CS-29 AMENDMENT 3 - CHANGE INFORMATION

Certification Specifications (CS) are used for establishing the certification basis for applications made after the date of entry into force of a CS including any amendments. Since the complete text of a CS, including any amendments to it, is relevant for establishing the certification basis, the Agency has decided to enact and publish all amendments to CS's as consolidated documents instead of enacting and publishing only the amended text.
Consequently, except for a note '[Amdt. 29/3]' under the amended paragraph, the consolidated text of CS-29 does not allow readers to see the detailed changes introduced by the new amendment. To allow readers to also see these detailed changes this document has been created. The same format as for publication of Notices of Proposed Amendments has been used to show the changes:

1. deleted text is shown with a strike through: ~~deleted~~
2. new or changed text is highlighted with grey shading: new
3. ...

   Indicates that remaining text is unchanged in front of or following the reflected amendment.

...

CS-29 BOOK 1 – AIRWORTHINESS CODE

1. Editorial change to Preamble.

The order of the amendments has been changed to place the latest amendment at the top of the page.

2. Editorial change to Book 1 Cover Page

'Airworthiness Code' has been changed to read: 'Certification Specifications'.

3. Editorial change to Contents

'BOOK 1 – AIRWORTHINESS CODE' has been changed to read:
'BOOK 1 – CERTIFICATION SPECIFICATIONS'

Book 1 – Subpart C

4. Amend CS 29.571.

Delete the existing CS 29.571 and replace with the following:

CS 29.571 Fatigue Tolerance Evaluation of Metallic Structure

(a) A fatigue tolerance evaluation of each Principal Structural Element (PSE) must be performed, and appropriate inspections and retirement time or approved equivalent means must be established to avoid Catastrophic Failure during the operational life of the rotorcraft.

(b) Reserved

(c) Reserved

(d) Each PSE must be identified. Structure to be considered must include the rotors, rotor drive systems between the engines and rotor hubs, controls, fuselage, fixed and movable control surfaces, engine and transmission mountings, landing gear, and their related primary attachments.

(e) Each fatigue tolerance evaluation must include:

(1) In-flight measurements to determine the fatigue loads or stresses for the PSEs identified in sub-paragraph (d) in all critical conditions throughout the range of design limitations required in CS 29.309 (including altitude effects), except that manoeuvring load factors need not exceed the maximum values expected in operations.

(2) The loading spectra as severe as those expected in operations based on loads or stresses determined under sub-paragraph (e)(1), including external load operations, if applicable, and other high frequency power-cycle operations.

(3) Take-off, landing, and taxi loads when evaluating the landing gear (including skis and floats) and other affected PSEs.

(4) For each PSE identified in sub-paragraph (d), a threat assessment, which includes a determination of the probable locations, types, and sizes of damage taking into account fatigue, environmental effects, intrinsic and discrete flaws, or accidental damage that may occur during manufacture or operation.

(5) A determination of the fatigue tolerance characteristics for the PSE with the damage identified in sub-paragraph (e)(4) that supports the inspection and retirement times, or other approved equivalent means.

(6) Analyses supported by test evidence and, if available, service experience.

(f) A residual strength determination is required that substantiates the maximum damage size assumed in the fatigue tolerance evaluation. In determining inspection intervals based on damage growth, the residual strength evaluation must show that the remaining structure, after damage growth, is able to withstand design limit loads without failure.

(g) The effect of damage on stiffness, dynamic behaviour, loads and functional performance must be considered.

(h) The inspection and retirement times or approved equivalent means established under this paragraph must be included in the Airworthiness Limitation Section of the Instructions for Continued Airworthiness required by CS 29.1529 and paragraph A29.4 of Appendix A.

(i) If inspections for any of the damage types identified in sub-paragraph (e)(4) cannot be established within the limitations of geometry, inspectability, or good design practice, then supplemental procedures, in conjunction with the PSE retirement time, must be established to minimize the risk of occurrence of these types of damage that could result in a catastrophic failure during the operational life of the rotorcraft.

