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RECOMMENDATIONS FOR THE DEVELOPMENT OF MSG-4

Abstract

In order to meet the challenges envisioned by the introduction of emerging and future technologies, changes to MSG logic and methodologies are required. This document lays out the research and analysis carried out to determine whether the introduction of a new MSG methodology is required, and provides the recommendations to be considered within MSG-4.

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Recommendations for the Development of MSG-4

Table of Contents

Recommendations for the Development of MSG-4

1.0 Introduction

Since the introduction of Maintenance Steering Group 3 (MSG-3) in the 1980s, there have been numerous advances in technology within aviation; and Maintenance Steering Group (MSG) methodology has continually evolved over this time. Now though, we are facing a step change in emerging technologies and materials, with cutting edge technology including unmanned aircraft innovations, alternative fuels, hydrogen powered and electric aircraft. The abundance of data coming off the aircraft and its systems provides the whole industry with an unprecedented opportunity to monitor various parameters continuously, a significant improvement from inspections spread over specific time intervals. Additionally, the development of Artificial Intelligence (AI), Machine Learning (ML) and other tools provide a leap in data analysis methodologies that can be implemented to assist decision making and optimize safety and efficiency. Across Aviation in general, there is a move towards Condition Based Maintenance (CBM) and Integrated Aircraft Health Management (IAHM). The purpose of this report is to determine how these changes in philosophy towards on-wing maintenance practice could, and should, lead to a change in MSG methodology.

1.1 Formation of MSG-X Task Force

During planning for the 2022 MSG-3 revision, meetings were held with the International Maintenance Review Board Policy Board (IMRBPB), Maintenance Programs Industry Group (MPIG) and Rotor Maintenance Program Industry Group (RMPIG) leadership regarding the scope of the 2022 revision, future challenges, and the need to understand the primary stakeholder (Manufacturer, Operator, Regulator) perspectives towards IAHM and CBM. The result was the launch of a survey to determine whether there was sufficient support to move to MSG-4 with the MSG-3 2022 revision. The Survey results showed that of the 65 participants in the survey, 61.5% supported an immediate move to MSG-4. A breakdown of results showed 60.5% of manufacturers, 73.3% of operators and 50.0% of regulators that took part, supported a move to a new standard; the comments provided during this process disclosed that while there was support for an MSG-4, it was deemed that the introduction of Issue Paper (IP)180 alone did not warrant the move to MSG-4. Further comments related to the need for regulatory and guidance material updates to enable a move to a new MSG standard. As a result, the 2022 revision remained MSG-3, but it was agreed that work would be carried out to determine various areas that are likely candidates for improvement and that would warrant the introduction of a new MSG methodology.

The IMRBPB voted during the 2022 Policy Meeting to form an MSG-4 Working Group. This Working Group was subsequently created and opened to regulators and members of MPIG, with a total membership of 30. A smaller task force of 9 was selected to define the scope and whether a move to MSG-4, or whether an iteration of MSG-3 would be warranted. To avoid pre-determining the answer, the group was renamed MSG-X Task Force.

1.2 Mission statement

An A4A Task Force to review MSG-3 and identify various areas that are likely candidates for improvement. Some of these areas are the emergence of new technology, impact of aircraft systems and maintenance activities on the environment, and reliability of the aircraft operations across all mission types for the evaluated fleet. Additionally

a) New generation aircraft (rotorcraft, drones, eVTOL, etc..) and emerging technologies provide a focus, as well as motivation, for an evolutionary advancement in the development of the MSG concept.

b) Considering the extended use of condition-based maintenance and the impact on the development of scheduled maintenance, including the availability of digital solutions and ground-based capabilities.
c) In order to fully utilize the benefits of this MSG concept we encourage the incorporation of MSG methodology during the requirements phase in order to influence the design solutions.
d) Maintenance programs require careful analysis to ensure that only those tasks were selected which provided genuine retention of the inherent designed level of safety and reliability or provided economic benefit, taking into account all parameters influencing aircraft integrity.
e) Harmonize the development of new MSG documentation and standards with existing and emerging guidance and policies.

1.3 Terminology

A review of documentation carried out by the Task Force has shown significant number of terms used across the aviation industry to describe similar technology applications, including Engine Health Monitoring (EHM), Aircraft Health Monitoring (AHM), Aircraft Health Management (AHM), Integrated Aircraft Health Monitoring (IAHM), Integrated Vehicle Health Management (IVHM), Health and Usage monitoring System (HUMS) and Condition Based Maintenance (CBM) among others. This variability demonstrates the need for common terms across the industry. This white paper does not address this need. While a separate review is recommended to align definitions across this industry, the decision of the MSG-X Task Force has been to use the term Integrated Aircraft Health Monitoring (IAHM) throughout this document.

2.0 Introduction of a new MSG standard

The MSG-X Task force has determined that changes would need to be made to MSG logic and methodologies for MSG to remain current and to meet the challenges envisioned by the introduction of emerging and future technologies. Due to the number of changes proposed, the MSG-X Working Group recommends the introduction of MSG-4.

The move from MSG-2 to MSG-3 involved a complete change in approach, following the Introduction of Reliability-Centered Maintenance (RCM) [1] in 1978, which led to a change in approach for Scheduled Maintenance practice and policies across multiple industries world-wide. MSG-3 introduced a reversal from bottom-up Hard Time and On Condition to top-down task-oriented approach. MSG-3 additionally introduced different systems, structure, and zonal methods and was a fundamental improvement on MSG-2, leading to a full replacement of MSG-2 by MSG-3. While MSG-4 will introduce a philosophy shift towards Integrated Aircraft Health Monitoring (IAHM) and will introduce fundamental changes for emerging and future technologies, MSG-3 continues to adequately meet the need for existing technologies and products in service today. This is a fundamental difference between the move from MSG-2 to MSG-3 and the move from MSG-3 to MSG-4. While further work is needed to ensure a smooth introduction of MSG-4 and to define the roll-over from MSG-3 to MSG-4, it is foreseen that MSG-3 and MSG-4 can co-exist. It is anticipated that the airframer would define the most appropriate MSG standard (MSG-3 or MSG-4) for the technology type in the Policy and Procedures Handbook (PPH), and that both standards would continue to be kept up to date until such time as the prevalence of technology through the industry warrants a full move to MSG-4.

