

HUMS

HEALTH AND
USAGE
MONITORING
SYSTEMS



Courtesy of American Eurocopter

Health and Usage Monitoring Systems Toolkit US JHSIT



INTERNATIONAL HELICOPTER SAFETY TEAM

Health and Usage Monitoring Systems Toolkit

US Joint Helicopter Safety Implementation Team
HFDM Working Group

International Helicopter Safety Team

International Helicopter Safety Team
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About

About This Document

The *Health and Usage Monitoring Systems (HUMS) Toolkit* is designed to provide a summary of existing HUMS programs and to serve as a step-by-step guide for helicopter operators considering or currently implementing a HUMS or condition-based maintenance (CBM) program. It is also intended to address some unique challenges specific to helicopter operations.

HUMS programs, as well as CBM programs, are a subset of wider reaching system health management (SHM) programs. For aircraft, SHM programs enable:

- Efficient fault detection, isolation, and recovery
- Prediction of impending failures or functional degradation
- Increased reliability and availability of aircraft
- Enhanced situational awareness for crews
- Condition-based and just-in-time maintenance practices
- Efficient ground processing and increased asset availability

Most importantly, HUMS and CBM programs enhance safety. As a byproduct, these programs improve prognostics for maintenance and engineering personnel, and increase aircraft reliability, productivity, and asset availability, which could ultimately lead to improved economics.

It is our hope that you find this toolkit a valuable resource as you work toward implementing a HUMS program in your organization. This edition includes case studies, industry best practices, and detailed information of management decisions. Additional HUMS guidance and resources are included as appendices or attachments to this document.

We encourage you to seek additional information from others who have implemented HUMS programs in their organizations; there is no better resource available.

About the IHST

The International Helicopter Safety Team (IHST) is a cooperative government-industry team that was formed in 2006 with the goal to reduce the worldwide helicopter accident rate by 80% by the year 2016. The IHST is comprised of an executive committee and the following teams (multi-regional):

- Joint Helicopter Safety Analysis Team (JHSAT) - Analyzes aviation accidents, identifies problems, and recommends solutions
- Joint Helicopter Safety Implementation Team (JHSIT) - Strategically addresses and implements JHSAT recommendations

The US JHSAT analyzed a group of US helicopter accidents and recommended the following related to information recorders and HUMS programs:

- Information recorders can be utilized reactively (after the accident) and proactively (to monitor precursor events and data needed for an SMS). Information recording devices will allow accident investigators to obtain essential information about the circumstances of an accident to allow greater understanding of accident causes and potential for safety improvements. Proactive use of recorders allows the operator to provide individual aircraft flight operations oversight and to identify and correct poor habits and [standard operating procedures (SOP)] non-compliances before they escalate into an accident. (Recommendation # IN2)
- Install [Health Usage Monitoring Systems] HUMS to detect needed maintenance interventions, and utilize [Helicopter Flight Data Monitoring programs (HFDM)] to evaluate flight operations and address flight crew habits that may contribute to an accident. (Recommendation # SE1)

Members of the US JHSIT evaluated these recommendations and researched existing FDM and HUMS programs in helicopter operations. They also researched existing guidance material on HUMS, which they found to be very limited. Based on the success of the previous two editions of the IHST HFDM Toolkit, the JHSIT determined specific guidance was needed for the implementation of HUMS programs in helicopter operations, thus the IHST HUMS Toolkit was developed.

IHST Resources

A list of just a few resources available on the IHST website:

HFDM Toolkit

Designed to provide a summary of existing flight data monitoring guidance, and to serve as a step-by-step guide to the implementation of HFDM.

HFAP(P) Interactive Tool

Designed to provide interactive development of HFDM events based on available parameters.

Maintenance Toolkit

Designed to provide operators a framework to ensure that they can safely maintain their aircraft in the most cost-effective manner possible.

Risk Assessment Toolkit

Designed to provide small and medium sized operators and private pilots an opportunity to assess their operation relative to key IHST recommendations for the US fleet.

SMS Toolkit

Designed to help organizations understand the fundamentals of a safety management system, and to provide guidance in the implementation and management of an SMS.

Training Toolkit

Designed to help organizations understand the fundamentals of effective training, and to provide guidance in the implementation of a functional training department.

For more information...

Please visit the IHST website at www.ihst.org



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Thank you all for your contributions to increase our understanding of HUMS/CBM and for your exceptional commitment to making our industry safer.