5. Create CS 29.573.

CS 29.573: Damage Tolerance and Fatigue Evaluation of Composite Rotorcraft Structures

(a) Composite rotorcraft structure must be evaluated under the damage tolerance requirements of sub-paragraph (d) unless the applicant establishes that a damage tolerance evaluation is impractical within the limits of geometry, inspectability, and good design practice. In such a case, the composite rotorcraft structure must undergo a fatigue evaluation in accordance with sub-paragraph (e).

(b) Reserved

(c) Reserved

(d) Damage Tolerance Evaluation:

(1) Damage tolerance evaluations of composite structures must show that Catastrophic Failure due to static and fatigue loads is avoided throughout the operational life or prescribed inspection intervals of the rotorcraft.

(2) The damage tolerance evaluation must include PSEs of the airframe, main and tail rotor drive systems, main and tail rotor blades and hubs, rotor controls, fixed and movable control surfaces, engine and transmission mountings, landing gear, and any other detail design points or parts whose failure or detachment could prevent continued safe flight and landing.

(3) Each damage tolerance evaluation must include:

(i) The identification of the structure being evaluated;

(ii) A determination of the structural loads or stresses for all critical conditions throughout the range of limits in CS 29.309 (including altitude effects), supported by in-flight and ground measurements, except that manoeuvring load factors need not exceed the maximum values expected in service;

(iii) The loading spectra as severe as those expected in service based on loads or stresses determined under sub-paragraph (d)(3)(ii), including external load operations, if applicable, and other operations including high torque events;

(iv) A Threat Assessment for all structure being evaluated that specifies the locations, types, and sizes of damage, considering fatigue, environmental effects, intrinsic and discrete flaws, and impact or other accidental damage (including the discrete source of the accidental damage) that may occur during manufacture or operation;

(v) An assessment of the residual strength and fatigue characteristics of all structure being evaluated that supports the replacement times and inspection intervals established under sub-paragraph (d)(4); and

(vi) allowances for the detrimental effects of material, fabrication techniques, and process variability.

(4) Replacement times, inspections, or other procedures must be established to require the repair or replacement of damaged parts to prevent Catastrophic Failure. These replacement times, inspections, or other procedures must be included in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by CS 29.1529.

(i) Replacement times must be determined by tests, or by analysis supported by tests to show that throughout its life the structure is able to withstand the repeated loads of variable magnitude expected in-service. In establishing these replacement times, the following items must be considered:

(A) Damage identified in the Threat Assessment required by sub-paragraph (d)(3)(iv);

(B) Maximum acceptable manufacturing defects and in-service damage (i.e., those that do not lower the residual strength below ultimate design loads and those that can be repaired to restore ultimate strength); and

(C) Ultimate load strength capability after applying repeated loads.

(ii) Inspection intervals must be established to reveal any damage identified in the Threat Assessment required by sub-paragraph (d)(3)(iv) that may occur from fatigue or other in-service causes before such damage has grown to the extent that the component cannot sustain the required residual strength capability. In establishing these inspection intervals, the following items must be considered:

(A) The growth rate, including no-growth, of the damage under the repeated loads expected in-service determined by tests or analysis supported by tests; and

(B) The required residual strength for the assumed damage established after considering the damage type, inspection interval, detectability of damage, and the techniques adopted for damage detection. The minimum required residual strength is limit load.

(5) The effects of damage on stiffness, dynamic behaviour, loads and functional performance must be taken into account when substantiating the maximum assumed damage size and inspection interval.

(e) Fatigue Evaluation:

If an applicant establishes that the damage tolerance evaluation described in sub-paragraph (d) is impractical within the limits of geometry, inspectability, or good design practice, the applicant must do a fatigue evaluation of the particular composite rotorcraft structure and:

(1) Identify structure considered in the fatigue evaluation;
(2) Identify the types of damage considered in the fatigue evaluation;
(3) Establish supplemental procedures to minimise the risk of Catastrophic Failure associated with damage identified in sub-paragraph (e)(2); and
(4) Include these supplemental procedures in the Airworthiness Limitations section of the Instructions for Continued Airworthiness required by CS 29.1529.