Recommendations for the Development of MSG-4

2.1 Introduction of MSG-4

The introduction of MSG-4 is required to meet the challenges envisioned by the introduction of emerging and future technologies. While this is a necessary step for future technology aircraft, the MSG-X Task Force do not envision this being retroactively applied to existing products. Under this scenario, MSG -3 would still require updates for existing fleets currently operating with this standard. To ensure that this is a workable solution, the MSG-X Task Force recommend a feasibility study be carried out on the ability to maintain two MSG standards.

A review of documentation carried out by the Task Force has shown significant references to MSG-3 across the aviation industry, in guidance material, processes and particularly in regulatory documentation. Of particular importance is the regulatory references to MSG-3. In order to enable the introduction of a new MSG standard, these references would need to be amended; the proposal from the MSG-X Task Force is that the term MSG-3 be replaced by the term "MSG methodology" to ensure applicability of both the current and future standards. A separate review is recommended to document all use of the term MSG-3 in regulatory documentation and guidance material. The MSG-X Taskforce will forward change recommendations to the regulations of certifying authorities to the IMRBPB, for appreciation. Recognition of the new MSG standard would be subject to each certifying authority.

While reviewing documentation, it has become apparent that there are lessons that can be learnt from industry regarding the provision of guidance and definitions. This is specifically beneficial when relating to depth of analysis to be carried out. It is apparent that existing guidance can be interpreted in many ways, leading to some OEMs carrying out far greater depth of analysis than others, particularly relating to analysis that will result in no task selected. MSG methodology in general would benefit from additional guidance and definitions to prevent unnecessary analysis work being carried out.

Benefits can also be gained from strengthening ties with colleagues in IATA and SAE, ensuring accurate cross referencing of guidance and documentation.

3.0 Exec Summary

Since the introduction of MSG-3 in the 1980s, there have been numerous advances in technology within aviation; and MSG methodology has continually evolved over this time. Now though we are facing a step change in emerging technologies, with cutting edge technology including new aircraft designs, unmanned aircraft innovations, novel materials, alternative fuels and electric or hydrogen powered aircraft. The MSG-X Task Force has determined that a new MSG methodology is required to meet these challenges envisioned by the introduction of emerging and future technologies, and that due to the number of changes this should be named MSG-4, rather than introducing an iteration of the existing MSG-3 policy.

Consideration is to be given to the following for inclusion in MSG-4

- Introduction of IAHM without the need for a classic task selection, by considering AHM as a task type.
- Expansion of alternative tasks to allow operators to select the most applicable task for their operation from multiple relevant and applicable 'classic tasks'.
- Inclusion of off-aircraft operations and data processing within MSG methodology, including data security and integrity.
- Introduction of new workflows to account for new materials as well as those with a combination of metallic and non-metallic properties.

- Introduction of new workflows allowing for integration and co-dependency of systems and structures.
- Introduction of a simplified approach for highly integrated electronics.
- Publication of a combined MSG Volume for fixed wing and rotor craft.
- Expansion of IAHM to include safety, as well as non-safety failure effect category (FEC) tasks.

Consideration is to be given to the following for guidance material:

- Reviewing guidance and regulatory documentation for the term MSG-3, this term would need to be replaced with MSG methodology, to enable introduction of MSG-4.
- Encouraging the introduction of MSG concepts earlier in the product design.
- Reviewing recommendations to align definitions across the industry, specifically when relating to Condition Based Maintenance.
- Strengthening of ties with bodies including IATA and SAE to align guidance material.
- Recommending working with universities and other research institutions to understand the potential impact of AI in MSG-4.

While the introduction of MSG-4 is a necessary step for future aircraft technology, the MSG-X Task Force does not envision this being retroactively applied to existing products.

4.0 Design Phase and Requirements

The introduction of MSG-4 is required to meet the challenges of a more integrated approach to scheduled maintenance and introduction of emerging and future technologies. This philosophy shift towards Condition Based Maintenance (CBM) and Integrated Aircraft Health Monitoring (IAHM) in turn requires a certain level of monitoring capability and sensing technology to be present within the aircraft and engine; these need to be specified at the early design requirements phase, either for a new product, or for a modification. For this to be effective, it is necessary to incorporate IAHM capability, advanced analytics, predictive maintenance capability, recyclability, and environmental considerations at the design requirements phase of new aircraft development.

Ideally IAHM and predictive maintenance capability would be incorporated in the OEM Design Manual and subsequently the PPH. Considerable thought would need to be given to how this can best be encouraged, whether in the General section of MSG-4 or in a separate MPIG position paper. Further benefit could be gained by incorporating guidance in the SAE development process and updating guidance material within IMPS or other guidance material. The Task Force recommend that this be considered as part of the introduction strategy for MSG-4.

5.0 Fixed Wing and Rotorcraft

A major factor in future and emerging technologies is sustainability and affordability. New advances in battery and electric propulsion technologies, as well as major investments in start-ups are enabling development of novel aircraft, including new vertical take-off and landing (VTOL), electric vertical take-off and landing (EVTOL) and Urban Air Mobility (UAM) aircraft [2]. Thus, Urban Air Mobility – defined as an air transportation system for passengers and cargo in and around urban environments – may be deployed in Europe before 2030, offering the potential for greener and faster mobility solutions. In an effort to keep the philosophy consistent between fixed wing and rotorcraft along with the growth of the VTOL and eVTOL aircraft, it is considered appropriate to consider whether MSG-4 should consist of one combined volume or continue to be two separate volumes. An initial review has indicated that a single volume may be achievable, with notation or appendices included as needed for specific guidance applicable to fixed wing or rotor craft. A single MSG document would reduce the workload to maintain the document, as well as reducing the possibilities of inconsistencies amongst different documents.

To ensure that a combined volume is a workable solution, the Task Force recommends a review of the differences between the Rotorcraft specific, fixed wing specific and VTOL specific content and issues. This should be accomplished prior to the development of the workflows for MSG-4.

It is noted that IP180 and IP197 have recently been incorporated into Vol 1 of the MSG-3 document with limited effectivity for non-safety items only. Since the IP was initially developed some use cases have been identified to remove this limitation and allow for the use of AHM for any items where identified failure effect can be effectively monitored by an AHM system. IP180 and IP197 are not currently applicable to Vol 2, IP170 (HUMS) has been approved for Vol 2 but is not applicable to Vol 1. The differences between these IP's and their related terms will need to be reviewed prior to creating MSG-4 as a single volume.

