

Safety Regulation Group

CAP 753

Helicopter Vibration Health Monitoring (VHM)

Guidance Material for Operators Utilising VHM in Rotor and Rotor Drive Systems of Helicopters

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Revision History

Edition 1

June 2006

In the early 1990s Vibration Health Monitoring (VHM) systems were introduced to almost all large helicopters operating in the North Sea in support of the oil and gas industry. UK and Norwegian operators took this action voluntarily. Later, in June 1999, the UK Civil Aviation Authority (CAA), having recognised the potential safety benefit of these systems, issued Additional Airworthiness Directive (AAD) 001-05-99. This made the installation and use of VHM mandatory for UK registered helicopters issued with a Certificate of Airworthiness in the Transport Category (Passenger), and having a maximum approved passenger seating configuration of more than nine. Supporting information, providing general guidance and describing an acceptable means of compliance with AAD 001-05-99, was published in CAP 693 - Acceptable Means of Compliance Helicopter Health Monitoring.

The primary objectives of AAD 001-05-99 and CAP 693 were to define the necessary scope of helicopter VHM and ensure that the VHM systems were operated correctly. CAP 693 does not, however, give detailed guidance for VHM system design in order to achieve effective health monitoring. The purpose of CAP 753 is to provide additional guidance for Operators utilising VHM in rotor and rotor drive systems of helicopters. This covers both VHM system design and operation.

The Operator is advised to use this guidance in satisfying himself that the VHM system meets acceptable standards and continues to meet these standards in operation. Based upon the Operator's assessment the CAA will seek a compliance statement from the Operator as evidence that the VHM meets the objective of the Air Navigation Order (ANO). Systems previously accepted under the CAA AAD or other provisions will not need any additional statements of compliance, unless they are modified or operated in a different manner.

Amendment 2012/01 to Edition 1

August 2012

Updated in response to an AAIB recommendation to include a process where operators receive detailed component condition reports in a timely manner to allow effective feedback as to the operation of the Vibration Health Monitoring system.

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Glossary

AAD	Additional Airworthiness Directive
AC	Advisory Circular
ANO	Air Navigation Order
BCAR	British Civil Airworthiness Requirements
CAP	Civil Aviation Publication
CAA	Civil Aviation Authority
CBIT	Continuous Built In Test
COTS	Commercial Off The Shelf
CS	Certification Standard
CSI	Controlled Service Introduction
EASA	European Aviation Safety Agency
EMC	Electromagnetic Compatability
FAA	Federal Aviation Administration
FAR	Federal Aviation Requirements
GG	Gas Generator
IBIT	Initiated Built In Test
ICA	Instructions for Continued Airworthiness
JAR	Joint Aviation Requirements
LRU	Line Rectification Unit
MEL	Minimum Equipment List
PT	Power Turbine
SO(n)	Shaft Order (n-1 harmonic)
STC	Supplemental Type Certificate
TCH	Type Certificate Holder
VHM	Vibration Health Monitoring

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Section 1 Introduction

1 Background

- 1.1 VHM has been used on the majority of UK large public transport rotorcraft, operating in the North Sea, since the early 1990s. The purpose of embodying VHM at this time was to reduce the likelihood of rotor, rotor drive system and engine failures that could prevent continued safe flight and safe landing. Since this time the accident rate attributable to such failures for this category of helicopter has reduced significantly, and the Civil Aviation Authority (CAA) believes that VHM played and continues to play a major role in this achievement.
- 1.2 In order to ensure that acceptable minimum standards were achieved and maintained, regarding the use and operation of VHM, the CAA issued AAD 001-05-99 which became effective on 1 June 1999. This made the installation and use of VHM mandatory for UK registered helicopters, issued with a Certificate of Airworthiness in the Transport Category (Passenger), and having a maximum approved seating configuration of more than nine.
- 1.3 In September 2003 the European Aviation Safety Agency (EASA) was formed. EASA reviewed the need for helicopter VHM requirements and the appropriate applicability of such requirements across Europe. The conclusion from this review was that National Aviation Authorities should introduce national operational VHM requirements for demanding operations, such as that of the North Sea, where they considered this to be necessary.
- 1.4 Mindful of the likelihood of future VHM operational regulations and recognising the need for updated requirements for VHM design, the UK CAA decided that CAP 693 needed to be replaced with a new document addressing these minimum standard issues. Accordingly this CAP 753 provides additional guidance for Operators utilising VHM in rotor and rotor drive systems of helicopters; this covers both VHM system design and operation.
- 1.5 It should be noted that the Helicopter Health Monitoring Advisory Group (HHMAG) have drafted a "VHM Specification" which is expected to be issued in the near future. This specification defines a design standard for VHM which is considered by the members of the HHMAG, a cross-industry body, to be a suitable benchmark minimum standard for helicopter VHM. This CAP reflects that guidance material produced by the HHMAG.