Book 1 – Subpart E

<u>6. Editorial change CS 29.955.</u>

CS 29.955 Fuel flow

…

(a) General …

(7) The fuel filter required by CS 29.997 is blocked to the degree necessary to simulate the accumulation of fuel contamination required to activate the indicator required by CS 29.1305 (a)(18~~17~~).

…

Book 1 – Subpart F

<u>7. Create CS 29.1465.</u>

CS 29.1465 Vibration Health Monitoring

(a) If certification of a rotorcraft with vibration health monitoring of the rotors and/or rotor drive systems is requested by the applicant, then the design and performance of an installed system must provide a reliable means of early detection for the identified failure modes being monitored.

(b) If a vibration health monitoring system of the rotors and/or rotor drive systems is required by the applicable operating rules, then the design and performance of the vibration health monitoring system must, in addition, meet the requirements of this paragraph.

(1) 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;

(2) All typical VHM indicators and signal processing techniques should be considered in the VHM System design;

(3) Vibration health monitoring must be provided as identified in subparagraph (1) and (2), unless other means of health monitoring can be substantiated.

Book 1 - Appendices

8. Amend Appendix A A29.4;

Appendix A Instructions for continued Airworthiness
…
A29.4 Airworthiness Limitations Section

The instructions for continued airworthiness must contain a section titled airworthiness limitations, that is segregated and clearly distinguishable from the rest of the document. This section must set forth each mandatory replacement time, structural inspection interval, and related structural inspection procedure ~~approved under CS 29.571~~ required for type-certification. If the instructions for continued airworthiness consist of multiple documents, the section required by this paragraph must be included in the principal manual. This section must contain a legible statement in a prominent location that reads: ‘the airworthiness limitations section is approved and variations must also be approved.

Book 2

9. Create AMC 29.547;

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 approved by requesting compliance with CS 29.1465(a).

10. Create AMC 29.851;

Based on EU legislation(Footnote), in new installations of hand fire extinguishers for which the certification application is submitted after 31 December 2014, Halon 1211, 1301 and Halon 2402 are unacceptable extinguishing agents.

The guidance regarding hand fire extinguishers in FAA Advisory Circular AC 20-42D is considered acceptable by the Agency. See AMC 29.1197 for more information on Halon alternatives.

Footnote
Commission Regulation (EU) No 744/2010 of 18 August 2010 amending Regulation (EC) No 1005/2009 of the European Parliament and of the Council on substances that deplete the ozone layer, with regard to the critical uses of halon (OJ L 218, 19.8.2010, p. 2).

11. Create AMC 29.917;

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 approved by requesting compliance with CS 29.1465(a).

12. Create AMC 29.1197;

AMC 29.1197 Fire extinguishing agents

1. This AMC addresses alternatives to Halon and provides further guidance and acceptable means of compliance to supplement FAA AC 29-2C AC 29.1197. As such it should be used in conjunction with the FAA AC and take precedence over it in the showing of compliance.
2. The Montreal Protocol, in existence since 1987, is an international agreement to phase out production and use of ozone-depleting substances, including halogenated hydrocarbons also known as Halon. A European regulation(*Footnote 1*) governing substances that deplete the ozone layer was published in 2000 containing initial provisions for Halon phase-out, but also exemptions for critical uses of Halon, including fire extinguishing in aviation.
3. ‘Cut-off’ dates (i.e. Halon no longer acceptable in new applications for type certification) and ‘end’ dates (i.e. Halon no longer acceptable for use in rotorcraft) have been subsequently established by a new regulation in 2010(*Footnote 2*), as presented in Table 3.1 below:

Table 3.1: ‘Cut-off’ and ‘end’ dates

Rotorcraft compartment	**Type of extinguisher**	**Type of halon**	**Dates**	
			Cut-off	**End**
Lavatory waste receptacles	Built-in	1301 1211	31 December 2011	31 December 2020