6.0 Propulsion

A major factor in future and emerging technologies within aviation is sustainability and, the global energy transition. Many aviation organizations have committed to reaching net zero carbon emissions by 2050. Although our understanding of how to reach this goal is evolving, novel aviation fuels, including electric and hydrogen powered propulsion will be essential to significantly reduce aviation's emissions.

Electric power has increasingly been developed within aviation starting with auxiliary systems, owing to the relative lightweight and higher efficiency compared to mechanical systems. Full-electric propulsion could lead to zero onboard emissions and high levels of energy efficiency and noise reduction. For these reasons policymakers around the world are starting to show interest in electric aircraft. There are numerous electric aircraft research and development projects on-going, around the world. Of note, In 2022, start-up Eviation flew the first all-electric passenger jet, a medium-range electric airplane called Alice. It is envisioned that the aircraft could fly up to 250 miles with 9 passengers [3]. The first all-electric aircraft, the Pipistral Velis Electro was certified by EASA in 2020 [4]; then in November 2021, the Spirit of Innovation, an all-electric aircraft built by Rolls-Royce broke two world speed records [5]. While there have been notable successes with fully electric and hybrid aircraft to date, numerous large challenges remain.

Hydrogen too has enormous potential as a widespread clean energy source in the future, with the Leipzig Statement for the Future of Aviation proposing the introduction of a 'hydrogen in aviation' strategy by the end of 2019 [6]. In 2008 Boeing teamed up with a number of European companies to demonstrate a fuel cell powered modified two seater Dimona aircraft [7]; then in 2022 a successful trial run of a modern aero engine utilizing hydrogen propulsion was completed by Rolls-Royce and easyJet [8]. Use of hydrogen, both as a source of propulsion power and on-board power, has the potential to reduce noise pollution, increase efficiency and reduce emissions associated with the aviation sector, provided the hydrogen is produced from a renewable source.

6.1 Short haul vs Long haul

Electrically enhanced propulsion, also known as hybrid electric could provide significant benefits, including fuel and emissions savings and noise reduction, but there are technical challenges associated with battery energy and power density. There are many degrees of electrification and different architectures are possible; while this provides numerous possibilities, the complexity involved in a multi fuel source system would require considerable MSG assessment.

Due to the relatively limited range anticipated for fully electric aircraft, there are potential operational impacts, such as limitations on the number of 'go-arounds' and restrictions on deferring to a different airport/ base due to inclement weather. With the variability in the power management, an operational impact could very quickly escalate to a safety critical situation. This would require very careful consideration during requirements phase, design and during MSG Assessment, with a focus on IAHM solutions for the power management systems, and for its monitoring system in turn. There would be benefit of introducing MSG assessment methodology considerations earlier into the design phase in order to best capture and define on-wing scheduled maintenance.

One of the major factors restricting development of fully electric propulsion is the low energy density of today's battery technology [9]. It is likely this will limit use of electrical propulsion to Urban Air Mobility (UAM), or so called 'air taxis'. Beyond this the limiting factor becomes the weight and number of the batteries themselves. It is therefore anticipated that fully electric or hybrid electric are more suited to aircraft with a range below that of 500km. Norway, for example, has announced that all of its short-haul flights will be electric by 2040 [10]. Other opportunities for single aisle market may exist with Turbo-electric aircraft, or hydrogen.

Hydrogen as a fuel can be used in two ways: powering fuel cells in electric aircraft or used directly as fuel for the engine. Fuel cell-powered aircraft are based on electrical engines, so predominantly of benefit for short-haul routes, while hydrogen powered aircraft have the potential of powering long-haul routes. Despite hydrogen being a promising alternative to jet fuel, there are significant challenges, such as storage, flammability, crash response and low volumetric density, to name a few.

Hydrogen Fuel Cells convert chemical energy into electrical energy that could be used to power on-board electrical equipment, or an electric propulsion system. One use for Fuel Cells could be in parallel to or in place of traditional auxiliary power units (APUs) [11]. A gradual integration of fuel cells into aircraft APUs is possible, replacing batteries as a source of electric power.

6.2 Impact of novel and emerging propulsion on Aircraft Design

Modifications to the engine are required when using hydrogen, with specific changes to burners, fuel ducts, heat exchangers, cooling system and turbine blades. This would introduce significant new functional failures and failure progression sequences, many of which would be expected to be FEC Hidden Safety, resulting in the requirement for careful monitoring of everything from storage through to combustion. Careful integration will be required of all systems, in this instance an IAHM approach could be considered effective; This would require an extension of IAHM to allow safety as well as non-safety FEC tasks to be covered using IAHM.

One of the most significant challenges of using hydrogen and all-electric is storage and weight. The Alice aircraft being built by Eviation will have lithium batteries constituting of 65% of its weight [12], while the challenges with hydrogen are more complex; Hydrogen has a much higher gravimetric energy density than kerosene and much lower volumetric energy density, both characteristics are critical to airframe design and performance [13]. Liquid hydrogen (LH_2) requires four times more volume on the aircraft than jet fuel. The required weight of hydrogen may only be about a third of jet fuel, but the need for a much higher volume would result in higher aircraft structural weight. Additionally, while jet fuel can be stored in wing tanks, hydrogen cylinders would be too large in diameter to fit into wings. One solution to this challenge would be to use cryogenic cylinders to store LH_2 while keeping the volume to a minimum; although these tanks are considered too heavy for placement in the wings. Hydrogen melts from solid to liquid at -434°F (-259°C) and boils at -423 °F (-253°C). Cryogenic cylinders can store hydrogen at approximately -420°F (-250°C)[13]. Such temperatures mean specialized materials, thicker walls, and sufficient isolation between stacks of cylinders is required. A 'Cryoplane' study commissioned by the European Commission in 2000 with Airbus [14] focused on the conceptual design of an aircraft equipped with hydrogen-fueled turbofan engines and cryogenic tanks to store LH_2. The study found that energy consumption increases by 10% compared to a reference kerosene aircraft, due to the additional weight of the hydrogen tanks [13]. More recent studies [15,16] argue that the Cryoplane project adopted a 'minimal change' approach to wing planform and engine design for hydrogen aircraft. When airframe and engine design are optimized for a hydrogen-fueled aircraft, an energy saving up to 12% is achievable on long-haul aircraft compared to a kerosene powered aircraft. However, short-haul flights are penalized in terms of energy consumption when switching to hydrogen.