2 Terminology

Alarm: An alert that, following additional processing or investigation, has resulted in a maintenance action being required.

Alert: A warning produced by the VHM system that requires further processing or investigation to determine if a maintenance action is required.

Applicant: A person or organisation applying for approval of a VHM system in accordance with the ANO. For the purpose of this document Applicants will simply be referred to as the Operator and the Design Organisation.

Operator: This will be a UK AOC or PAOC helicopter Operator.

Design Organisation: This will be a Design Organisation who seeks the Operator's approval of installation of a VHM system and/or evaluation of its performance in accordance with Section 2, Sub-sections A, B, C, D and E of this CAP.

Close Monitoring: This may be required when a VHM component or indicator requires focussed and increased monitoring, e.g. in the event that an indicator value exceeds a "maintenance action" threshold or shows other signs which warrant increased attention. The close monitoring procedure typically reduces the maximum period between successive indicator downloads to no more than 10 hours. Note that close monitoring is not intended to be a long-term solution, but a period of heightened monitoring, diagnostic support and assessment to ensure that determinations of serviceability are made using all the data available.

Commercial Off-the-Shelf (COTS): This term defines equipment hardware and software that is not qualified to aircraft standards.

Controlled Service Introduction (CSI): A period in-service where capabilities and functions that could not yet be verified prior to entry into service (including support functions) are evaluated.

Coverage: The percentage of components in the engines, rotor and rotor drive systems that have VHM Indicators to provide advance warning of incipient failures that could prevent continued safe flight and landing.

Critical Component: There are a number of definitions of "critical" in different CS requirements. For the purpose of this CAP it is defined as "any component, individual failure of which would prevent continued safe flight and landing".

Data Download Process: The process for downloading VHM data from the aircraft to the Ground Station. Typically, but not necessarily, a memory card, or portable device shall be specified which allows the required VHM data to be downloaded for analysis after every flight.

Data Management: Management of VHM data addresses integrity of data transfer from the helicopter to Ground Station, between Ground Stations (possibly at different bases), database integrity, data assessment and recovery methods.

Design Organisation: A European organisation which is approved to Part 21 Subpart J by EASA, or a US organisation approved to the equivalent FAR regulation by the FAA.

False Alarm: Alert that after further processing or investigation has resulted in the unnecessary removal of a component or nugatory maintenance action.

Ground Station: A Ground Station is the means of access to VHM data, including Alerts, for immediate post-flight fault diagnosis by the responsible maintenance staff. It should also be capable of accessing other historical and relevant health monitoring data from other aircraft in the fleet, for the purpose of comparison, to assist in the analysis of exceedences and fault diagnosis. A Ground Station may have the ability to link interactively to Ground Stations at other line stations, the Operator's main base and third party engineering support over an Internet or Intranet connection or by a direct dial-up modem. While initial VHM systems used a specific computer as a Ground Station a 'virtual' Ground Station using means of access to a central server may also be acceptable. However, it would need to be substantiated that integrity of data could be maintained to an appropriate standard.

Integrity Level: The level of accuracy and reliability that the VHM system should achieve. The integrity level necessary for each VHM Application is dependent on the criticality of the functions being performed.

Line Replaceable Units: Elements of the system that can be readily replaced during line maintenance.

Sensors: The hardware that measures vibration. Sensors need to provide a reliable signal of appropriate and defined performance in a typical helicopter operating environment. Sensors may have CBIT/IBIT capabilities sufficient to determine the correct functioning of the component.

Signal Sampling Rate: The frequency at which the signal is recorded. This should be sufficient for the required bandwidth and also to address anti-aliasing.

Vibration Health Monitoring (VHM): Use of data generated by processing vibration signals to detect incipient failure or degradation of mechanical integrity.

VHM Application: The use of a VHM Indicator for a specific component failure, for example, shaft order one (SO1) vibration monitoring of tail rotor drive shaft balance.

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 particular component failure modes.

Primary VHM Indicators will be those which can be monitored directly for the purposes of generating Alerts. Secondary VHM Indicators are those which can be used in the diagnostic process after an Alert is generated but themselves are unsuitable for direct Alert generation.

A VHM Indicator may itself be further processed with other VHM Indicators to give a further indicator.

NOTE: Indications of VHM data abnormality may also be used in the future, if and when this technology becomes sufficiently mature.

VHM Indicator Generation Rate: The rate at which each VHM Indicator value is acquired. This is usually a function of the data recording/processing speed, the number of VHM Indicators being recorded and the quantity of data required for each sample.

VHM System: Typically comprises vibration sensors and associated wiring, data acquisition and processing hardware, the means of downloading data from the helicopter, the Ground Station and all associated instructions for operation of the system.

