COTS hardware and software. FAA noted that HUMS systems need to have processing elements on the ground to analyze sensor data with more precision that can be done on board. To ensure that commercial off-the-shelf (COTS) elements could be safely incorporated into the HM function, MG15 suggested a number of means of mitigation. These were ideas such as using dissimilar hardware elements, parallel paths for data retrieval, independent software development, etc. More details can be found in FAA (2003).

A more recent document that the FAA produced was AC 43-218, which was published finally in July 2022 after several years of development, dialog with the industry, and internal legal reviews (FAA, 2022). A significant aspect of this AC is that it is authored by people working in the Flight Standards division of the FAA, as opposed to the Certification Office. Flight Standards personnel are responsible for continued airworthiness and represent FAA on the IMRBPB.

AC 43-218 also accepts that IVHM systems will have COTS elements and that the applicants need to deal with these. As an aside, the use of COTS systems will become increasingly critical in all aviation applications, especially when the applications involve any complex ground-based equipment. When new technologies such as artificial intelligence (AI) and generative AI are thrown in, it becomes even more critical to know how to deal with COTS elements. Approving these systems or subsystems for use in safety-critical applications will bring up interesting issues regarding the testing and verification. This AC lists the steps an applicant needs to take to introduce health management in an aircraft. It also specifies that the AH system needs to have mitigation against failure because it will be a safety-critical item if the system it is protecting is safety-critical. The AC discusses not just the steps to certification, but also the supporting actions that need to be taken, such as training of personnel, inclusion of the IVHM system in the minimum equipment list, actions related to the generation, transmission, storage and security of data related to the IVHM system. The publication of this AC proved that the FAA considers PHM an important emerging technology, and that they will not be averse to seeing increased usage of this technology in commercial aviation. However, this does not obviate the need to prove that every IVHM system is technically and economically beneficial, and as safe as the scheduled maintenance actions that they may be replacing.

5. CREDITS

The idea of airworthiness credits derived from that of maintenance credits. The ODMS example is revisited in detail to succinctly illustrate how maintenance credits may be earned. The failure mechanism spalling or pitting of bearings or race material, which releases debris in the oil system. Since most bearing assemblies are metal, typically magnetic chip detectors (MCD) are installed in lubrication lines which can capture metal debris. These can be inspected on a regular basis to determine whether the amount of material adhering to their tips are excessive or within limits. The first diagnosis would entail further scrutiny and possibly more elaborate repairs. This is an on-condition method of maintaining the bearings. This regular inspection might be done every 100 EFH. Now assume that the engine OEM has made a modification to the lubrication system and installed an inline ODMS. The ODMS estimates the amount of debris being carried by the flowing oil and alerts the engine operator in case it exceeds a given threshold. Because of the presence of this continuous monitoring system, the OEM has determined that the inspection interval for the MCD can now be extended to 500 EFH, This means that the engine operator will save 400 EFH worth of inspections, i.e., four 100-EFH worth. The maintenance credit that accrues by the installation of the ODMS is therefore worth 400 EFH. The labor and time associated with this saving will need to be compared to the cost of substituting the old engine with an engine with the ODMS before the operator can objectively determine whether it is worth doing.

This simple calculation is easier to do when a classic task is being replaced with a new task that is affected by some PHM technology. This is not always going to be the case. For example, in the future it is quite conceivable that the ODMS is designed into the lubrication system when the engine is originally designed. This means that there will not be a classic task to compare the new inspection procedure to. In this case, the benefit accruing from the addition of the inline ODMS is defined as an airworthiness credit, and the IVHM system is said to have been installed *for airworthiness credit*, because the actual maintenance credit cannot be quantified.

The two documents ARP5987A and ARP7122 that SAE International has published recently have adopted this terminology and only the concept of airworthiness credits is discussed throughout as a more generalized term (SAE, 2024, and SAE, 2025). Because ARP7122 is slated to replace ARP5987A in the near future, only the former is discussed in this paper.

The primary rationale for introducing IVHM capabilities is to reduce the maintenance burden and increase vehicle availability without compromising system safety. These are no different from the motivations for introducing the systematic MSG maintenance guidance to aviation. Because PHM is a relatively new technology and because it spans all aspects of vehicle design, it was always more difficult to justify than other capabilities. But the developments described in this paper should make this job easier.