In all studies a co-dependency of structures and systems is necessary to enable successful hydrogen, and potentially also large all-electric propulsion concepts. This crossover of systems and structures is considered to be outside the capability of the existing MSG-3 methodology, and new methodology would be required for MSG-4. This complexity exists both across systems- structure but also across ATA chapters; with, in the example of hydrogen propulsion, the aircraft structure becoming part of the fuel storage system and vice versa.

6.3 Monitoring

Significant advancements have been made in digital solutions and software development since 1980 and the introduction of MSG-3. Since the introduction of Full Authority Digital Engine Control (FADEC) in the mid-1980s the capability of sensors and engine monitoring has grown enormously, with near continuous monitoring of most aircraft engine systems. The introduction of IP180 provided the ability to take credit for this technology to alleviate on-wing scheduled maintenance burden. Prior to the introduction to IP180 there were instances where on-wing scheduled maintenance was removed due to the presence of engine monitoring. This appears to have been more prevalent on the engine powerplant side than on the aircraft side. Effectively the monitoring of many engine systems is now carried out near continuously with near instantaneous feedback of data, and can be considered a form of on-wing scheduled maintenance – the interval in such cases being tiny. While the introduction of AHM to MSG-3 was a philosophy shift towards IAHM, the introduction of emerging and future propulsion technology requires a far greater level of integration for monitoring systems.

One major challenge facing all electric propulsion concepts is thermal heat runaway, especially where lithium batteries are involved. Several instances of lithium battery fires have occurred on aircraft in the past decade. [17]. This highlights a need to define careful monitoring for all electric aircraft concepts. A second consideration is the variability of battery life in terms of power management. Unlike a traditional aviation fuel, where the same quantity of fuel always has the same calorific value, battery power output varies with factors including age and charge level. An older battery will hold less charge and discharge at a faster rate than a new battery, while temperature and power rate also have a bearing. Relatively simple fuel monitors and fuel warnings used for traditional fuels are therefore not applicable. Power monitoring and usage becomes far more critical and requires very complex measurement, leading to complex diagnostics required for the power monitoring and measuring systems themselves. While there is some precedent within engine, aircraft and powerplant design in terms of EICAS messages and EEC diagnostics, the complexity of the monitoring for such a complex fuel source, and the criticality of maintaining accuracy for this system would require very careful mapping during MSG analysis. It is recommended by the Task Force that the enhanced monitoring requirements of electric propulsion systems and the mapping of integrated health monitoring systems be a feature of MSG-4. Thought should also be given to the complexity of MSG workflows for complex monitoring to determine what optimization is possible.

6.4 Powerplant Analysis

MSG-3 analysis is assessed at the aircraft level under CS 25-1529 or 14 CFR Part 25.1529, with the engine and powerplant considered as part of this assessment. For engine related Maintenance Significant Items (MSIs) during later task amendment this can cause some confusion. As a separate TC holder, the engine manufacturer seeks regulatory approval for engine related inspections, including safety inspections, captured in Airworthiness Directives (ADs), Time Limits Manual (TLM) – Airworthiness Limitation Section (ALS) and Inspection Bulletins or Non-Modification Service Bulletins (NMSBs) through a different part of the regulatory authorities via their own certification standards e.g. CS-E through engine EASA, or 14CFR33 through the FAA. In some instances, it may not be clearly identifiable which part of the regulatory authorities to approve inspections through – and could lead to the same inspection appearing in multiple manuals with the risk of 'revision trap'. In order to clarify this, it is recommended that improved guidance is provided for engine OEMs and amendment is made to the International MRB/ MTB Process Standards (IMPS), alternatively support be given from the engine regulators at the Industry Steering Committee (ISC) for Engine related (MSI). The same is also true for propeller, which similarly has its own type certificate.

7.0 Materials

The continuous improvement of air transport's environmental performance, and its impact on climate change, is one of the big challenges for today's aviation industry and scientific research. New materials offer solutions to improve environmental performance and reducing overall life cycle cost [18,19], by reducing weight and thereby overall fuel burn, or by increasing efficiency through achieving higher engine core temperatures.

The improvement and development of materials for aviation applications can be segregated in three main areas:

1. The design and development of new materials.
2. The improvement of current material properties (unique processing methods for new applications; and by application of new manufacturing methods).
3. Selecting materials for specific operations and reducing cost for maintenance.

New materials can be defined as materials recently applied, or yet to be applied, in a design application in aviation. Some of these, particularly Metal Matrix Composites (MMC) and Ceramic Matrix Composites (CMC) have seen some in-flight testing and are gaining acceptance by OEMs for various applications. Other materials, such as Polymer Matrix Composites (PMC) are already seeing use in aircraft primary and secondary structures owing to their light-weight properties, as well being stronger and stiffer than unreinforced polymers or conventional metals [20].

Significant advancements have been made in material development since the introduction of MSG-3 in 1980. While previously it was considered straight forward to separate materials into metallic and non-metallic when carrying out structural assessment (SSI), the introduction of composites and laminate materials has added complexity, leading to variability in how such materials are treated during MSG-3 structural analysis. It is recommended that this be considered as part of MSG-4, with new or amended workflows for materials not clearly categorized as metallic or non-metallic.

Consideration should also be given as to how to treat novel materials in the future. The rapidly evolving advancements in new materials will further require a new approach in handling and maintaining aircraft structures. Some materials, such as fiber metal laminates, have already been applied to aviation, while others, such as the introduction of aluminum foam or cellular systems are still at the laboratory stage. The Smith School of Enterprise and the Environment believes that foam structures will replace particularly honeycomb structures and could lead to higher performance at reduced cost. The use of low-density super-alloy foam in noise abatement applications, replacing acoustic liners, would allow for an increase in engine burn efficiency, again reducing fuel burn and emissions. It is recommended that a method for MSG analysis be considered for other material properties as they are developed and introduced into the industry.

There are also questions regarding application of aircraft structure health monitoring (SHM) in future structural design and maintenance. The harmonization of SHM and IAHM would be an effective first step in aligning structural and system assessments.

8.0 Integrated Electronics and Condition Based Maintenance

Maintenance methodologies and policies are changing and evolving, arguably more rapidly than at any other time. In some organizations and industries, maintenance and repair procedures and policies were developed during design or post-design only in response to unpredicted maintenance issues. Now, however, new technologies and changing views on maintenance organization, policies, and responsibilities are emerging. This is due, in part, to greater understanding at management and organization level of the impact of equipment failures on safety, availability, mission readiness, and the environment. It is also a result of the latest advances in digital technology, Internet of Things (IoT) and Artificial Intelligence (AI), brought by the 4th Industrial Revolution in equipment health management and advancement in material manufacturing. These changes are driving new demands for a balanced improvement in equipment and systems efficiency and effectiveness in order to control program costs, availability and readiness.