Visibility: The ability of sensors to acquire appropriate data sufficient for a particular VHM Indicator to be applied to a particular component.

3 Guidance to Operators on how to use this CAP

- 3.1 When required by the ANO, the Operator should install and operate a VHM system. The Operator must also be satisfied and make statements of compliance to show that the system will be operated in accordance with all necessary ICA and mandatory requirements. Following entry into service it may be necessary for the VHM system to undergo a period of further modification and refinement (Controlled Service Introduction) followed by final verification of capability. Once this capability is verified, there will remain a need for suitable in-service support.
- 3.2 There are five aspects addressed in this CAP which are described below. It is important to note that the Operator should address in his compliance assessment/statement Section 2, Sub-sections A, B,C, D and E and Section 3.

3.3 These Sections are briefly summarised below:

Section 2 addresses VHM system design issues where the Design Organisation should show compliance to the Operator.

Sub-section A addresses Installation Approval. In Europe, Canada and USA the method of approval for installation of each VHM system type, for each helicopter type, will either be an STC, a major change or modification (granted to the TCH only), or granted as part of the helicopter Type Certification.

Sub-sections B and C address VHM system capability. The objective of approval in accordance with these Sub-sections is for the Design Organisation to demonstrate to the Operator that the VHM system is capable of providing the necessary rotor and rotor drive system VHM to minimise the risk of incipient failures. This Operator's acceptance will be for use on specified helicopter types and will not be a generic approval across all helicopter types. The Design Organisation making application for approval or assessment of the VHM system, in accordance with Sub-sections B and C, will typically be the helicopter TCH or the installation STC holder/applicant, and in all cases should have an appropriate design approval granted by their local airworthiness authority.

Sub-section D addresses verification of VHM system performance post initial entry into service. In order to validate the design and other assumptions associated with the VHM system a CSI is normally required. Initial compliance with Sub-sections B and C may therefore be satisfied but compliance with this CAP remains conditional on the CSI closure being accepted at a future date. The objectives of the CSI will be agreed with the Design Organisation prior to initial approval of the system. In some cases a CSI may not be required if representative and adequate data (evidence) is presented.

Sub-section E addresses the in-service support of a VHM system expected by the Operator for the Design Organisation, an activity that will continue beyond the CSI until withdrawn from service.

Section 3 addresses operational issues where the Operator should show compliance.

This addresses the need for procedures for operating and maintaining the VHM system. The procedures must be consistent with the Operator's scope of work and intended VHM system/aircraft combination.

NOTE: VHM systems that have significant service experience may be able to utilise that experience to demonstrate compliance (to the Operator), or equivalent safety, with most of the requirements of Section 2, Sub-sections B, C and D. Specifically, in the UK, VHM systems that have been accepted by the UK CAA as suitable for compliance with AAD 001-05-99 may be accepted as compliant (to the Operator) with this CAP (but this will still need verification on a case by case basis) with respect to Section 2, Sub-sections B, C and D. However, it will still be necessary to continue to require development of system operating performance and VHM Indicators, (including threshold settings) in accordance with Section 2, Sub-section B, paragraph 8 "Alert Generation and Management", and paragraph 10, "Instructions for Continued Airworthiness". Sub-section E will need to be shown for all VHM systems.

Section 2 Guidance to Operators with VHMs for Design Aspects

Sub-section A VHM System Design

1 VHM Installation

1.1 Airborne equipment and the associated installation qualification procedures are the same as for other airborne equipment and consequently should comply with EASA CS/FAR/JAR 27 and 29 and BCAR 29, as applicable to the specific helicopter type. For VHM systems designed by the TCH, compliance with the necessary installation requirements of EASA CS/FAR/JAR/BCAR, as applicable to the specific helicopter type, should be demonstrated and be approved by the certificating Authority of the TCH. The installation qualification and the equipment qualification may be considered as two separate activities. Signal independence, irrespective of method of implementation, should exist to the extent that acquisition of VHM signals should not compromise the level of safety or reliability of functions provided by other equipment as a result of signal sharing.

1.2 Equipment not approved by other methods must be approved as part of the installation and must consider overall system requirements.

1.3 Software

RTCA/DO-178/EUROCAE ED-12 should be used for the software development standard. The software level appropriate for VHM Applications providing monitoring for maintenance personnel only, i.e. functions that do not change maintenance practices or flight operations, the failure of which could result in a major or severe/major/hazardous event, would be RTCA/DO-178B Level D or higher. The failure of VHM functions which could result in catastrophic effect are not addressed in this CAP; Operators seeking such approval should contact their regulator.

NOTE: For Applications that also seek maintenance credit (see AC 29 MG15), the level of system integrity required may be higher.

1.4 Installation Specific Considerations

The overall installation considerations should include, as a minimum, supply of electrical power, environmental conditions, system non-interference, and human factors if flight operations are affected.

