NOTICE OF PROPOSED AMENDMENT (NPA) NO 2010-12

DRAFT DECISION OF THE EXECUTIVE DIRECTOR OF THE EUROPEAN AVIATION SAFETY AGENCY

Amending Decision No 2003/16/RM of the Executive Director of the European Aviation Safety Agency of 14 November 2003 on Certification Specifications for large rotorcraft (CS-29)

'Vibration Health Monitoring'

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A. Explanatory Note

I. General

1. The purpose of this Notice of Proposed Amendment (NPA) is to envisage amending Decision No 2003/16/RM of the Executive Director of 14 November 2003[1]. The scope of this rulemaking activity is outlined in the Terms of Reference (ToR) 27&29.019 and is described in more detail below.

2. The European Aviation Safety Agency (hereinafter referred to as 'the Agency') is directly involved in the rule-shaping process. It assists the Commission in its executive tasks by preparing draft regulations, and amendments thereof, for the implementation of the Basic Regulation[2] which are adopted as 'Opinions' (Article 19(1)). It also adopts Certification Specifications, including Airworthiness Codes and Acceptable Means of Compliance and Guidance Material to be used in the certification process (Article 19(2)).

3. When developing rules, the Agency is bound to follow a structured process as required by Article 52(1) of the Basic Regulation. Such process has been adopted by the Agency's Management Board and is referred to as 'The Rulemaking Procedure'[3].

4. This rulemaking activity is included in the Agency's Rulemaking Programme for 2011. It implements the rulemaking task 27&29.019: Vibration Health Monitoring Specification and Update to Miscellaneous Guidance (MG)15.

5. The text of this NPA has been developed by a rulemaking group. It is submitted for consultation of all interested parties in accordance with Article 52 of the Basic Regulation and Articles 5(3) and 6 of the Rulemaking Procedure.

II. Consultation

6. To achieve optimal consultation, the Agency is publishing the draft Decision of the Executive Director on its website. Comments should be provided within 3 months in accordance with Article 6(4) of the Rulemaking Procedure. Comments on this proposal should be submitted by one of the following methods:

CRT: Send your comments using the Comment-Response Tool (CRT) available at http://hub.easa.europa.eu/crt/.

E-mail: In case the use of CRT is prevented by technical problems, these should be reported to the CRT webmaster and comments should be sent by e-mail to NPA@easa.europa.eu.

Correspondence: If you do not have access to the Internet or e-mail, you can send your comment by mail to:

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[1] Decision No 2003/16/RM of the Executive Director of the Agency of 14 November 2003 on certification specifications for large rotorcraft («CS-29»). Decision as last amended by Decision No 2008/10/RM of the Executive Director of the Agency of 17 November 2008.

[2] Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC (OJ L 79, 19.3.2008, p. 1). Regulation as last amended by Regulation (EC) No 1108/2009 of the European Parliament and of the Council of 21 October 2009 (OJ L 309, 24.11.2009, p. 51).

[3] Management Board decision concerning the procedure to be applied by the Agency for the issuing of opinions, certification specifications and guidance material (Rulemaking Procedure), EASA MB 08-2007, 13.6.2007.

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Comments should be submitted by **15 January 2011**. If received after this deadline, they might not be taken into account.

III. Comment response document

7. All comments received in time will be responded to and incorporated in a comment response document (CRD). The CRD will be available on the Agency's website and in the Comment-Response Tool (CRT).

IV. Background

8. Due to the particular design features of rotorcraft, with single load paths and reliance on the integrity of Critical Parts, a single failure of a rotor or rotor drive component can result in catastrophic effects. Vibration Health Monitoring (VHM) is one method which has been developed to reduce the likelihood of such failures and is now established as a powerful safety tool to aid operators identify the on-set of mechanical failure. Such systems, either individually or integrated into a Health and Usage Monitoring System (HUMS), have been installed on helicopters for many years and have matured with the experience gained.

9. ICAO has recognised the safety benefit of VHM systems and has issued recommendations in Annex 6 for the installation of such equipment to helicopters for certain applications and for certain categories and types of operations. Some European states have mandated the installation of such systems through national operating rules. The European wide need to mandate the installation of VHM systems through operating rules will be assessed by the Agency in rulemaking task OPS.074, currently scheduled to start in 2013.

10. Rulemaking task 27&29.019 set out with the objective of developing new Miscellaneous Guidance (MG) for inclusion as AMC to CS-27 and CS-29. In early discussions within the rulemaking group, however, it was agreed that the addition of a dedicated VHM Certification Specification was necessary to clearly outline the obligations on an applicant when certification of a helicopter with VHM is requested. The legal basis for mandating VHM is complex, crossing traditional design/operational boundaries which can lead to confusion. The specific issue is that while the design of VHM systems is fully the responsibility of design organisations, the applicability to individual rotorcraft types may arise from various sources including: voluntarily; as a direct application of national operating rules; or as a compensating provision to the design assessments of CS 29.547 and CS 29.917. There was general agreement in the rulemaking group that providing a new certification specification for VHM (CS 29.1465), similar in style to the existing ditching provisions of CS 29.801 that referenced operational requirements, would clarify the situation.

11. The group discussed whether to develop a single Miscellaneous Guidance (MG) chapter for all HUMS/VHM or to develop separate documents. It was agreed to develop separate documents, with AMC 29.1465 dedicated to VHM and suitable for use in showing compliance with European operational rules and the design assessments of CS 29.547(b) and CS 29.917(b). FAA AC 29-2C MG15 on 'Airworthiness Approval of Rotorcraft Health Monitoring Systems (HUMS)' would be updated but remain as general advice on approval of 'HUMS' credits.