		2402		
Cabins and crew compartments	Hand (portable)	1211 2402	31 December 2014	31 December 2025
Propulsion systems and Auxiliary Power Units	Built-in	1301 1211 2402	31 December 2014	31 December 2040
Normally unoccupied cargo compartments	Built-in	1301 1211 2402	31 December 2018	31 December 2040

4. In the course of Halon replacement, novel agent types such as fluorine ketone liquids and aerosols are being developed. In contrast to the gaseous agents, e.g. Halon 1301, which disperse more or less easily inside a given volume when released, liquid and powder-type substances require the evaluation of precise spray vectors and more complex piping configurations inside the compartment in order to achieve the concentration-over-time certification limits as required to act as an effective fire agent.

5. Hand fire extinguishers and agents

Historically, Halon 1211 has been the most widespread agent in hand (portable) fire extinguishers to be used in rotorcraft compartments and cabins. Minimum Performance Standards (MPS) for the agents are laid down in Appendix A to Report DOT/FAA/AR-01/37 of August 2002, while acceptable criteria to select the fire extinguishers containing said agents are laid down in the FAA Advisory Circular AC 20-42D. Three agent alternatives to Halon are presently known to meet the MPS: HFC-227ea, HFC-236fa and HFC Blend B. However, these agents are significantly heavier and occupy a greater volume than Halon 1211. This may indirectly (i.e. additional weight of the fire extinguisher and additional weight of the structures supporting it), increase CO_2 emissions. Furthermore some of these agents have also been identified for having a global warming potential much higher than Halon. Therefore, further research is underway to develop additional alternatives to Halon 1211 for hand fire extinguishers.

Should an applicant wish to propose, even before the end of 2014, any alternative agent for hand fire extinguishers meeting the mentioned MPS, the Agency will initiate a Certification Review Item addressing the use of such an alternate fire extinguishing agent.

6. Fire protection of propulsion systems and APU

Historically, Halon 1301 has been the most widespread agent used in engine or APU compartments to protect against Class B fires (i.e. fuel or other flammable fluids). The MPS for agents to be used in these compartments are particularly demanding, because of the presence of fuel and other volatile fluids in close proximity to high temperature surfaces. Various alternatives are being developed (e.g. FK-5-1-12), while the FAA is aiming at issuing a report containing the MPS.

Should an applicant wish to propose, even before the end of 2014, any alternative agent for Class B fire extinction in engine or APU compartments, even in the absence of a published MPS, the Agency will initiate a Certification Review Item addressing the use of such an alternate fire extinguishing agent.

Footnote 1

Regulation (EC) No 2037/2000 of the European Parliament and of the Council of 29 June 2000 on substances that deplete the ozone layer.

Footnote 2

Commission Regulation (EU) No 744/2010 of 18 August 2010 amending Regulation (EC) No 1005/2009 of the European Parliament and of the Council on substances that deplete the ozone layer, with regard to the critical uses of halon (OJ L 218, 19.8.2010, p. 2).

13. Create AMC 29.1465;

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

Note 1: FAA AC 29-2C Miscellaneous Guidance (MG)15, which addresses the use of HUMS in Maintenance, is complementary to this AMC.

Note 2: If an applicant wishes to install a VHM system that is not compliant with CS 29.1465(a), it may still be accepted for installation on a “No hazard/No credit” basis. However, it cannot replace any existing type-design maintenance instructions or change the established methods of complying with CS-29.

b. Procedures

(1) CS 29.1465 does not mandate the fitment of VHM systems. However, if a VHM system is installed on the rotorcraft to meet a type-certification or operational rule,

then compliance is required. Three typical scenarios are foreseen as to when compliance by the applicant may be requested. The three scenarios in question are:

(i) as a means of demonstrating compliance with an operational rule requiring helicopters 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 requirement or company objective.