Equipment qualification should consider environmental qualification (RTCA/DO-160/EUROCAE ED 14) including high intensity radiated fields (HIRF) and lightning.

1.5 Supply of Electrical Power

An adequate source of electrical power for the VHM system must be provided. The reliability of the power source must be commensurate with the required equipment qualification level. There should be no unacceptable reduction in the level of safety or reliability for other equipment as a result of acquiring power for the VHM system.

1.6 Electromagnetic Compatibility

Electromagnetic compatibility (EMC) must be addressed. Complex systems may require an EMC test plan, which includes a matrix of aggressors versus victims. The end result should be to assure that the VHM system does not interfere with or is not affected by any other installed equipment.

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Sub-section B VHM System Capability

1 General

- 1.1 The process should begin with a declaration of the intended capability of the VHM system. This should detail all of the VHM Applications provided by the system and declare the components/failures which are intended to be monitored. The intended performance for each VHM Application should also be declared. Performance criteria must be applied to the “end-to-end” process (from sensor to alert through to ICA) and should be consistent with the VHM Application’s intended use.
- 1.2 The VHM system should measure vibration characteristics of rotating critical components during flight utilising suitable vibration sensors and recording equipment. The frequency and flight phases of this data measurement must be declared. The vibration measurements being processed, in order to generate VHM Indicators, should normally relate to specific component failure modes or be capable of detecting changes that affect safe operation. This data analysis can be performed in flight or on the ground, providing the requirements of Section 2, Sub-section B, paragraph 4 are complied with. VHM systems traditionally utilise a Ground Station to process VHM data, display results to maintenance personnel and store the helicopter’s recent VHM history. A reliable and robust means of transferring data from the helicopter to the Ground Station is also required. In order to manage the processed data appropriately and focus upon significant issues, an alerting system needs to be established. Due to the volume of data and the limited time available for review, this is normally automatic. Accordingly, reliable alert generation processes need to be developed to advise maintenance personnel of the need to review data and determine what maintenance intervention is required. Acquisition will normally be automatic when entering a predefined flight regime, although pilot initiated acquisition is also acceptable.

2 Scope of Monitoring Capability

- 2.1 When referring to VHM, it is the monitoring of vibration data and characteristics that can provide advance information relating to the development of incipient failures in the engine(s) rotor drive systems. The intended monitoring capability of the VHM system is defined in Table 1 below.

Table 1 VHM System Monitoring Capability

Assembly	Component Type	VHM Indicators for Measurement and Recording
Engine	Power Turbine Gas Generator	Vibration spectrum during run-up. SO1, SO2 of GG and PT.
Engine to main gearbox input drive shafts	Shafts	Imbalance, misalignment – monitored from engine and gearbox.
Main gearbox	Gears, Shafts and Bearings	SO1, SO2 of shafts, gear meshing frequencies, gear tooth indicators, bearing wear indicators, modulation of web tone epicyclic gear indicators.

Table 1 VHM System Monitoring Capability (Continued)

Assembly	Component Type	VHM Indicators for Measurement and Recording
Accessory gearbox	Gears, Shafts and Bearings	SO1, SO2 of shafts, gear meshing frequencies, gear tooth indicators, bearing wear indicators.
Tail rotor drive shaft	Shafts and Hanger Bearings	Imbalance, misalignment, bearing wear.
Intermediate and tail gearboxes	Gears, Shafts and Bearings	SO1, SO2 of shafts, gear meshing frequencies, gear tooth indicator, bearing wear.
Oil cooler/NOTAR style circulation control fan	Oil Cooler/Circulation Control, Blower and Drive Shaft	SO1, SO2, bearing wear.
Main rotor		Blade track and balance, swashplate bearings wear indicators.
Tail rotor/Fenestron		Blade track and balance, swashplate bearings wear indicators.

- NOTE:**
- Gear tooth indicator = indicator capable of detecting gear tooth damage and tooth bending fatigue cracks.
 - Modulation of web tone = indicator capable of detecting gear web fatigue cracks and loss of gear support.
 - Epicyclic gear indicators = indicator capable of monitor planet gear load sharing and detecting planet carrier damage.
 - Recording of "raw data" is also of significant value.

2.2 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, will need to be substantiated and recorded in compliance statements. It is acknowledged that the above provides a rather prescriptive scope for monitoring engine, rotor and rotor drive system components. If alternative methods are proposed, which can be shown to be as effective and reliable as those prescribed to the satisfaction of the CAA, then these can also be accepted for the Operator's compliance with VHM as required by the ANO.

3 Sensor Capability, Location and Installation

3.1 Sensors need to provide a signal of appropriate performance capable of operating reliably in a typical helicopter environment. CBIT/IBIT capability may be desirable to determine the correct functioning of the sensor.