Industrial companies are increasingly dependent on the availability and performance of their equipment to remain competitive. This circumstance demands accurate and timely maintenance actions in alignment with the organizational objectives. The main purpose of CBM is to consider information about the equipment condition in order to recommend appropriate maintenance actions. Moreover, CBM is to prevent functional failures or a significant performance decrease of the monitored equipment.

8.1 Condition Based Maintenance

Condition-Based Maintenance (CBM) is a maintenance methodology that monitors the actual condition of an asset to decide what type of maintenance needs to be done. CBM dictates that maintenance should only be performed when certain indicators show signs of decreasing performance or upcoming failure. The goal of CBM is to perform maintenance only when there is evidence of need [21].

CBM is maintenance performed based on evidence of need, using a system engineering approach to collect data, enable analysis, and support the decision-making processes for system acquisition, sustainment, and operations. CBM is an established approach to identifying and scheduling maintenance tasks. It employs continuous or periodic assessment of system conditions using sensors or external tests and measurements through first-hand observation or portable equipment. Synergy from integrating the enabling CBM capabilities builds upon the foundation of CBM.

A review of other industries, including Nuclear, Oil, Gas and Rail carried out by the Task Force, showed a prevalence across all industries towards fully integrated CBM with standards and specifications to aid the incorporation of CBM. The Open System Architecture for Condition-Based Maintenance (OSA-CBM) specification is a standard architecture for moving information in a CBM system. A more in-depth look reveals a way to reduce costs, improve interoperability, increase competition, incorporate design changes, and further cooperation in the realm of condition-based maintenance. The OSA-CBM specification was developed by the Machinery Information Management Open System Alliance (MIMOSA), founded in 1994 and introduced in the September 1995. MIMOSA's purpose and goal is to develop open conventions for information exchange between plant and machinery maintenance information systems. Additionally SAE has taken a leading role in defining standards for health management and CBM, with a defined data architecture for health management systems called SATAA; Sense Acquire Transfer Analyze Act, the five main steps in acquiring and using data from aircraft towards maintenance.

A review of other on-wing Scheduled Maintenance processes in the aerospace industry carried out by the Task Force have shown similar incorporated approaches to CBM, with both S4000P [22] and RCM processes used by the US Department of Defense (DoD) [23] having an integrated approach to CBM. While IP180 introduced AHM as a move towards CBM, further work would be required to fully integrate CBM and MSG-3. It is the recommendation of this Task Force that Condition Based Maintenance (CBM) be defined for MSG-4 and include the concept of soft, or flexible scheduling.

Rather than treating AHM as a separate stand-alone analysis it is proposed to enhance MSG processes and workflows and rethink the requirements of health monitoring system(s) designed for the whole aircraft life cycle. This should include introduction of AHM capabilities that preclude the need for a classic task selection by considering CBM as a task type. Another focus should be beyond the systems side, by enhancing structural health monitoring (SHM) availability and seeking to identify possible Zonal and L/HIRF applications. It is recommended that a review be carried out of all possible CBM applications within MSG-4 to ensure that work flows fully enable all emerging and future technology, thereby ensuring that MSG-4 is both future proof and future ready.

8.2 Off-aircraft data processing and Autonomous flight

Increasingly we are seeing moves to off-aircraft data processing in terms of processing data and defining health trends from systems components; while this has been the case for many years, it is not fully reflected in MSG methodology which principally focuses on the on-aircraft systems. As IAHM solutions develop and become increasingly complex, there is a need to bring the off-aircraft processing into MSG methodology, rather than focusing purely on the on-aircraft components and processing, thereby ensuring that the end-to-end systems and reliability are assessed as part the scheduled maintenance task. This becomes increasingly important as manufacturers look to develop and introduce 'digital twin' solutions. Another factor is the importance of ensuring data links are secure and protected from malicious attacks. These are currently not considered when analyzing functions and functional failures. It is recommended that all aspects of the health monitoring systems, both on and off aircraft be considered as part of the mapping, and included in MSG-4, and that the security of data links be taken into consideration to ensure that all necessary precautions are taken to protect critical aircraft systems.

Similarly, when considering the operating crew the emphasis has been on an in-aircraft operating crew, and whether the occurrence of a functional failure is evident to them in normal duties, whether that is through sight, smell, vibration or sound. When considering autonomous flight, or remotely piloted flight, an operating crew may not have the same level of ability to note the occurrence of a functional failure as a crew that is onboard the aircraft. While certain senses, such as smell would be impeded others may be heightened. It is recommended that this be taken into consideration when defining any change to MSG methodology or workflows.

8.3 Analysis of Highly Integrated Electronic Devices

MSG-3 MSI analyses of highly integrated electric/electronic devices using the top-down approach as described in the current MSG-3 methodology is deemed inefficient given the detectability of most, if not all, failure modes are considered during the design and development and addressed via automatic monitors or initiated Built-In-Test (BIT). Moreover, the failure rate of those components is random.

Industry and regulatory members involved in MSG-3 analysis for fixed and rotary wing aircraft have reported opportunities to make the MSG-3 analysis of electric or electronic systems or equipment more efficient. It is common that electronic systems host a vast number of functions driving the need to invest a considerable amount of labor from aircraft OEMs, suppliers and regulators producing and reviewing the MSG-3 analysis. Industry experience shows that the contribution to identifying maintenance tasks using the current MSG-3 methodology is negligible for those devices.

For electric or electronic devices used in aviation, the most likely failure modes are considered during the design so that the effects of those are minimized by circuitry design, monitors/ BIT and other design and architecture techniques.

With modern electric and electronic devices used in aviation, the combination of robust design techniques with comprehensive testing and quality control has led to the simplification of Failure Mode and Effects Analysis (FMEA) / Failure Mode Effects and Criticality Analysis (FMECA) by systems and components suppliers. Such an approach reduces the availability of detailed information to the MSG-3 engineer/analyst to produce a detailed MSG-3 analysis, particularly when assessing the failure cause and modes for a given failure effect. This is easily understood when considering the typical electric or electronic equipment failure modes and the possible applicable and effective maintenance action to reduce the risk of failure and/or ensure adequate system availability.

The following table lists the typical failure modes of electric or electronic equipment (Newton et al., 2002, p.267) adding a column for 'Possible MSG-3 task' to the original reference contents.