(2) CS 29.1465(a) allows non-required and/or partial VHM applications with limited capability to monitor specific failure modes to be approved. Such systems can offer safety benefits and it is not the intention here to discourage their installation and use. However, any installed system must meet CS 29.1301 and be of a kind and design appropriate to its intended function and function properly when installed. The guidance given in this AMC is therefore considered to be applicable to these types of VHM systems.

(3) Where an operating rule mandates installation of a VHM system, CS 29.1465(b) aims to provide a VHM system capability that maximises the safety benefit. All typical VHM indicators and signal processing techniques should be considered in the VHM design and a system safety assessment undertaken to identify failure modes where VHM could provide early detection of incipient failures. VHM must be provided for all potential failure modes unless other means of health monitoring can be substantiated.

(4) The safety analysis required by CS 29.1465(b)(1) 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.

(5) CS 29.1465(b)(2) requires the design and performance of the VHM system to consider indicators and processing techniques used on typical existing VHM installations. A non-exhaustive list is provided in Table 1 of this AMC.

(6) CS 29.1465(b)(3) states that VHM must be provided as identified in subparagraph (b)(1) and (b)(2), unless other means of health monitoring can be substantiated. For many failure modes, there may be other compensating provisions which are capable of providing protection against the risk of premature failure. In such cases, the added benefit of VHM in increasing the likelihood of early detection should be assessed. It will not be necessary to implement VHM for a given failure mode if no safety benefit can be established.

c. Definitions

(1) **Alarm**: An Alert that, following additional processing or investigation, has resulted in a maintenance action being required.

(2) **Alert**: An indication produced by the VHM system that requires further processing or investigation by the operator to determine if corrective 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 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.

(ii) Synchronous Spectrum where phase information or frequency tracking is required.

(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).

Note 1: When showing compliance to CS 29.1465(a), for non-required and/or partial VHM applications with limited capability to monitor specific failure modes, it is not necessary to address the scope of VHM capability stated in Table 1.

Note 2: When showing compliance to CS 29.1465(b), 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.

Note: The fixed or learnt thresholds for each individual health monitoring indicator may have a limited capability to detect incipient failures in a timely manner. This is because the process for threshold setting is sometimes a compromise between increasing sensitivity and incurring a higher risk of false alarms, or reducing sensitivity, which will delay the point at which a rising indicator value will trigger an alert. In-service experience has shown that MGB component fatigue failures can propagate from initiation to failure in a relatively short period of time, thus the use of fixed thresholds alone may not provide a timely indication of impending failure. One characteristic that can often provide an earlier indication of anomalous behaviour is the rate of change of a health monitoring indicator, and automatic trend detection software has been developed and shown to be effective. Another method, commonly referred to as Advanced Anomaly Detection (AAD), combines numerous indicators into multi-dimensional parameters, whereby simultaneous changes of multiple indicators can provide increased confidence of the anomalous behaviour at an earlier point in the failure process. (Further information on AAD can be found in Related documents v.(3)).

(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.

Note: The level of system integrity for VHM provided under this AMC is not sufficient to support the provision of in-flight cockpit VHM alerts.

i. Maintenance Personnel Interface

The person responsible for releasing a rotorcraft into service should be provided with 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 should 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 ground-based system software (specifically developed for VHM processing and COTS) should be developed to EUROCAE ED-109A/RTCA DO-278A Assurance Level 5 (AL5). DO 278 Assurance Level 5 (AL5) provides an acceptable method for acceptance of ground-based systems which include COTS.

VHM applications with hazard severity level Major or higher are addressed by MG15 and not AMC 29.1465.

Note: EUROCAE ED-12C/RTCA DO-178C Level D software for airborne systems and EUROCAE ED-109A/RTCA DO-278A Assurance Level 5 for non-airborne systems can be applied where VHM is utilised in addition to traditional helicopter design provisions. This will not require certification to a level any higher than Minor, based on the required reliability for these VHM applications. Should a design be proposed where greater reliance was placed solely on VHM, this would not be in compliance with the "minimise" target of CS 29.917(b) and CS 29.547(b).