3.2 The location of sensors and the method of installation have a significant effect on monitoring performance. The design selected should be investigated to confirm 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 from monitoring.

3.3 Maintenance instructions should ensure that correct function and any calibration of sensors, and their installation, is adequately controlled.

4 Signal Acquisition and Processing

- 4.1 It is likely that processed VHM data will be sensitive to the flight regime of the helicopter. For this reason it may be desirable to focus data acquisition to particular operating conditions or phases of flight. Consideration should be given to the likely operation of helicopters that may potentially utilise the VHM system and the practicality of acquiring adequate data from each flight to permit the alert and alarm processing to perform to the required standard and both intra flight and inter flight trending to be performed. 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.
- 4.2 Some fatigue failures may only be detectable a few hours prior to failure. In general, components subject to higher rotational speed are likely to fail more quickly. Accordingly, it may be necessary to reduce the period between acquisitions of consecutive VHM data points for indicators of such failure modes.
- 4.3 The Signal Sampling Rate should allow recording to be carried out at a frequency sufficient for the required bandwidth and for anti-aliasing. The Acquisition Rate should allow the data necessary for processing each indicator value to be acquired, preferably at least once per flight. Should this not be possible, a determination should be made to establish which indicators should be recorded first in the monitoring cycle. The system should be designed such that partial data sets can still be processed trigger alerts and be downloaded to the Ground Station.
- 4.4 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 will need to be reviewed and be shown to be effective.

5 Pilot Interface (where applicable)

The pilot's role in the VHM process may involve entering specific data regarding the flight and the weight of the helicopter, requesting that VHM data is recorded during any in-flight events and assisting in the Data Download Process. The VHM system may also be integrated with equipment used for performing engine power assurance checks. This activity is usually performed via a control panel located on the flight deck. Pilot interaction with the system should be specified in the Flight Manual and any additional workload resulting from operating the VHM system should be kept to a minimum. The pilot should not be responsible for initiating routine VHM data acquisitions.

6 Download and Storage Capability

In the event of a Ground Station failure, either the airborne system or the devices used for a data download should have the capability of storing data for at least as long as the period of operation permitted by the MEL without a successful download. For airborne systems that store data on removable memory cards this will not be an issue. The system should ideally be capable of allowing data to be downloaded during Rotors Running Turnarounds. The download process should be capable of

downloading partial data sets to the Ground Station if for any reason a full data acquisition has not occurred. The means of transfer include flash RAM cards which are taken from the helicopter by the pilot and downloaded at a remote Ground Station, or connection of the airborne system to a portable computer, however, the vulnerability of the latter to the likely environmental operating conditions and accidental damage must be considered.

7 Validation of Failure Detection Performance

- 7.1 There are a number of different approaches that can be used to validate failure detection performance. Some components, such as external drive shafts, can be straightforward to monitor and for these components it should be relatively simple to obtain a signal with a good signal-to-noise ratio. Incipient failures are likely to give rise to shaft speed frequency vibration and/or harmonics and in such cases the demonstration of unusual/abnormal conditions is relatively straightforward and should normally be demonstrated by simple test. Thresholds can either be learnt or fixed. Experience of misalignment and out of balance shafts/couplings can be verified either in service, during the CSI period, or by rig tests.
- 7.2 Vibration monitoring of internal components is less direct, reducing the signal-to-noise ratio and thus making the process more sensitive to other influences such as operation, component variability (gearbox casing vibration characteristics) and maintenance. These component failures are also likely to require more complex analysis of the VHM data.
- 7.3 Seeded defect testing should normally be the basis to demonstrate detection capability for a representative range of likely defects. This testing should cover the full range or extremes of anticipated service cycles. Effort should be made to show that the processed vibration signal-to-noise ratio is acceptable and that it is capable of discriminating the features required to identify the potential incipient defects being monitored and that the methodology of setting thresholds is optimised. It is expected that thresholds will continue to be developed throughout the CSI period.
- 7.4 The Design Organisation will be expected to have an experimental and/or in-service experience base to demonstrate capability.

8 Alert Generation and Management

- 8.1 Thresholds may take the form of absolute vibration levels, levels set based on fleet experience or levels learnt for an individual helicopter. VHM systems, may also use the concept of primary and secondary indicators, where thresholds are only applied to the primary indicators using secondary indicators to support primary indications. Alerts can be triggered at different threshold sensitivity levels, providing either advisory information to maintenance personnel to allow preliminary investigation of a potential problem, or an alert requiring that further flight should be avoided until specific maintenance action has been taken to return the indicator value to an acceptable level. The latter case would only be expected for rotors and external shafts where existing TCH vibration limits exist. Current VHM systems generate indicator values from vibration recordings taken from different positions on the rotor drive system. These indicators will highlight different pre-failure conditions such as gear tooth damage, shaft imbalance, shaft misalignment etc. Each indicator will have one or more Alert thresholds (such as 'high' or 'low' or dependent on different flight regimes) which, when the indicator value is higher, will result in a message being provided to maintenance staff for investigation to determine the maintenance action required.