Type	Main failure modes	Proportions (%)	Possible MSG-3 task
Microcircuits			
Digital Logic	Output stuck at high or low No function	80 20	●Operational check if latent (iBIT)
Linear	Parameter drift No output	20 70	●Operational check if latent (iBIT)

Type	Main failure modes	Proportions (%)	Possible MSG-3 task
	Hard over output	10	
Transistors			
	Low gain Open-circuit Short-circuit High leakage collector-base	20 30 20 30	●Operational check if latent (iBIT)
Diodes			
Rectifier, general purpose	Short-circuit Open-circuit High reverse current	10 20 70	●Operational check if latent (iBIT)
Resistors			
Film, fixed	Open-circuit Parameter change	30 70	●Operational check if latent (iBIT)
Composition, fixed	Open-circuit Parameter change	10 90	●Operational check if latent (iBIT)
Variables	Open-circuit Intermittent Noisy Parameter change	30 10 10 50	●Operational check if latent (iBIT)
Relays			
	No transfer Intermittent Short-circuit	20 70 10	●Operational check if latent (iBIT)
Capacitors			
Fixed	Short-circuit Open-circuit Excessive leakage Parameter change	60 20 10 10	●Operational check if latent (iBIT)
Solder, connectors	Open-circuit Short-circuit Intermittent	50 20 30	●Operational check if latent (iBIT) ● Cleaning of heat sink features (reduces temperature extremes, thus thermal cycling range) ● Restoration for solder

Experience shows that for most failure modes, except for ‘Solder, connectors’, the Weibull shape parameter for typical components or packaged components is either close to 1 or lower than 1, which indicates that preventive maintenance would not be applicable and effective due to the constant failure rate behavior of those components. Assuming that all components are subject to failure modes associated with soldering, the solder failure mode being considered from this point forward would apply to the equipment’s circuit board, and not limited to capacitors as listed by the reference from the table above. One can reasonably expect that the overall line replaceable units (LRU) behavior would show signs of wear out due to thermal fatigue of the solder joints. Therefore, thermal management of LRUs plays a significant role in the thermal fatigue failures of the LRU. Such a behavior would affect most, if not all, functions of the highly integrated electronic equipment.

The maintenance philosophy is the test or identification of the faulty LRU and its replacement. The maintenance of internal components to the LRU are considered to be done off-wing after the failure is identified, at an approved maintenance facility. If a scheduled maintenance for internal LRU components is identified as applicable and effective, the part should be sent for a 'restoration' if the failure cannot be detectable by built-in-tests or operational checks done with the LRU installed in the aircraft. Nonetheless, the item under consideration must show functional degradation characteristics at an identifiable age for maintenance to be considered applicable, which would not apply to the types of items listed above given its failure modes and reliability over time behavior, with the exception for 'Solder, connectors'.

The Task Force recommends that for some cases of electric or electronic equipment, a simplified approach, with new workflows would provide the opportunity to further enhance the efficiency of the MSG methodology in selecting appropriate maintenance for these electric/electronic devices. Additional guidance on the depth of analysis needed for redundant integrated systems could be reviewed for potential opportunity to eliminate unnecessary analysis. Further guidance material would be necessary to ensure that a simplified analysis does not jeopardize the goals of the scheduled maintenance identification process.

9.0 Aircraft Design

Aircraft design may include many different mission types for a given fleet type, the parameters for which need to be evaluated when developing the maintenance requirements. This is more prevalent on some aircraft types than others – with some operators flying very different stage lengths and operations. When these different mission types and operations give rise to different maintenance actions recommended by the OEM, there needs to be a method to provide those differences to operators.

When specific operations are going to be certified based on MSG analysis, it is recommended to provide clearer guidelines on how the logic is to be applied for the development of maintenance tasks peculiar to those kind of operations (e.g. ETOPS, Single Pilot, RVSM): the result would be the availability of alternate tasks depending on the type of operation, allowing a greater customization of the maintenance program, not a 'one size fits all' approach as happens today, and a focus on maintenance that is both applicable and effective for that operation.

In order to enable this to be introduced, it is recommended that a review be carried out to understand the extent of the potential variability in on-wing maintenance.

10.0 Human Factors

While consideration for Human Factors (HF) are given in MSG-3 through structures, zonal, and L/HIRF, consideration of human factors should also be assessed when reviewing maintenance tasks for effectiveness. In general, MSG-3 reduced unnecessary maintenance significantly compared to MSG-2 but there is a non-negligible dependency of excessive maintenance HF issues. While there is variability in the approach to HF between civil and military applications, processes typically used in modern aircraft design are considered effective to address those concerns at the aircraft design and in-service phases, hence throughout the aircraft lifecycle.

FAA AC 120-72A provides references for HF Training document resources, primarily focused on providing information for Human Factors training to operators and repair stations. It provides a great source of requirements ranging from access, posture, installation considerations, error proofing and others.

10.1 Maintenance Human Factors during the design process

MIL-STD-1472 (current revision is "H") is typically used for military or a reference to civil aircraft human factors design considerations. MIL-HDBK-470 also includes Human Factor Analysis as part of the Maintainability Plan, when it comes to Analyses and Test, highlighting the need to verify the design that should have followed the requirements published in MIL-STD-1472.

For civil aircraft design process, the aircraft designer will establish a process to identify the requirements, typically using SAE ARP 4754, whereby the maintainability requirements would be captured at the aircraft, system, sub-system and sometimes at the item level. Those requirements guide the design of a maintainable aircraft, which include but are not limited to accessibility, visibility and other design characteristics important from a Human Factors perspective.

Aircraft Safety Maintenance Human Error is addressed not only by the requirements process, to which MIL-STD-1472 and MIL-HDBK-470 contribute in terms of providing guidance, but also by the aircraft safety process. Although FAA AC 25.1309-1B Arsenal and EASA's AMC 25.1309 recognize that quantitative assessments of the probability of maintenance errors are not feasible, the guidance document highlights the need to assess human errors as part of the Zonal Safety Analysis (ZSA). Moreover, FAA AC 25.1309-1B Arsenal, EASA's AMC 25.1309 and SAE ARP4761, also highlight the importance of conducting maintenance errors analysis not only as part of the ZSA, but also as part of the Common Mode Analysis (CMA), to confirm the independence that are taken into account to meet the safety objectives are not invalidated due to incorrect maintenance actions. The ZSA process in the SAE ARP4761 identifies the first task of the process as the preparation of design and installation guidelines where maintenance errors should be considered. Those guidelines typically define error-proofing requirements such as error-proofing connections and installation measures, that can effectively prevent maintenance errors during the accomplishment of scheduled or unscheduled maintenance tasks. As part of the SAE ARP4754A process concept, all requirements shall be validated and verified prior to type-certification.