12. When CS 29.1465 and AMC 29.1465 were conceived, the rulemaking group was primarily focussed on CS-29 helicopter applications as experience to date is primarily with large helicopters operating off-shore in support of the oil/gas industry. The safety benefits

obtained relative to the costs also make the installation of VHM systems an affordable safety enhancement for other multi-engine and single-engine rotorcraft. However, although the new Certification Specification and AMC could be useful for small rotorcraft, the rulemaking group acknowledged that there may be small rotorcraft VHM applications that do not meet the full intent of these proposals. The group did not want to put obstacles in the way to prevent the development and acceptance of small rotorcraft VHM systems, and so the proposal for CS-27 was subsequently withdrawn. Applicants who intend to install VHM on CS-27 rotorcraft could elect to comply with the CS-29 Certification Specification where they felt this was appropriate.

13. Consideration was given to include engine VHM systems within this task. However, the primary purpose of VHM on engines is to improve reliability. As engine reliability is a responsibility of the engine TC holder it would be more appropriate for any requirements addressing VHM on engines to be included within CS-E. In addition, although improving engine reliability is obviously desirable, it is generally considered that the current level of engine reliability on CS-29 rotorcraft is acceptable and is adequately controlled by existing provisions in CS-E. Engines were therefore excluded from these proposals.

14. The update of previously published guidance on HUMS (FAA AC 27-1B MG15 and AC-29-2C MG15), which formed part of this task, has not progressed within the timeframe of this task due to the group’s focus on developing the new CS 29.1465 and associated AMC. The update to MG15 and compatibility with CS 29.1465 and AMC 29.1465 will now be performed in association with rulemaking task 27&29.029, using the existing rulemaking group.

V. Content of the draft Decision

15. The aim of this NPA is to propose a new Certification Specification (CS 29.1465) and associated AMC (AMC 29.1465) covering the design and certification of VHM systems.

16. CS 29.1465 does not in itself mandate the installation of VHM systems but sets the minimum design and performance standards if such a system is fitted. Compliance with CS 29.1465 can either be on a voluntary basis, to comply with an operational requirement or as a compensating provision to mitigate a Hazardous/Catastrophic failure condition identified through a design assessment.

17. AMC 29.1465 is based on a VHM specification developed by the Helicopter Health Monitoring Advisory Group (HHMAG) as a guide to designing, certificating and operating a VHM system. This group was set up in the late 1980s, with an international membership from across the industry, and has been actively involved in developing and assisting in the introduction of health monitoring in helicopters.

18. The envisaged changes to Decision 2003/16/RM are:

- creation of CS 29.1465: Vibration Health Monitoring,
- creation of AMC 29.547: Main Rotor And Tail Rotor Structure,
- creation of AMC 29.917: Rotor Drive System Design,
- creation of AMC 29.1465: Vibration Health Monitoring.

VI. Regulatory Impact Assessment

1. Purpose and intended effect

   a. Issue which this NPA is intended to address

   Rotorcraft are potentially more vulnerable to catastrophic mechanical failures than fixed-wing aeroplanes due to their reliance on the integrity of fatigue loaded, single load path components within the rotor and rotor drive systems and hundreds of other Critical Parts. A single failure of any of these components can result in catastrophic effects on the rotorcraft.

   For many years metallic particle detectors have been used to indicate if a gearbox is generating metal and thus provide advance warning of bearing failures and accelerated wear of other components. However, this method cannot provide a reliable early warning of component failure resulting from certain failure modes, including fatigue cracking. It was this vulnerability and the high accident rate in the 1970s and 1980s that led to the development of VHM systems able to monitor the health and integrity of helicopter rotor and rotor drive systems.

   VHM systems entered service in the UK in 1991 as a voluntary initiative by the helicopter operators and the offshore oil and gas industry following a successful series of operational trials. VHM technology has now been established as a valuable safety tool that aids operators to identify the on-set of mechanical failure. Such systems, either individually or integrated into HUMS, have been installed on working helicopters for over 19 years and have matured with the experience gained. VHM provides the helicopter industry with a method of indicating incipient failures within the rotor and rotor drive system, including fatigue failures of shafts and gears and any failures which cause misalignment or imbalance of rotating assemblies.

   b. Scale of the issue (quantified if possible)

   VHM systems are currently fitted to multi-engine helicopters operating off-shore in a hostile environment. In the UK, a VHM system has been a requirement[4] to be fitted to helicopters with a maximum approved passenger seating configuration (MAPSC) of more than nine. From 1 July 2005, Norway required helicopters with a MAPSC greater than nine and operating in support of oil and gas exploitation to be fitted with VHM systems.

   Worldwide there are over 2 million flying hours of VHM experience and studies have shown that VHM systems have provided the first warning for approximately 69% of the rotor and rotor drive system failure types monitored by VHM and for approximately 60% of all potentially catastrophic failure cases.

   In 1999, a further study by the HHMAG showed that incidents of serious vibration occurring in-flight had reduced dramatically within the UK fleet following the introduction of these systems. Ongoing worldwide experience has continued to demonstrate that vibration health monitoring systems can provide early warning of developing failures.

   c. Brief statement of the NPA objectives

   The NPA proposes a new Certification Specification and associated AMC. The aim is not to mandate the use of VHM but to ensure that if VHM/HUMS is installed on a rotorcraft, either voluntarily or to meet an existing requirement, it meets a minimum airworthiness and performance standard acceptable to the Agency.

[4] CAP 393 Air Navigation: The Order and the Regulation (Schedule 4(15)).

2. Options

a. The options identified:

Option 1: Do nothing

Current AMC material does not reflect the latest developments and experience gained in the application of VHM technology. The 'do nothing' option will therefore fail to provide clear regulatory guidance to industry on the acceptable design and performance standards of VHM systems.

With no uniform airworthiness criteria specified, operators are only required to demonstrate that the equipment is able to perform its intended function.

Option 2: Provide additional AMC

Additional AMC will provide a clear means of compliance to demonstrate that new VHM systems meet the expected design and performance standards for such systems.