- 8.2 All primary VHM Indicators should be clearly defined and have recommended thresholds set by the Design Organisation. Changes to threshold values should be agreed by the Design Organisation and be reviewed during the CSI phase and possibly post CSI, the CAA should be advised of any data that suggests the VHM is not achieving the desired safety benefits.
- 8.3 A review of VHM performance was carried out in the mid 1990s. This concluded that these systems were capable of successfully detecting approximately 70% of the failure modes which occurred on components that the system was designed to monitor. This is considered to be a minimum for any VHM system to be compliant with this CAP post CSI. In order to prevent False Alerts from becoming an unacceptable maintenance burden, a rate of Alert resulting in maintenance action on the helicopter of no worse than 1 per 50 flight hours is considered to be a reasonable post CSI target. To prevent False Alerts from resulting in unacceptable cost, a target of no more than 5% of all Alerts becoming Alarms would be considered reasonable at the end of a CSI (with subsequent improvements expected).
- NOTE:** Minor inspections and VHM system LRU changes required as part of the diagnostic process in order to eliminate False Alerts are not considered to be nugatory maintenance actions.
- 8.4 Where the helicopter TCH has proven standards published in helicopter ICA for Alert and Alarm processing then these should be adopted in addition to the VHM Design Applicant's own techniques.
- 8.5 Periodic reviews should be held to verify the effectiveness of indicator processing, detection limits and consequent Alert rates.

9 Data Management

The Ground Station should be capable of displaying the status of VHM data after each download, identifying any Primary VHM Indicators that are higher than their established thresholds. The recent history of both Primary and Secondary VHM Indicator data, along with threshold data should be made readily available to maintenance personnel and should be provided in a user friendly graphical form which will also allow comparison with data for past Alerts and False Alarms contained in the ICA or elsewhere. The ability to trend data and facilitate comparison with data from other aircraft, fleet average thresholds or other health indicators is also recommended.

NOTE: It is a maintenance responsibility to release an aircraft for service and thus maintenance personnel must have direct access to this data.

10 Instructions for Continued Airworthiness and Associated Documentation to Support Operation

- 10.1 The Design Organisation should provide ICA developed in accordance with FAR/CS 29 to the satisfaction of the Operator. This ICA documentation will provide instructions for installation, maintenance, operation and minimum equipment requirements for the VHM system. The Design Applicant should provide this documentation prior to approval of the system. The ICA should also address VHM system integration with the aircraft and cover both airborne and ground-based systems as appropriate. The ICA for a typical VHM system will need to include as a minimum:
- a) Maintenance Manual instructions defining the diagnostic action necessary in the event of all Alerts.

- b) All routine maintenance to be carried out on the VHM system itself, including any verification of sensor performance.
 - c) Installation Manual for retrofit VHM systems addressing all aspects of VHM system integration with the aircraft.
 - d) Operating Instructions for maintenance personnel operation of the VHM system.
 - e) Flight Manual Instructions for pilot operation of the VHM system.
- 10.2 Requirements of the CSI may need to be reflected in ICA documentation, as defined in Sub-section D, where applicable.

11 Training

Operation and maintenance of the VHM system will require training. As part of the Operator's compliance substantiation/finding for use of a VHM system it will be necessary to show that suitable training courses will be made available for all levels of maintenance staff and, where applicable, flight crew.

12 Minimum Equipment List (MEL) Recommendation

The MEL should address both the Airborne Element of the VHM system and also any necessary components of the Ground Station and data transfer system. This should limit the period for the unsuccessful download and assessment of any primary VHM Indicator, used for monitoring the engine and rotor drive system components, to a suitable period which in any case should not exceed 25 hours. Diagnostic procedures will require "Close Monitoring" of individual VHM Indicators in certain situations. "Close Monitoring" will result in a reduction in this time period of not more than 10 hours and procedures for enhanced review of VHM data by maintenance personnel within the ICA.

Sub-section C VHM Ground-Based System Capability

- 1 Ground-based equipment is typically used to process and display the data collected by airborne means. This processed data will ultimately be used to make decisions involving maintenance action on the helicopter. If the ground-based equipment performs an essential part of the health monitoring process (including Alert generation and presentation), then its integrity and accuracy requirements will be higher than if it is simply used to present and handle data. If all essential tasks are performed by the airborne system, such that the ground-based system is used only for data handling and presentation, then its integrity and accuracy requirements may be lower than that of the airborne system providing that system performance and integrity can be demonstrated not to be solely dependent on the data handling and display system.