A Maintenance Human Error Analysis (MHEA) of the maintenance task procedures are typically used as a means to verify those requirements that can be used as a requirement verification artifact for the ZSA and CMA. Although not all maintenance errors can be prevented, this process may identify significant or unacceptable risks resulting from maintenance errors that could significantly reduce the aircraft safety margins. The ultimate goal of the process is to justify that no unacceptable risks exist within the design that could significantly reduce the aircraft safety margins. Moreover, identification of maintenance that could result in a failure, malfunction, or defect endangering the safe operation of the aircraft, if not performed properly or if improper parts or materials are used, so called Required Inspection Items (RII), is required by regulation. Industry guidance already exists to identify RII, such as ATA Spec 108 - Required Inspection Items (RII) Best Practices.

Maintainer safety is also addressed by the requirements process, to which MIL-STD-1472 and MIL-HDBK-470 contribute in terms of providing guidance. A very robust process also exists to mitigate and identify risks associated with maintenance and the safety of the maintainer, under OSHA requirements and the Safety Management Systems that airliners and aircraft OEMs should adopt.

Within the current framework of MSG-3, HF and maintenance errors do not play a direct role in the methodology. Since scheduled and unscheduled maintenance can be equally affected by human factors, it is considered more effective to leave the requirements identification, validation and verification outside of MSG-4, keeping the intent of the MSG methodology to identify the minimum scheduled maintenance requirements for aircraft.

While HF should be kept outside the scope of MSG methodology, it is recommended that operators be provided with the opportunity to select from appropriate alternative task types. Current MSG-3 methodology forces the selection of the most appropriate task for that failure cause; where in reality multiple tasks could be applicable, albeit with potentially different inspection intervals. Enabling the specification of multiple tasks would allow operators a greater say in the maintenance of their aircraft and would enable selection of a task type most appropriate to their operation and taking their own HF policies into consideration. This could be considered an extension on IP180, which introduced an alternative task type, allowing operators to select between a classic task and an AHM task. Taking the example of AHM vs classic task introduced by IP180, a symbol could be used to denote the task with greater burden to maintenance personnel. Details regarding the complexity of the task and the time required to carry out the task would also aid operator decision making when considering task selection.

11.0 Artificial Intelligence

Artificial Intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to think and learn like humans. Alternatively, it refers to the ability of machines or computer systems to mimic or replicate human intelligence, including the ability to learn, reason, and solve problems.

AI can be categorized in several ways but is typically separated into weak and strong AI. Weak AI simulates human behavior but does not have the human intelligence that strong AI is capable of. Weak AI lacks understanding of the world, and typically carry out tasks such as looking for patterns in huge amount of data. It is unclear if a perfect strong or even weak AI can be developed since there are infinite unforeseeable events [24]. Today, there is no strong AI on the market; Alexa, chatGPT, DALL E 2, Jasper Chat, Siri are all examples of weak AI designed for a particular purpose. To work properly, they require human interaction and are based on human data. Combinations of multiple weak AI, such as a combination of Natural Language Processing (NLP), speech synthesis and picture recognition increase the fields of application, but this is still not considered strong AI. A key feature of AI is that it can learn to a certain extent by itself and does not rely entirely on human supervision [25].

There are different levels of autonomous artificial intelligence and they can provide recommendations, decision support, up to autonomous decisions. Good examples are self-driving cars which are divided in several autonomy levels:

Level 0: no assist
Level 1: assist by holding the speed
Level 2: more comprehensive support e.g., by holding the line and keeping the distance to other cars Level 3: under certain conditions, the car can take full control but it can request the driver to take the control
Level 4: similar to Level 3 but the car will not ask the driver to take the control
Level 5: full autonomous driving independent from conditions

To date, no modern cars is certified above Level 3, beyond this is difficult due to ethical implications [26]. Currently, a lot of effort is made to make a trusted AI which is reliable, explainable, fair and secure. AI programmers become responsible for the AI decision, this is necessary to gain trust and acceptance of the people [27]. High standards of data quality, security, privacy, laws, and ethics are needed before AI finds a wide application within aviation.

11.1 Applications for AI in aviation maintenance

AI significantly exceeds human capabilities in some fields, being able to generate complex planning which can be applied in scheduling maintenance actions. Another strong capability is the pattern recognition in huge amount of data; useful in the area of health management by recognizing anomalies of component behavior response, adaption of prognostics and determination of Remaining Useful Life.

A basis for effective and efficient health management is the creation of digital twins in combination with the Internet of Things. This combination is anticipated to bring a step change in maintenance capability. Other potential applications of AI include evaluating structural and zonal inspections to detect potential damages; combining this with a General Visual Inspection carried out remotely (GVR) is a powerful option to quickly find damages. AI does have a lot of possibilities for OEM and TC holders, from maintenance program optimization to answering technical queries with supervision and ultimately generating task content.

EASA define the levels of AI as follows [28, 29]

a). Level 1 – Assistance to Humans
b). Level 2 – Human / Machine Teaming
c). Level 3 – Autonomous Machine

Guidance developed by EASA provides the first usable guidance for Level 1 and 2 machine learning (ML) applications; No guidance yet exists for Level 3. SAE and Eurocae are similarly working to develop standards for the use of non adaptive ML systems in controlling aircraft functions. The field of AI is relatively young and is undergoing continual development. Current data quality is variable with outcomes containing a high degree of uncertainty. Due to the complexity of AI, it is difficult or impossible to understand how the outcome was produced and how trustworthy it is, which in turn limits the application. Since AI is trained with data available on the internet, it uses data without permission of the owner which opens the question of plagiarism. This introduces a potential security risk since the outcome can be manipulated via biased data. While it is possible to supervise one AI by another AI in order to make the human supervised training more efficient [26], there are many drawbacks to this approach.

Considerable amounts of data are necessary to train the AI which is often either unavailable or subject to limited access due to secrecy, confidentiality and anonymization/deidentification. Low amount of data will reduce the AI accuracy significantly. Federated learning describes a decentralized approach where a model is trained on a local device, before combining with similar models for the same purpose on a centralized server. The result is fed back to the local devices. The full circle starts again to achieve iterative improvements. There are several downsides of this approach such as a high effort for data transmission or the ability of the participants to negatively manipulate the model with biased data [30].