The form this AMC should take was subject to some debate within the rulemaking group. Consideration was given to using an ETSO, Miscellaneous Guidance or a specific AMC paragraph. The general opinion was that an ETSO would be appropriate for anything which can be accurately specified (such as hardware, interfaces, etc.) but would be unsuitable for design guidance on issues like developing health indicators and threshold settings. Furthermore, an AMC paragraph was not a viable option due to the lack of a dedicated certification specification in Book 1 to link the AMC.

Option 3: Non-mandatory rulemaking action

The main advantage of a dedicated certification specification addressing VHM is to clearly define the design considerations and VHM functionality necessary to be compliant with the minimum acceptable design standards of CS-29 and operational requirements.

Providing non-mandatory VHM design standards in CS-29, similar in style to the existing ditching provisions of 27/29.801 that referenced operational requirements, would clarify the situation. This was also a recommendation from the HHMAG.

Option 4: Mandatory rulemaking action

Option 4 would mandate the installation of a VHM system through a dedicated certification specification in CS-29.

b. The preferred option selected (if possible)

Please see paragraph VI-5 below.

3. Sectors concerned

Manufacturers and operators of rotorcraft and designers of VHM equipment.

4. Impacts

a. All identified impacts

i. Safety

Following a series of accidents in the UK, the Air Accident Investigation Branch (AAIB) have made recommendations suggesting that the occurrences might have been prevented had VHM systems been utilised.

Following a fatal accident to a helicopter fitted with a VHM system, the Norwegian AAIB concluded that the occurrence would have been prevented had the relevant VHM sensor not been unserviceable for some time and therefore unable to detect the developing fault. They also concluded that this accident showed that such VHM systems were capable of being an important tool in accident prevention, and recommended that National Aviation Authorities (NAAs) 'around the North Sea basin' assess requirements for such systems. A major independent study in Norway into helicopter safety also concluded that VHM systems were 'probably the most significant isolated safety improvement of the last decade'.

Option 1

In the absence of a single design and certification standard, VHM systems are currently being installed in rotorcraft without the benefit of previous knowledge and experience and, as a consequence, may not achieve the level of safety benefit being claimed.

Option 2

Updating and providing additional AMC that reflects good design and certification practice will contribute to improving VHM systems design and operation and provide a safety benefit if voluntary compliance is selected.

Option 3

Creating a certification specification in CS-29 will provide a legal obligation on the applicant to develop VHM systems that comply with a minimum standard when required to do so through an operational rule, if selected as a compensating provision in a design assessment or on a voluntary basis. This will ensure that installed VHM systems provide an acceptable level of effectiveness and reliability.

Option 4

Option 4 will extend the safety benefit of VHM systems to all rotorcraft within a given category, irrespective of intended operational use.

ii. Economic

Option 1

Not having any VHM design standards and/or guidance will inevitably lead to systems of varying standards being presented to the Agency for certification and will not ensure that VHM systems meet an acceptable minimum design standard. VHM systems that do not meet the standards and expectations of customers may require extensive development once in service. This will create a high economic impact.

Option 2

The primary purpose of VHM, whether required to comply with design or operational rules, is to improve safety by providing advanced warning of incipient failures. At this point in time there is general agreement across regulators and industry that a single standard, with a common objective, could be applied to both design and operational requirements for VHM and that one common standard would be beneficial to the industry.

Defining Acceptable Means of Compliance that gives applicants prior knowledge of what is acceptable to the Agency, will enable better planning and give the applicant some confidence that a system could be certified. This will ensure that certification costs are minimised.

Option 3

As this option is non-mandatory, there will be no specific compliance costs associated with it. Voluntary compliance or compliance with an existing operating rule will have a similar economic impact as detailed in Option 4.

Option 4

Manufacturers would incur additional costs associated with the design, development and certification of equipment. Additionally, new operators of VHM/HUMS would incur additional costs associated with the ground facilities and training if they had not operated a VHM/HUMS system before.

Many large helicopters intended for operations over water in a hostile environment in support of the oil/gas industry, will already be compliant with the proposed rule and AMC.

Typical costs for a new VHM are estimated at:

- VHM hardware €50k–400k/rotorcraft depending on specification,
- cost of ground-based equipment and software: €15k,
- support costs over 5 years: €35k–70k/rotorcraft.

In addition, development and certification costs and costs associated with personnel training and labour spent addressing VHM alerts will need to be added.

Any additional costs must be balanced against enhanced safety and the avoidance of the costs related to accidents (including those due to fatalities, injuries, rotorcraft damage/loss, rescue, salvage and accident investigation, third party liability, loss of revenue, loss of customer confidence and disruption to customer operations). Furthermore, VHM systems offer operational cost savings due to fewer maintenance test flights, reduced component maintenance and increased maintenance insight.

iii. Environmental

None identified.

iv. Social

None identified.

v. Other aviation requirements outside EASA scope

This task will support ICAO Annex 6 operational SARPs on the installation of VHM systems.

vi. Foreign comparable regulatory requirements

FAR Part 29.

b. Equity and fairness in terms of distribution of positive and negative impacts among concerned sectors.

No equity and fairness issues are expected from any of the options identified. All applicants are equally affected.

5. Summary and final assessment

a. Comparison of the positive and negative impacts for each option evaluated

Option 1

VHM is seen as an important safety enhancing technology for the detection and indication of insipient failure conditions. VHM has matured since its introduction in the 1990s and is now a cost effective technology with the potential to save both lives and cost. The ‘do nothing’ option will not aid industry in creating a single certification standard for VHM based on experience and best practice, which is accessible to the whole industry.

Option 2

Defining AMC that gives applicants prior knowledge of what is acceptable to the Agency will enable better planning and give the applicant some confidence that a system could be certified. This will ensure that certification costs are minimised.

However, in the absence of a dedicated VHM system certification specification in the CSs, the only viable option available to provide rotorcraft and VHM system designers with greater design guidance is through a Miscellaneous Guidance paragraph in the adopted FAA AC.