In ARP7122, the main design challenges related to the development of an IVHM system have been reduced to nine questions that need to be asked when designing. These are shown in Figure 3 along with a flowchart that indicates where these might be incorporated during the design process. Different companies may have different design processes, so it should be emphasized that this is just one possible flow process. These checklist items may be grouped under three main categories:

1. Justification for the HM solution. (Checklist item 1)
2. Design of the HM solution along with any mitigation measures. (Checklist items 2 to 7)

3. Documentation of HM solution, its maintenance and continued validation. (Checklist items 8 and 9)

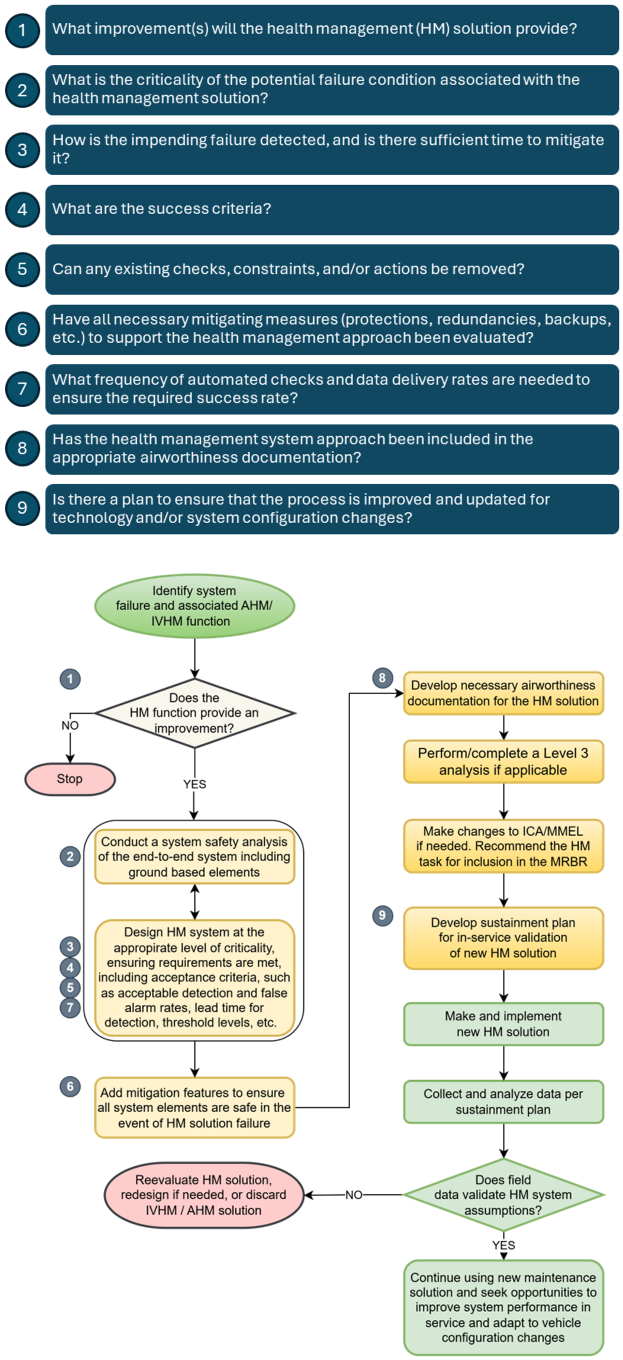

Figure 3. The HM checklist and where it may be used in a typical IVHM design process

These principles have been used in a number of recent IVHM implementations and details of five such implementations can be found in SAE (2025). Reference to a sixth example is also provided without details. Two of these examples relate to structural health management (SHM) solutions implemented by Delta Tech Ops. Details of these applications – SHM for a Boeing 737NG aft pressure bulkhead and SHM for the installation of Wi-Fi antennas on the B737-800 – can be found in Piotrowski (2019). More details on how IVHM has been used to obtain credits can be found in Rajamani (2020).