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

Software partitioning is addressed in both EUROCAE ED-12C/RTCA DO-178C and EUROCAE ED-109A/RTCA DO-278A.

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 related to the minimum adequate frequency of data collection determined under AMC 29.1465(e)(2), and in any case no longer than 25 flying hours.

Where subsystem 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.

In the event that a complete data set is not recorded, the data transfer process should be capable of downloading a partial data set to the Ground-Based System. In such a case, the ground station should alert maintenance personnel of a missing maintenance log or that the data set provided is incomplete.

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

The Alert and Alarm generation processing should be designed to achieve a claimed probability of detection that is acceptable to the Agency 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. <u>Performance Validation</u>

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, including information from module strips, component removals, inspections and other investigations which is relevant to the review of VHM system performance.

(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.

<u>Note</u>: A mechanism should 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 its contribution to the overall integrity of the component being monitored.

(2) The criticality categories are defined in FAA 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. Where a VHM application is not necessary for compliance with CS 29.547(b) and/or CS 29.917(b), the failure effect of these functions is considered to be ‘No Safety Effect’ when there have been no changes to the traditional techniques.

(ii) Where a VHM application is identified as a compensating provision in order to comply with CS 29.547(b) and/or CS 29.917(b), then the failure criticality is considered to be ‘Minor’. A proposed design that places greater reliance on VHM would not be deemed compliant with the “minimise” target of CS 29.547(b) and CS 29.917(b).

(iii) When an on-board VHM system is used to replace existing portable test equipment, and is performing an identical function, (though not necessarily utilising the same method of detection), this can be classified as ‘No Safety

Effect', providing that in such cases there will be no reduction in scheduled component inspection, or extension of overhaul or replacement intervals. A level of system integrity related to Minor criticality supports the reduction or elimination of check flights after standard vibration reduction checks and/or adjustments (rotor track and balance, balancing, absorber tuning, etc.).

As this equipment is airborne equipment, it is considered that a quality standard for the software used is necessary. For this reason software to EUROCAE ED-12C/RTCA DO-178C Level D is necessary.

Note: As there should be no effect on safety of the helicopter as a result of utilising the airborne system, it will not be necessary to carry out recurring independent verification means.

(iv) When a validated on-board VHM system is used to replace an existing maintenance task, this can be considered to be minor if the validated detection capability and integrity is better than the maintenance task being replaced. For example, VHM system monitoring of grease packed bearings which results in modification to manual inspection intervals.

For use of EUROCAE ED-12C/RTCA DO-178C level D software, it will be necessary to carry out periodic functional verification of the VHM system for dormant hardware or software failure or following a hardware or software change. An alternative approach to periodic functional verification is the retention of the original inspection at an increased interval. These instructions will need to be specified in the ICA.

Note: In cases (iii) and (iv), it is essential that the reliability and accuracy of the VHM must be equal to or better than that of the process it is replacing. This will require direct or indirect verification such as seeded fault testing (bench) or operational experience in accordance with paragraph (o) of this AMC. Compliance with paragraph (o) may require access to the design data and MSG3 analysis (or equivalent) used during substantiation of the original maintenance task.

q. Technical Publications

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. <u>Minimum Equipment List (MEL) Recommendation</u>

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.

Note: If the VHM data is subject to close monitoring due to an increased likelihood of a developing mechanical problem, the maximum alleviation of 25 hours provided by the MMEL should be reduced or removed.

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

In the absence of any VHM data, reversion to the standard procedures used to ensure component integrity should be made.

u. <u>Controlled Service Introduction</u>

(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 targeted failures or defects 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. Prior to any VHM function replacing an existing maintenance task, it may be necessary to complete a period of in-service operation. 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

(3) CAA Paper 2011/01: Intelligent Management of Helicopter Vibration Health Monitoring Data

http://www.caa.co.uk/docs/33/2011_01RFS.pdf