The determination of compliance with the integrity requirements for ground-based equipment can be complicated when the equipment, for the most part, may be commercial and is not designed specifically for the VHM system. However, it is acceptable to utilise COTS hardware and software for this function and some guidance is provided below.

- 2 The determination of compliance to the integrity requirements for COTS is based on equivalence, which can be subjective. COTS service history alone may not be sufficient to comply with the requirements herein. Any ground-based processing equipment, which consists of commercial hardware and software, must have satisfactory service history and an independent means of verifying the results of the processing. This independent verification means may be discontinued with the certificating Authority's agreement, possibly requiring modification of the original VHM system approval, after the integrity of the processed data has been established. This verification process may be carried out during the CSI period.

NOTE: The suggested processes contained in this sub-section for acceptance of a ground-based system that possibly includes COTS hardware and software, is limited to ground-based VHM equipment only.

- 3 Independent verification means may consist of one of many methods and may only be used for approval of the ground-based system. They may parallel all or any portion of the process that includes COTS equipment processing. Some acceptable methods may include the following:
 - a) Physical inspection(s).
 - b) Redundant processing by a second equipment set incorporating dissimilar COTS processor and software.
 - c) A combination of physical inspection(s) and independent dissimilar processing.
 - d) Any other independent means of verifying the accuracy/integrity of the equipment, including software, by a satisfactory comparison to the VHM system processed data.
- 4 The applicable methods for independent verification are independent of the VHM system's integrity level, as they relate to COTS hardware and software. However, the compliance requirements will vary. The processes described in this section should be applied if the criticality of functions performed by the VHM system is considered to be Hazardous/Severe-Major or Major. Minor criticality category level will also require qualification by this process, except that independent verification can be performed after the CSI period, provided that an approved plan is submitted for this activity. Other VHM systems that do not employ COTS should use standard engineering practices to

satisfy the integrity level considerations. Modification of the approved system, including both equipment and software, should be qualified on a case-by-case basis that is dependent on the effect on the integrity and functionality of the system. Data integrity software can be provided to ensure complete data transfer, with reversionary modes to recover lost or corrupted data.

5 Ground-Based Equipment Hardware

This hardware may consist of data processing, display, and possibly printing equipment or other accessories. The hardware must be compatible with the intended VHM Application and software. An independent means of verification will be required in the case of the use of COTS hardware. VHM Applications which use COTS hardware, failure of which would result in Hazardous/Severe-Major or Major consequences, should be part of the system for which independent verification is necessary. Hardware whose failure would result in only minor consequences, need not be independently verified.

6 Ground-Based Equipment Software

Most systems will employ two types of software. One type is the operational software and the other is the VHM specific software. The operational software may be COTS.

- a) **COTS:** This type of software can only be accepted by subjective considerations, such as service history, independent verification means, and design of the system to limit access to the operational COTS software to make changes.
- b) **VHM Specific Software:** This software should be developed to the integrity level required by the system criticality assessment using the applicable version of RTCA DO-178/EUROCAE ED-12 as the standard. This system determined level should be a result of the end-to-end criticality assessment and, in general, the same as the airborne software.

7 Data Communications and Virus Protection

Network applications, modem interfaces, and other system sharing and transmission features may be utilised for integrity levels associated with Major and Minor criticality categories, provided that the independent verification means covers the use of these features.

When using VHM data as part of a networked system, controls should be implemented to detect and prevent accidental or malicious corruption of code and data. If the internet is used as the data transmission means between networks, particular consideration should also be given to the protection (which may include encryption) of sensitive data.

Sub-section D Development and Verification of VHM System Performance Post Entry into Service

1 Controlled Service Introduction

- 1.1 For some VHM Applications, validation may be possible during the development period prior to approval. This will usually only be possible if there is extensive prior service experience in similar applications however, most VHM Applications will need to continue development during a CSI prior to validation of the Application. This activity should be detailed in a CSI plan to be agreed prior to initial approval, detailing the Applications being developed and the criteria for the successful completion of the CSI. Such criteria may include duration of service experience, verification of specific categories of VHM Application against in-service failures, False Alarm Rate, evolution of thresholds, demonstration of specific support processes, system hardware reliability, download success rates, Ground Station reliability, system usability (including Ground Station man-machine interface), system maintainability, ICA usability, effectiveness of diagnostic support, effectiveness of training and effectiveness of any software upgrades. A CSI may also be required by the certificating Authority, in which case it would need the certificating Authority's agreement that the targets of the CSI have been achieved prior to their agreement for closure of the CSI.
- 1.2 One concern is the possibility for False Alerts requiring nugatory maintenance action to arise at an unacceptably high rate. A primary function of the CSI is to monitor the rate of False Alert requiring nugatory maintenance action and trigger corrective action so as to ensure this rate becomes acceptable. However, this concern should not drive thresholds to levels that could result in a failure to detect incipient failures.
- 1.3 During the CSI, meetings should take place to review service experience against the CSI criteria. These should involve the Design Organisation, customer and the Operators of the VHM system. At these meetings, the Design Organisation should present a review of system performance including Alert/False Alarm Rate, success and failures to detect component abnormalities, reliability and usability of the system. The Operators will also be requested to present their experience of the system. It is expected that the Authority will be advised as to the outcome of these meetings. Once the targets specified in the CSI report have been met the CSI phase can formally be closed by the customer with the agreement of the Authority. If the CSI plan includes multiple VHM applications, a phased introduction of approval is possible.
- 1.4 Thresholds must be set for all primary VHM Indicators at the commencement of the CSI, and means shall be in place to ensure these evolve in a timely manner.