It must be emphasized that ARP7122 does not propose anything radically new; it merely uses existing guidelines and streamlines them into a set of easy-to-verify steps. The applicant still needs to consult existing – in many cases, long-standing – guidelines to establish that their IVHM function will respect the required design assurance levels and will not create any safety issues during operations. For example, to answer Step 6 in Figure 3, the applicant may have to consult recommended practices published by SAE (2023A and 2023B). Similarly, if the IVHM function involves the development of onboard software, this software would need to be developed according to established guidelines such as those published by the RTCA (2011). Step 4 involves establishing success criteria. This would involve the use of PHM metrics, which are defined, e.g., in SAE (2020). In summary, ARP7122 should be considered a roadmap for the design process and not a prescriptive document.

6. Next Steps

The next steps for the use of PHM functionality in aerospace are now clearer. Advisories published by the regulators, standards from SDOs, and updated guidance from the MPIG, make the job of developing the necessary validation and verification artifacts and accompanying documentation much easier. The key is to ensure that there is sufficient mitigation built into the IVHM function that the safety of the overall system is maintained in the event of any failures. Because the reliance on IVHM-generated advice can result in delayed maintenance, and thus have safety implications, the incorporation of mitigating actions is of critical importance. Be it a retrofit design or a new one, the fundamental steps remain the same: Follow sound aerospace design principles applied to all constituent elements on board and on the ground; ensure that a thorough FHA has been conducted; all mitigations are in place; everything has been documented as required; and finally, establish a monitoring regimen to ensure continued airworthiness of all elements of the IVHM function. Of practical importance is the use of COTS elements. As more experience is gained in the use of these systems, it will become easier to design the mitigations necessary to justify their use. In the end, allowing airframers and suppliers to build PHM capability into their systems is good for the industry, and because of the recent developments described in this paper, it is becoming easier to do so. It must be reiterated that the applicant must still use existing guidelines to develop their IVHM solutions; there are no prescriptive details in ARP7122. Technical teams within E-32 and HM-1 are working on publishing more prescriptive guidance, but it will be a while before that happens. Just because ARP7122 has been published, does not mean that all challenges to developing IVHM solutions have been removed. The applicant still needs to justify the investment in the new system. Sound design and systems engineering practices need to be employed to develop the solution. Reliability and safety analysis need to be completed and mitigation for failures accounted for. None of this is easy, but the newly published guidance at least lays out the roadmap for negotiating the landscape.

7. Conclusion

This paper describes several recent developments supporting the application of PHM to aerospace systems. These are, the publication of key advisory circulars from regulators, incorporation of a Level 3 analysis related to the use of HM systems in the MSG maintenance guidance, and the publication of key recommendations by SAE International. These developments have been placed in the historic context of how maintenance practices evolved in the famously risk-averse aviation industry. Due to the fact that these standards and updated guidance now exist, it is expected that going forward, incorporating IVHM functions in aircraft should become easier.

Acknowledgement

Many people have contributed to the development of standards and procedures that are now allowing PHM technology to enter the aviation sector in a meaningful way. Listing individual names would fill up pages, so I will express my deep gratitude to the many participants in E-32 and HM-1 who worked on ARP5987 and ARP7122. That journey was started in East Hartford in 2008, and has taken these many years to finish. In addition, I thank MPIG committee members and key individuals from various global regulatory bodies I have interacted with in the course of developing PHM standards over the last two decades.

8. Abbreviations

Term	Definition
A4A	Airlines for America
AC	Advisory Circular (FAA)
AD	Airworthiness Directive (FAA)
AISC-SHM:	Aerospace Industry Steering Committee on Structural Health Monitoring
ALS	Airworthiness Limitations Section
ARP	Aerospace Recommended Practice (SAE)
CBM	Condition Based Maintenance
EASA	European Union Aviation Safety Agency
EFH	Engine Flight Hour
FAA	Federal Aviation Administration
HM	Health Management
IATA	International Air Transport Association
ICA	Instructions for Continued Airworthiness
IMRBPB	International Maintenance Review Board Policy Board
ISC	Industry Steering Committee
IVHM	Integrated Vehicle Health Management
MCD	Magnetic Chip Detector
MPD	Maintenance Planning Document
MPIG	Maintenance Programs Industry Group
MRB	Maintenance Review Board
MRBR	MRB Report
NAA	National Aviation Authorities
ODMS	Oil Debris Monitoring System
OEM	Original Equipment Manufacturer
PPH	Policy and Procedures Handbook
RCM	Reliability Centered Maintenance
RMPIG	Rotorcraft MPIG
SDO	Standards Development Organization
TC	Type Certificate
TCH	TC Holder

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