In the case of a VHM system being introduced as a compensating provision to comply with CS 29.547/917, this approach will not provide a clear legal basis and Acceptable Means of Compliance.

Option 3

Presently, there is no direct link between operating rules mandating the installation of VHM equipment and the certification specifications. Rotorcraft operators and customers therefore have no common benchmark on which to assess the acceptability of installed VHM equipment.

The new certification specification will ensure that where operating rules requiring VHM are in place or the applicant declares the use of VHM as a compensating provision in the system design assessments of CS 29.547/917, the VHM system will meet a minimum standard of design and performance that provides an acceptable level of effectiveness and reliability.

It is the aim of the new certification specification to simplify the process of assessment and approval of VHM system design.

Option 4

While Option 4 will provide an increased level of safety, mandating the installation of VHM systems on all rotorcraft types within a category, irrespective of operational role, will extend the scope of VHM beyond that currently envisaged by ICAO.

Furthermore, the design assessment of 29.547/917 allows alternative means to minimise the likelihood of failures that would prevent continued safe flight and landing. Associated AMC is not prescriptive as to the specific compensating provisions to be applied and is largely left to the engineering judgement of the applicant.

VHM has been established as an effective safety system for use in off-shore operations over hostile areas as it provides advanced warning of incipient failures, so that parts can be inspected and replaced before a flight-critical situation develops. This ability to maintain safe flight is paramount in off-shore operations over a hostile area, as the ability to make a controlled ditching may be compromised by sea conditions and the subsequent survivability of occupants may not be assured. These factors will not be present in other operating environments, and an immediate landing, either power-on or power-off, may prevent an incident escalating into a major safety concern.

It is considered unlikely that option 4 would find acceptance within Europe as a whole and would introduce a significant difference with FAA.

b. A summary describing who would be affected by these impacts and analysing issues of equity and fairness

Manufacturers and operators of rotorcraft and designers of VHM equipment are affected. No issues of equity and fairness have been identified.

c. Final assessment and recommendation of a preferred option

Option 3: Non-mandatory rulemaking action, is selected.

Option 3 provides a flexible solution that can easily adapt to changing ICAO SARPS. It does not in itself mandate the installation of VHM from an airworthiness standpoint, but allows applicants to choose the appropriateness of such a system on a case-by-case basis. Where VHM is mandated through an operational rule, this option will provide the necessary link to ensure such equipment meets the minimum certification standard.

Additional and updated AMC on VHM/HUMS will give applicants prior knowledge of what is acceptable to the Agency, will enable better planning, enhance confidence in the acceptance of a VHM system and minimise certification costs.

It is recognised that system performance and some operational issues can only provide benefit once a 'Controlled Service Introduction' phase has been completed and a full set of condition indicators and associated Alert levels have been defined. The AMC will address general design issues, for example: sensors, signal acquisition, signal processing, use of COTS, data transfer, etc., and will contain specific design criteria and performance targets.

The design of the ground-based system is fundamental to the capability of the VHM system and will be included in the AMC.

The rulemaking group was content to recommend this proposal in the knowledge that no additional burden on industry would be created as it will not mandate the installation or use of VHM.

B. Draft Decisions

The text of the amendment is arranged to show deleted text, new text or new paragraph as shown below:

1. deleted text is shown with a strike through: ~~deleted~~
2. new text is highlighted with grey shading: new
3. … indicates that remaining text is unchanged in front of or following the reflected amendment.

I. Draft Decision CS-29

1. Add a new Certification Specification to Book 1 to read as follows:

Book 1
SUBPART F - EQUIPMENT

CS 29.1465 Vibration Health Monitoring

If certification of a rotorcraft with vibration health monitoring of the rotors and/or rotor drive systems is requested, then the design and performance of the vibration health monitoring system must meet the requirements of this paragraph.

(a) A safety analysis must be used to identify all component failure modes that could prevent continued safe flight or safe landing, for which vibration health monitoring could provide a reliable means of early detection.

(b) Vibration health monitoring must be provided for the failure modes identified in sub-paragraph (a), when it can increase the likelihood of early detection.

Book 2
SUBPART F – EQUIPMENT

2. Add a new AMC 29.547 to read as follows:

AMC 29.547 Main Rotor And Tail Rotor Structure

Where Vibration Health Monitoring is used as a compensating provision to meet CS 29.547(b), the design and performance of the vibration health monitoring system should be shown to meet AMC 29.1465.

3. Add a new AMC 29.917 to read as follows:

AMC 29.917 Rotor Drive System Design
Where Vibration Health Monitoring is used as a compensating provision to meet CS 29.917(b), the design and performance of the vibration health monitoring system should be shown to meet AMC 29.1465.

4. Add a new AMC 29.1465 to read as follows:

AMC 29.1465
Vibration health monitoring

a. Explanation

(1) The purpose of this AMC is to provide an Acceptable Means of Compliance and Guidance Material for the design and certification of Vibration Health Monitoring (VHM) applications. VHM is used to increase the likelihood of detection of dynamic component incipient faults in the rotors and rotor drive systems that could prevent continued safe flight or safe landing, by providing timely warning of potential failures to maintenance personnel.

(2) Designing a VHM system in accordance with this AMC is expected to achieve the required performance together with acceptable levels of system integrity and reliability for compliance with type certification and operational regulations that require VHM of rotor and/or rotor drive systems.

(3) This AMC defines terms, processes, performance and standards that a VHM system should meet and also the support that a VHM approval holder should provide after the system has entered into service.

(4) VHM systems compliant with this AMC and that perform functions, the failure of which are categorised as Minor or No Safety Effect (see paragraph p.(4)), can be accepted without the need for additional compliance with AC 29-2C MG15.