Best regards,



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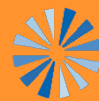
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Abbreviations

Abbreviations

ARMS	aircraft recording and monitoring system
CAA	Civil Aviation Authority (UK)
CBM	condition-based maintenance
CI	condition indicator
CG	center of gravity
COTS	commercial off-the-shelf
CVR	cockpit voice recorder
DFT	discrete Fourier transform
DSC	digital source collector
EVM	engine vibration monitoring
FAA	Federal Aviation Administration (USA)
FDR	flight data recorder
FFT	fast Fourier transform
HUMS	health and usage monitoring systems
IAS	indicated airspeed
ICP	integrated circuit preamplifier
IGB	intermediate gearbox
IPS	inches per second
MARMS	modular aircraft recording and monitoring system
MGB	main gearbox
OEM	original equipment manufacturer
RMS	root mean square
RTB	rotor track and balance
SO (<i>n</i>)	shaft order (<i>n</i> -1 harmonic)
TBM	time-based maintenance
TBO	time between overhaul
TDS	tail drive shaft
TGB	tail gearbox
VHM	vibration health monitoring
VMS	vibration monitoring system



Definitions

Definitions

acceleration. The rate of change of *velocity* in time along a specified axis, usually expressed in *g* or gravitational units.

accelerometer. A *sensor* or *transducer* for converting *acceleration* to an electrical signal, effective at higher rpm ranges (above 60 krpm).

airworthiness. A demonstrated capability of an aircraft or aircraft subsystem or component to function satisfactorily when used and maintained within prescribed limits.¹

alignment. A desired machinery condition in which the axes of components of a machine are adjusted so as to be collinear, parallel, or perpendicular.

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

alert. A warning produced by the HUMS that requires further processing or investigation to determine if a maintenance action is required.

amplitude. The magnitude (amount) of variation (in its changing quantity) from its zero value.

asynchronous. Of or relating to *vibration* features which do not occur at an integer multiple of the rotational frequency of a given shaft.

axial. Along the centerline of a shaft.

balancing. Adjusting the distribution of mass in a rotating element to reduce vibratory forces generated by rotation.

bandwidth. The *frequency* range (usually stated in Hertz or *Hz*) within which a measuring system can accurately measure a quantity.

baseline spectrum. A *vibration* spectrum taken when a machine is in good working condition (new or just overhauled) used as a reference for future monitoring or analysis.

broadband. An overall *vibration* level that encompasses a wide variety of *frequencies*

class A mishap. A mishap in which the resulting total cost of property damage is \$2,000,000 or more; or an injury or occupational illness results in a fatality or permanent total disability.

close monitoring. This may be required when a HUMS component or indicator requires focused and increased monitoring, for example, 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 available data.

commercial off-the-shelf (COTS). Equipment hardware and software that is not qualified to aircraft standards.

condition-based maintenance (CBM). The application and integration of appropriate processes, technologies, and knowledge-based capabilities to improve the reliability and maintenance effectiveness of aircraft systems and components. CBM uses a systems engineering approach to collect data, enable analysis, and support the decision-making processes for system acquisition, sustainment, and operations.²

condition indicator (CI). A measure of detectable phenomena, derived from *sensors* that show a change in physical properties related to a specific *failure mode* or *fault*.²

critical component. Any component whose *failure* would prevent continued safe flight and landing.

critical frequency. See **resonance**.

cycle. One complete period of a waveform.

data download process. The process for downloading HUMS data from the aircraft to the *ground station*. Typically, a memory card or other portable device shall be specified which allows the required HUMS data to be downloaded for analysis after every flight.

data mining. Reviewing or processing data in order to obtain information or knowledge. Depending on the format of the stored data, this process can range from signal processing of sampled measurements to queries performed on database tables.²

displacement. Specific change of position or distance usually measured from mean position to position of rest, usually referred to in mils (1 mil = 0.001 in), and best used with running speed of less than 1000 rpm.

diagnosis. The process of analyzing parameter data associated with a suspected *fault* and postulating the cause of the *fault*.²

digital source collector. An onboard aircraft data recording system used to collect *CBM* data.²

exceedance. An event in which the equipment operates outside of its specified limits.²

failure. A malfunction in which a system, subsystem, or component is unable to perform in the manner in which it was designed and intended.²

false negative. A *fault* not indicated by the *digital source collector* but found to exist by inspection.²

false positive. A *fault* indicated by the *digital source collector* but not found to exist by inspection.²

fast Fourier transform (FFT). An efficient mathematical method that converts a signal from the time domain to the *frequency* domain.