The task force recommends careful analysis be carried out during creation of MSG-4 work-flows, considering the impact and concerns relating to MSG-4. Consideration should be given to the formation of an advisory Subject Matter Expert (SME) to develop this aspect. The task force recommends a high level of cooperation between National Aviation Authorities (NAA)s to harmonize definitions and approach to AI regulations.

12.0 Further Considerations

A number of other topics and items reviewed by the task force were considered worthy of further analysis but are not considered imperative to MSG-4. These include the option to develop a set of MSG analyses for common equipment that can be utilized across multiple fleets and the evaluation of opportunities to introduce optimization methods for interval selection. Both items are potential efficiency improvements on existing MSG-3 policy but would require considerable work to determine effectiveness.

13.0 Conclusion

The MSG-X Task Force have concluded that a new MSG methodology is required to meet the challenges envisioned by the introduction of emerging and future technologies, and that due to the number of changes this should be named MSG-4, rather than introducing an iteration of the existing MSG-3 policy. While the introduction of MSG-4 is a necessary step for future technology aircraft, the MSG-X Task Force do not envision this being retro-actively applied to existing products.

Since the 1980s and the introduction of MSG-3 there have been numerous advancements in technology, notably with the introduction of FADEC and monitoring capabilities. In recent years, we are increasingly seeing a move to off – aircraft data monitoring and the analysis of data, health and trend monitoring on ground. As we see a progression towards 'digital twin' solutions, it becomes increasingly relevant that off wing analysis forms part of the MSG analysis. This inclusion could also extend to the consideration of data transmission and security. Similarly, the move towards autonomous flight and on-ground operations leads to a change in how we consider the terminology of existing workflows.

The drive towards sustainable aviation and reduction in fuel burn has led to a focus on new materials that are both lightweight and strong, including composites and laminate structures. This introduction of materials with both metallic and non-metallic properties, requires the introduction of new workflows to account for these material combinations, which fall outside the current MSG-3 structural analysis methodology. The focus on sustainable aviation has led also to a focus on alternative fuels, namely Sustainable Aviation Fuel (SAF), Hydrogen and Electric propulsion. While SAF is considered unlikely to lead to any change required to MSG policy, the introduction of hydrogen and electric propulsion require a greater integration of system monitoring. The introduction of IAHM for these technologies would require the expansion of IAHM to include safety, as well as non- safety FEC tasks; meanwhile, the complex dependencies between system and structure required to enable hydrogen propulsion, specifically relating to the storage of hydrogen require the development of new workflows and a new re-defining of the current system and structural analysis split.

Consideration has also been given to the expansion of options, in many ways an extension of IP180 and the introduction of AHM tasks. While the Task Force considers that IAHM tasks should be permitted without the need for a classic task, by considering IAHM as a task type; it is also practical to consider other alternate task types. This could extend to other, so called, 'classic tasks' which are equally applicable but perhaps with different complexity and / or inspection interval, but may also consider alternatives based on the type of operation being flown, for example ETOPS versus non ETOPS, thereby moving away from the existing 'one size fits all' approach that is applicable today.

A number of studies have been proposed, to review guidance and regulatory documentation for the term MSG-3, and to align terminology across the aerospace industry – especially when considering IAHM and Condition Based Maintenance. It is also considered practical to review the possibility of a combined

Volume for fixed wing and rotorcraft to reduce the possibility of inconsistencies amongst different documents.

This document marks the closure of phase one of this study ‘Recommendations for the development of MSG-4, phase two will follow, focusing on the content of MSG-4, the goal is that this work be concluded by the 2025 Revision date of MSG-3.

Appendix 1 – Abbreviations

AC	Advisory Circular
AD	Airworthiness Directive
AHM	Aircraft Health Monitoring, Aircraft Health Management
AI	Artificial Intelligence
ALS	Airworthiness Limitation Section
AMC	Acceptable Means of Compliance
APU	Auxiliary Power Unit
ARP	Aerospace Recommended Practice
BIT	Built in Test
CAT	Catastrophic
CBM	Condition Based Maintenance
CM	Condition Monitoring
CMA	Common Mode Analysis
EASA	European Union Aviation Safety Agency
EEC	Electronic Engine Control
EHM	Engine Health Monitoring
ETOPS	Extended-range Twin-engine Operations Performance Standards
EVTOL	Electronic Vertical Take-Off Lift and Landing
FAA	Federal Aviation Authority
FADEC	Full Authority Digital Engine Control
FEC	Failure Effect Category
FMEA	Failure, Mode and Effect Analysis
FMECA	Failure, Modes, Effects and Criticality Analysis
GVR	General Visual inspection Remote
HAZ	Hazardous
HF	Human Factors
HUMS	Health and Usage Monitoring Systems
IATA	International Air Transport Association
IAHM	Integrated Aircraft Health Monitoring
iBIT	Initiated Built-in-Test
ICA	Instructions for Continued Airworthiness
IMRBPB	International Maintenance Review Board Policy Board
IMPS	International MRB /MTB Process Standard
IOT	Internet of Things
IP	Issue Paper
ISC	Industry Steering Committee
IVHM	Integrated Vehicle Health Monitoring
L/HIRF	Lightning / High Intensity Radiation Field
LH_2	Liquid Hydrogen
LRU	Line Replaceable Unit
MHEA	Maintenance Human Error Analysis
MIMOSA	Machinery Information Management Open System Alliance
ML	Machine Learning
MPIG	Maintenance Programs Industry Group

MRB	Maintenance Review Board
MSG	Maintenance Steering Group
MSI	Maintenance Significant Item
MWG	Maintenance Working Group
NAA	National Aviation Authorities
NMSB	Non-Modification Service Bulletin
OEM	Original Equipment Manufacturer
OSA	Open System Architecture
OSHA	Occupational Safety and Health Administration
PPH	Powerplant Handbook
RCM	Reliability Centered Maintenance
RII	Required Inspection Items
RMPIG	Rotor Maintenance Program Industry Group
RVSM	Reduced Vertical Separation Minimum
SAE	Society Automotive Engineers
SHM	Structural Health Monitoring
SME	Subject Matter Expert
SSI	Structural Significant Item
TC	Type Certificate
TLM	Time Limits Manual
UAM	Urban Air Mobility
VTOL	Vertical Take-Off Lift and Landing
ZSA	Zonal Safety Assessment

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