Note: FAA AC 29-2C Miscellaneous Guidance (MG)15, which addresses the use of HUMS in Maintenance, is complementary to this AMC.

b. Procedures

(1) CS 29.1465 is non-mandatory in itself and compliance is only required if requested by the applicant. Three typical scenarios are foreseen as to when compliance by the applicant may be requested. In all three cases, if an applicant elects to certificate a VHM system, then it must meet the design and performance standards of CS 29.1465 and the guidance contained in this AMC, or equivalent. The three scenarios in question are:

(i) as a means of demonstrating compliance with an operational rule requiring helicopters to be fitted with a VHM system and that operators of such helicopters implement procedures covering data collection, analysis and determination of serviceability;

(ii) as a selected compensating provision to mitigate the probability of a failure condition, identified from the design assessments of CS 29.547(b) and/or CS 29.917(b), from arising;

(iii) on a voluntary basis to meet a customer requirements or company objective.

(2) The safety analysis required by CS 29.1465(a) is limited to rotors and rotor drive systems. The existing design assessments of CS 29.547 and CS 29.917 can be used for this purpose. All component failure modes that could prevent continued safe flight or safe landing (Catastrophic and Hazardous failure conditions) and for which vibration health monitoring could provide a reliable means of early detection must be identified. Previous experience together with the guidance in this AMC can be used to determine failure modes that could benefit from VHM and the applicable techniques that can produce reliable indications of incipient failures.

(3) CS 29.1465(b) states that VHM must be provided for the failure modes identified in sub-paragraph (a), when it can increase the likelihood of early detection. For many failure modes, there will be other compensating provisions which are capable of providing adequate protection against the risk of premature failure. In such cases, it is not necessary to implement VHM.

c. Definitions

(1) **Alarm**: An Alert that, following additional processing or investigation, has resulted in a maintenance action being required.
(2) **Alert**: A warning produced by the VHM system that requires further processing or investigation by the operator to determine if a maintenance action is required.
(3) **Commercial Off-the-Shelf (COTS)**: This term defines equipment hardware and software that is not qualified to aircraft standards.
(4) **Controlled Service Introduction (CSI)**: A period in-service where capabilities and functions that could not be verified prior to entry into service (including support functions) are evaluated.
(5) **False Alarm**: An Alert that after further processing or investigation has resulted in unnecessary maintenance action.
(6) **False Alert**: This is an Alert that after further processing or investigation has been determined to not require any further action.
(7) **Ground-Based System**: A means of access to VHM data, including Alerts, for immediate post-flight fault diagnosis by the responsible maintenance staff.
(8) **Prognostic Interval**: The predicted time between an Alarm and the component becoming unairworthy.
(9) **Vibration Health Monitoring (VHM)**: Use of data generated by processing vibration signals to detect incipient failure or degradation of mechanical integrity.
(10) **VHM Application**: A VHM function implemented for a defined purpose.
(11) **VHM Indicator**: A VHM Indicator is the result of processing sampled data by applying an algorithm to achieve a single value, which relates to the health of a component with respect to a particular failure mode.
(12) **VHM System**: Typically comprises vibration sensors and associated wiring, data acquisition and processing hardware, the means of downloading data from the rotorcraft, the Ground-Based System and all associated instructions for operation of the system.

d. Component Monitoring Capability

The scope of the VHM capability is determined by the range of components monitored and their incipient failures which can be detected. For each component to be monitored the range of potential damage being diagnosed should be declared and the principles of the monitoring techniques applied should be described. The health monitoring effectiveness should be demonstrable (see paragraph o).

e. System Design Considerations

(1) **Sensors**: They are the hardware that measures vibration. They should provide a reliable signal with an appropriate and defined performance. The position and installation of a vibration sensor is as critical as its performance. Sensor selection, positioning and installation should be designed to enable analysis of the processed signals to discriminate the vibration characteristics of the declared monitored component failure modes. Built-In Test capability is necessary to determine the correct functioning of the sensor. Maintenance instructions should ensure that the correct function, and any calibration, of sensors and their installation are adequately controlled.

(2) **Signal Acquisition**: It is likely that processed VHM data will be sensitive to the flight regime of the rotorcraft. For this reason it is desirable to focus data acquisition to particular operating conditions or phases of flight. Consideration should be given to the likely operation of rotorcraft that may utilise the VHM system and the practicality of acquiring adequate data from each flight to permit the Alert and Alarm processing to be performed to the required standard. The method of vibration signal acquisition should be designed so that:

(i) The vibration signal sampling rate is sufficient for the required bandwidth and to avoid aliasing with an adequate dynamic range and sensitivity.

(ii) The data acquired from the vibration signal should be automatically gathered in specifically defined regimes at an appropriate rate and quantity for the VHM signal processing to produce robust data for defect detection.

(iii) If the mission profile does not allow regular acquisition of complete data sets, then the data acquisition regimes should be capable of reconfiguration appropriate to particular flight operations.

(iv) The acquisition cycle should be designed in such a way that all selected components and their defects are monitored with an adequate frequency irrespective of any interruptions in the cycle due to the operational profile.

(3) **Signal Processing**: The helicopter's rotor and rotor drive systems are a mixture of complex and simple mechanical elements. Therefore the signal processing or the analysis techniques utilised should reflect the complexity of the mechanical elements being monitored as well as the transmission path of the signal and should be demonstrated as being appropriate to the failure modes to be detected. The objective of processing the sampled data should be to produce VHM Indicators that clearly relate to vibration characteristics of the monitored components, from which the health of these components can be determined. A key part of the success of in-service VHM is the signal-to-noise enhancement techniques such as vibration signal averaging for gears and signal band-pass filtering and enveloping for bearings. These techniques are used to generate enhanced component vibration signatures prior to the calculation of the VHM Indicators. Accordingly, the method of signal enhancement should be shown to be effective .The method of signal processing and the analysis techniques utilised to generate the data used for defect detection should be defined for the claimed defect detection capability (see Table 1 below).