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Sub-section E In-Service Support

1 Periodic review meetings should be held to verify the effectiveness of indicator processing, detection limits and consequent Alert rates.

2 It may be necessary for the Operator to be provided with additional technical diagnostic support in order to advise the appropriate action in the event of unexpected data, where specific actions are not included in the ICA. If the VHM system is supplied by the helicopter TCH, then they should establish links with the Operator in order to provide such support. If the VHM system is not supplied by the TCH, then the Design Organisation should provide technical support and/or establish a link with the helicopter TCH. This support should also cover:

- Review of detection types and setting;
- Review development/improvement of diagnostic work cards;
- Training;
- Help desk for help in VHM data interpretation and diagnosis.

ICA should be maintained and updated in a timely manner so as to ensure the continued effective operation of the system.

3 In order to avoid obsolescence issues, the Design Organisation must ensure that when COTS hardware or software solutions are employed (particularly for data transfer or Ground Station functions) that the range of permitted COTS hardware and software evolves during the life of the VHM system.

4 In order to maximise the effectiveness of the VHM Condition Indicators and associated Alert levels the operator must ensure the design approval holder is notified of all components removed as a consequence of an in-service failure associated to VHM alerts, indications, etc. and that this notification includes details of the removed item, any associated VHM data and which repair/overhaul agency the unit has been sent to for repair.

The design approval holder should identify any causal factors associated with the in-service defect, and confirm this against assumptions and controls of the VHM system. The results of investigations into such events should be communicated to the Operator.

Where the design approval holder is not the Type Certificate Holder (TCH), this information shall also be passed to the TCH.

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Section 3 VHM System Operation

1 General

The helicopter Operator will initially need to source a VHM system, which they have accepted in line with the guidance material of Section 2, sub-sections A, B and C of this CAP. If the Operator wishes to utilise a system that has not already been approved for the helicopter type proposed then application should be made by a suitable Design Organisation as described in Section 2. The Operator will also need to show that the operational issues identified in this Section are adequately controlled.

2 VHM Support Arrangements

The Operator must ensure that clear working arrangements are in place with the Design Organisation, which holds the approval of the VHM system, to ensure the necessary liaison for the continued in-service support of the VHM system. Agreement with the Design Organisation should be established to ensure participation in CSI and that continued airworthiness meetings will take place between the relevant parties as necessary.

3 Training

The Operator should determine which staff require VHM training, determine appropriate syllabi for VHM users, supervisors and managers and incorporate this into the organisation's initial and continuation training programmes as appropriate. This training can be provided by the Operator or another organisation.

4 Operational Procedures

The Operator should ensure that their Quality System (necessary for existing JAR-OPS 3, Part 145 and Part M requirements) covers the following VHM issues:

- Duties and responsibilities of VHM personnel;
- Specific VHM process procedures, including download policy, post flight actions, diagnostic consultation procedures and close monitoring procedures, event reporting;
- Supervision of subcontractors involved in VHM activity if appropriate;
- Threshold setting and adjustment (as appropriate);
- Minimum Equipment List;
- Training Requirements;
- Feedback to Design approval holders/TCH of in-service drive train component failure details including the removed item, any associated VHM data indicate which repair/overhaul agency the unit has been sent to for repair.

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Appendix A References

- [1] CS-29 Large Rotorcraft
- [2] AC 29 MG15 "Airworthiness Approval of Rotorcraft Health Usage Monitoring Systems (HUMS)"
- [3] AC 29 MG13, "Systems Certification Considerations"
- [4] JAA/INT/POL/27 and 29/1, Issue 2. Protection from the Effects of HIRF
- [5] EUROCAE ED-12B, RTCA DO-178B Software Considerations in Airborne Systems and Equipment Certification
- [6] EUROCAE ED-14E, RTCA DO-160C Environmental Conditions and Test Procedures for Airborne Equipment
- [7] EUROCAE ED-94B, RTCA DO-248B Final Annual Report for clarification of DO-178B/ED-12B

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