Table 1: Typical Vibration Health Monitoring Indicators & Signal Processing Techniques

Assembly	Component Type	Types of VHM indicators used
Engine	Power Turbine Gas Generator	Fundamental shaft order and harmonics and broad-band vibration
Engine to main gearbox input drive shafts	Shafts	Fundamental shaft order and harmonics
Gearboxes	Shafts	Fundamental shaft order and harmonics
	Gears	Gear meshing frequency and harmonics, modulation of meshing waveform, impulse detection and energy measurement, non mesh-related energy content
	Bearings	High frequency energy content, impulse detection, signal envelope modulation patterns and energies correlated with bearing defect frequencies
Tail rotor drive shaft	Shafts	Fundamental shaft order and harmonics
	Hanger Bearings	As for gearbox bearings, but can utilise simple band-passed signal energy measurements
Oil cooler	Oil Cooler Blower and Drive Shaft	Fundamental shaft order and harmonics, blade pass frequency
Main and Tail rotor	Rotors	Fundamental shaft order and harmonics up to blade pass frequency, plus multiples of this.

Recording and storing of some raw vibration data and the processed vibration signal, from which the Indicators are derived, may also be of significant diagnostic value. Typical signal processing techniques include;

(i) Asynchronous Power Spectrum where phase information or frequency tracking is not required (does not meet the criteria for gear monitoring).

(ii) Synchronous Spectrum where phase information or frequency tracking is required (does not meet the criteria for gear monitoring).

(iii) Band-pass filtered signal Envelope Power Spectrum Analysis (a recommended technique for gearbox bearings).

(iv) Synchronous Averaging for time and frequency domain signal analysis (a recommended technique for gearbox gears).

(v) Band-pass filtering and the measurement of filtered signal statistics, including crest factor (can be used for bearings not within engines or gearboxes).

(vi) Further signal enhancement techniques are typically required in the calculation of certain VHM indicators targeted at detecting specific defect-related features (e.g. localised signal distortion associated with a gear tooth crack).

It is not always necessary for the VHM system to cover the complete capability defined in Table 1. However, absence of any of these areas, and/or techniques, should be substantiated. It is acknowledged that the above provides a prescriptive scope for monitoring rotor and rotor drive system components. If alternative methods are proposed, which can be shown to be as effective and reliable as those prescribed and which are to the satisfaction of the Agency, then these can also be accepted.

f. Data Management

The data transfer process from the rotorcraft to the maintenance personnel interface should be sufficient to determine all the VHM Indicators post flight. The upload/download should have minimal impact on flight operations. VHM data should be accessible in order to permit alternative analysis and comparison. The following should be specified:

(1) Data transfer, processing, networking, data integrity assurance.

(2) Methods to ensure the reliability of this process.

(3) The time for upload/download and retrieval of data and/or health report.

(4) Facilities for the warehousing of all of the data downloaded from the VHM systems and to permit timely access to the data.

g. Alert Management

(1) **VHM Alert Generation**: VHM Alert criteria should be applied to every monitored component. VHM Alerts are produced to indicate possible anomalous behaviour or a specific defect.

(2) **VHM Alert Management**: Diagnostic processes are required to determine if VHM driven maintenance of the rotorcraft is necessary.

h. Pilot Interface

Pilot interaction with the VHM system, if any, should be specified and should not adversely impact on pilot workload.

i. Maintenance Personnel Interface

The person responsible for releasing a rotorcraft into service should have access to VHM data, maintenance recommendations and VHM system Built-In Test data necessary to release that rotorcraft. This should include the ability to view VHM Indicators, trend data and detection criteria, including thresholds, for relevant VHM parameters from that rotorcraft. These capabilities must be available locally to maintenance personnel for immediate post flight fault diagnosis.

j. Fleet Diagnostic Support Interface

Where an operator has multiple rotorcraft of the same type, facilities should be made available to the operator to support the analysis of all data acquired by the VHM systems in the operator's fleet. The operator and all parties supporting the operator should have remote, multi-user and timely access to the data and the diagnostic processes in order to assist in determining the continued airworthiness of their fleet.

k. VHM system installation

The VHM system installation must comply with CS-29, as applicable to the specific rotorcraft type.

l. Ground-Based System Architecture

Any Ground-Based System Architecture requirements should be specified (see paragraph q. Technical Publications). The Ground-Based System may include COTS hardware, software and services, compatible with the Data Management objectives of paragraph (f) above.

m. Software

(1) **For the case where the VHM system is stand alone**

All software that makes up the VHM processing, whether airborne or ground-based, is to be produced to the software quality standard required to achieve the necessary level of system integrity.

All COTS software should be identified and should be of a quality standard that does not compromise the overall system's integrity.

All software specifically developed for VHM should be developed to EUROCAE ED 12B/RTCA DO 178B level D, or higher.

(2) **For the case where the VHM is integrated into a system with other functions**

The software for these systems should ensure that supplied data meets VHM system integrity requirements and should not be less than EUROCAE ED 12B/RTCA DO 178B level D.

n. Performance Criteria

(1) **Signal Acquisition**

The applicant for VHM system certification should specify the rate of acquisition of data sets for defect diagnostics in consistent flight regimes.

As a target the total data set acquired in a flight should be sufficient for complete and reliable diagnostics to be produced for every flight above a defined duration in stabilised conditions. As a minimum, at least the data set for all components should be automatically obtained on each flight of greater than 30 minutes in stabilised conditions without the need for in-flight pilot action. For operations which do not contain periods of stabilised operation of greater than 30 minutes, alternative procedures need to be incorporated to ensure that the total data set is recorded within a specified number of flying hours and in any case no longer than 25 flying hours.

Where sub-system performance is critical or relied upon to achieve the quoted defect probability of detection or False Alert rate, such as sensor accuracy, dynamic range or bandwidth, then this should be quoted.

(2) **Data transfer and Storage Capability**

The VHM defect status data should be capable of being downloaded during rotors running turnarounds.

All the data sets acquired should be stored until successfully transferred to the Ground-Based System. The storage capacity should not be less than 25 flying hours.

The applicant should describe the maximum interval between data downloads for which the system memory capacity is not exceeded.

The data transfer process should be capable of downloading partial data sets to the Ground-Based System if for any reason a complete data set for every monitored component has not occurred.

(3) **VHM Alert generation and fault detection performance**

The Alert and Alarm generation processing should be designed to achieve a claimed probability of detection for each component defect being monitored. Processing to isolate False Alerts and False Alarms should not result in an unacceptable workload. Also this processing should not compromise the verification and validating evidence of claimed defect detection performance. This workload should be assessed prior to completion of the Controlled Service Introduction (CSI) phase.

o. Performance Validation

The applicant should demonstrate how the VHM system provides an acceptable defect detection performance. Experiences gained during the CSI phase should be reviewed to confirm that this is the case.

(1) **Validation methodology**

It is not practical to verify predicted component defect detection performance for all failure modes by in-service experience or by trials. Therefore it is necessary that the methodology employed can be clearly substantiated from an understanding of how the failure mechanisms affect vibration and how the diagnostic processing will generate appropriate Alarms. Direct or indirect evidence should be provided as follows:

(i) Direct evidence includes:

(A) Actual service experience on VHM equipped rotorcraft of the same or of similar type and configuration.

(B) Test rig results.

(C) Rotorcraft trials, investigating cause and effect (for example, introducing degrees of imbalance or mal-alignment and calibrating the techniques response). This should be supported by flight experience to demonstrate that the False Alert criterion can be met and that all the diagnostic indicators lie within reasonable ranges.

Note: It is recommended that a mechanism be established for requesting maintenance feedback with respect to component failure/degradation and VHM indication. The cases are as follows:

- to verify component condition following rejection after an Alarm, in order to establish the diagnostic accuracy, probability of detection and the False Alarm rate.
- to inform the TC holder in the event that a failure occurs which is monitored by VHM, where the VHM fails to provide an Alarm. This will provide the missed Alarm rate.

(ii) Indirect evidence includes:

(A) Evidence as to the provenance of the technology and its suitability for application to rotorcraft.

(B) Reference to adequate performance in other applications.

(C) Modelling of the processes

The types of evidence stated in (i) and (ii) above can be used to substantiate:

(A) That the Alert processing methodology can deliver an adequate False Alarm rate, Prognostic Interval and probability of detection.

(B) Data acquired in a flight is sufficient for complete and reliable diagnostics to be produced for every flight above a minimum duration in stabilised conditions.

(C) The sensitivity, dynamic range and bandwidth of the signal acquisition are adequate.

(D) That the processed vibration signal-to-noise ratio is acceptable and that it is capable of discriminating the features required to identify potential incipient defects for the monitored components.

Typically, the False Alarm Rate and Alert Management performance will be validated during the CSI phase.

p. VHM System Criticality

(1) It is necessary to understand the criticality of a VHM function in order to determine the appropriate level of integrity required. Criticality describes the severity of the end result of a VHM application failure/malfunction and is determined by an assessment that considers the safety effect that the VHM application can have on the rotorcraft.

Note: The criticality of the VHM function relates only to the contribution of the VHM function to the overall integrity of the component being monitored.

(2) The criticality categories are defined in AC 29-2C AC 29.1309. In order to determine the appropriate level of criticality of the VHM function, it will be necessary to perform a safety assessment or functional hazard analysis on the rotorcraft systems affected. This should be carried out in accordance with standard safety assessment requirements such as CS 29.1309. In performing this assessment it will be necessary to consider the possibility of dormant and common mode failures and the possibility of the VHM system introducing additional risks, e.g. due to the False Alarm rate.

(3) Different VHM Systems have functions that can have different levels of criticality, such as those described below:

(i) Many VHM applications provide a method of enhanced health monitoring which adds to traditional techniques that have been used to establish an acceptable level of component integrity. Accordingly, the failure effect of these functions is considered to be ‘No Safety Effect’ when there have been no changes to the traditional techniques.

(ii) When an on-board VHM system is used to replace existing portable test equipment, and is performing an identical function, this is considered to have ‘No Safety Effect’.

(iii) When an on-board VHM system is used to replace an existing maintenance task, this will have a criticality level that will be determined by the safety effect that the VHM application can have on the rotorcraft.

In cases (ii) and (iii) if the VHM function replaces a maintenance task, then the reliability and accuracy of the VHM must be equal to or better than that of the process it is replacing.

(4) VHM systems designed in accordance with this AMC should provide a level of system integrity appropriate for ‘No Safety Effect’ and ‘Minor’ effect category VHM applications. Below is a description of typical applications of a VHM system where the effect on the rotorcraft of their failure corresponds to ‘No Safety Effect’ and ‘Minor’. This does not override AC 29.1309 but provides guidance on the appropriate effect category for VHM applications.

(i) Severity classification: No Safety Effect

A 'No Safety Effect' is where the VHM System provides vibration monitoring with no change to existing maintenance practices. For example, this means that there will be no reduction in scheduled component inspection, overhaul, or replacement intervals. Functions conducted by portable test equipment can be replaced by VHM system functions as long as existing acceptance criteria are maintained and existing mitigation actions are retained, such as conducting maintenance test flights after any vibration reduction adjustments (rotor track and balance, balancing, absorber tuning, etc.).

(ii) Severity classification: Minor

Some examples of VHM System functions, the failure of which typically have Minor criticality are as follows;

(A) VHM system functions used to replace functions conducted by portable test equipment without requiring the mitigation of a maintenance verification test flight for standard vibration reduction checks and/or adjustments (rotor track and balance, balancing, absorber tuning, etc.).

(B) VHM system monitoring of grease packed bearings and replacing a manual inspection, if there is no change to other means of mitigation, i.e. not changing the preventative maintenance actions, such as servicing or the scheduled replacements of these type bearings.

(C) VHM system monitoring of swash-plate bearings to extend a manual inspection period.

These functions need validation (see paragraph o.), such as seeded fault testing (bench) or operational experience to show the system (airborne and ground components) is capable of detecting monitored faults with at least the same level of performance as the method it is replacing.

q. <u>Technical Publications</u>

Appropriate Instructions for Continued Airworthiness (ICA) are required by CS 29.1529 and Appendix A. ICA and other supporting data should be available to operators and maintenance organisations before entry into service and should be updated whenever necessary during the service life of the system.

ICA should include the following:

(1) Guidance for the interpretation of the diagnostic information produced by the VHM system for all components monitored, to include Alert and Alarm management, a description of the indicators, and Alert generation methods.

(2) Maintenance instructions defining the actions to be taken in the event of all Alarms, including the appropriate rotorcraft inspections (or other maintenance) necessary for fault-finding to verify the Alarm.

(3) Scheduled maintenance to be carried out on the VHM system itself, including inspections to confirm sensor performance and system functionality.

(4) Instructions for all maintenance of the VHM System, including Illustrated Parts Catalogue/Illustrated Parts Breakdown and wiring diagrams.

(5) Installation instructions for retrofit VHM systems addressing all aspects of VHM system integration with the rotorcraft.

(6) A recommendation of the maximum period of unavailability of VHM functions for inclusion in the rotorcraft Master Minimum Equipment List (MMEL) or maintenance instructions, as required.

(7) Operating Instructions detailing the operation of the VHM system including any ground-based elements or functions.

(8) Required Flight Manual instructions.

r. Training

Suitable training should be made available with respect to operation and maintenance of the VHM system. This training should be made available prior to initial delivery of the VHM system. Training material and training courses should evolve to include lessons learned from service experience and appropriate diagnostic case studies. Training material and training courses should cover:

(1) Installation of the VHM system.

(2) Line maintenance of the VHM system (including VHM system fault-finding, any calibration necessary).

(3) Use of the VHM System during Line maintenance to monitor the rotorcraft, including the data transfer, interface with data analysis, response to Alerts and Alarm processing, rotorcraft fault-finding and other Line diagnostic actions.

(4) Necessary system administration functions, covering operational procedures relating to data transfer and storage, recovery from failed down loads and the introduction of hardware and software modifications.

(5) Any data analysis and reporting functions that are expected to be performed by the operator.

s. Product Support — System Data and Diagnostic Support

The necessary support should be provided to operators to ensure that the VHM system remains effective and compliant with any applicable requirements throughout its service life. The support provided should cover both the VHM system itself (i.e. system support), and the data generated (data and diagnostic support).

The data and diagnostic support provided should ensure that:

(1) The operator has timely access to approved external data interpretation and diagnostic advice. It is the responsibility of the approval holder to provide this information; however, this may also involve the rotorcraft TC holder, or through formal agreement, from another suitably qualified organisation.

(2) There is a defined protocol for requesting and providing diagnostic support, including response times that meet VHM system operational requirements, with traceability of all communications.

(3) The organisation providing diagnostic support to an operator has a defined process for training and approving all personnel providing that support.

(4) VHM performance is periodically assessed, with an evaluation of Alert criteria, and a controlled process for modifying those criteria if necessary.

(5) Sufficient historical VHM data is retained and collated to facilitate the identification of trends on in-service components, the characterisation of rotorcraft fleet behaviour, and VHM performance assessment.

t. Minimum Equipment List (MEL) Recommendation

The MEL should address the Airborne Element of the VHM system. The maximum period for absence of an assessment of any VHM indicator, to which Alert criteria are applied, should be limited to a suitable period and should not exceed 25 hours.

It is recommended that the VHM system automatically generates a warning if no VHM data has been gathered for a particular component for longer than a certain number of hours.

u. Controlled Service Introduction

(1) When a VHM system initially enters into service or it is adapted to a new application on a different rotorcraft type, then a Controlled Service Introduction (CSI) phase is usually necessary in order to fully validate the system performance.

(2) If a CSI phase is considered to be necessary, then this activity should be detailed in a CSI plan to be approved prior to release to service, detailing the VHM applications being developed and the criteria for the successful completion of the CSI. Such criteria should address:

(i) The number of rotorcraft, number of operators, calendar time and flying hours.

(ii) Validation of specific sensor performance.

(iii) If failures or defects in monitored components occur during the CSI phase, it should be verified that the applicable VHM system applications provide an accurate timely Alarm.

(iv) Validate the False Alarm rate.

(v) Evolution of Alert criteria.

(vi) Validate the timeliness and integrity of the end-to-end data transfer and analysis process.

(vii) Demonstration of specific support processes.

(viii) System hardware reliability.

(ix) System maintainability.

(x) System usability (including rotorcraft and ground based man-machine interfaces).

(xi) ICA usability.

(xii) Effectiveness of training.

(xiii) Effectiveness and timeliness of diagnostic support.

(3) A CSI Plan should be agreed between the applicant for VHM system certification and the Agency prior to initial approval of the VHM system. This plan should then be implemented by the VHM approval holder and the operator(s) and monitored periodically by the Agency. The validation and improvement activities should be detailed in this plan which should also detail the objectives that must be achieved before the CSI can be considered to be completed.

(4) Formal CSI meetings should take place in order to review service experience against the CSI criteria. They should involve the VHM system approval holder, the Agency (as applicable), and the operators.

(5) Once all parties agree that the intent of the CSI has been satisfied, the CSI phase will be considered closed. The process of review and closure should be recorded.

v. Related documents

(1) Federal Aviation Administration (FAA) AC 29-2C MG 15 ‘Airworthiness Approval of Rotorcraft Health Usage Monitoring Systems (HUMS)’

http://www.faa.gov/regulations_policies/advisory_circulars/

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

http://www.caa.co.uk/docs/33/CAP753.pdf