fault. A condition in which a system, subsystem, or component is functioning outside its normal specifications.²

filter. A device that acts on a *signal* and passes certain *frequencies* (pass band) but blocks other *frequencies* (stop band). Classified as low-pass (high stop), high-pass (low stop), band-pass, or band-stop.

flight regime. An aircraft load event categorized by aircraft configuration, flight environment, and operating condition type and severity.²

frequency. A measure of the number of complete *cycles* that occur in a specified amount of time.

g units. A way to express *acceleration* in terms of a ratio.

gear mesh frequency (GMF). A potential *vibration frequency* on any machine employing gears. Calculated by multiplying the number of teeth on a gear and its rotational frequency.

ground station. The means of access to HUMS 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 exceedances and *fault* diagnosis.

harmonic. A sinusoidal quantity having a *frequency* that is an integral multiple (2x, 3x, etc.) of a fundamental (1x) *frequency*.

health and usage monitoring systems (HUMS). Equipment/techniques/procedures by which selected incipient *failure* or degradation can be determined.²

Hertz (Hz). The unit of *frequency*.

imbalance. Unequal distribution of weight or mass on a rotor. A condition where the center of mass does not lie on the center of rotation.

integrity level. The level of accuracy and reliability that the HUMS should achieve. The integrity level necessary for each HUMS application is dependent on the criticality of the functions being performed.

International Helicopter Safety Team (IHST). A government-industry team formed in 2006, whose goal is to reduce the worldwide helicopter accident rate by 80% by the year 2016.

Joint Helicopter Safety Analysis Team (JHSAT). Analyzes aviation accidents, identifies problems, and recommends solutions.

Joint Helicopter Safety Implementation Team (JHSIT). Strategically addresses and implements JHSAT recommendations.

line-replaceable unit. An element of a system that can be readily replaced during line maintenance.

linear rotor smoothing. A model that assumes a linear relationship between an adjustment type magnitude and the resulting change in measured *vibration* before and after the adjustment is made. The linear model uses coefficients that require flight test data for each available adjustment type. The adjustment types must be made one at a time. The linear coefficients are calculated by comparing the before and after measured *vibration* for a specific adjustment type.³

natural frequency. The *frequency* of an undamped system's free *vibration*; also the *frequency* of any of the normal modes of *vibration*. The resonant *frequency* will be lower than the natural *frequency* when damping is present.

neural network rotor smoothing. Neural networks provide non-parametric mappings between the spaces of adjustments and the measured *vibration*. The adjustment space consists of the available adjustment types while the measurement space consists of the magnitudes of the measured *vibration* from the rotor track and balance *accelerometers*.

peak. Extreme value of a varying quantity, measured from zero to mean value. Also, a maximum spectral value.

peak-to-peak. The algebraic difference between the maximum and minimum values in a signal.

physics of failure. The physical phenomena that are analytically defined and describe the process by which a mechanical component fails during operation.²

piezoelectric (PE) transducer. One that depends upon deformation of its sensitive crystal or ceramic element to generate electrical charge and voltage. Many present-day *accelerometers* are PE.

radial. A direction perpendicular to a shaft's centerline.

remaining useful life (RUL). An estimate of remaining time on-wing for *failure*-free operation of the described component or system based on statistics, physical measurements, test results, or a combination of the analytical methods thereof.²

resonance. The tendency of a system to oscillate at greater amplitude at some *frequencies* than at others. *Frequencies* at which the response amplitude is a relative maximum are known as the

system's resonant *frequencies*, or *resonance frequencies*.

Safety Management System (SMS). A systematic, explicit, comprehensive, and proactive process for managing safety risks that integrates operations and technical systems with financial and human resource management to achieve safe operations and compliance with applicable regulations.

sensor. A hardware component that measures *vibration*. A sensor needs to provide a reliable signal of appropriate and defined performance in a typical helicopter operating environment. It may have built-in test capabilities sufficient to determine the correct functioning of the component.

signal conditioner. An amplifier following a *sensor*, which prepares the signal for succeeding amplifiers, transmitters, readout instruments, etc.

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.

spectrum. The result of transforming a signal from the time domain to the *frequency* domain.

spectrum analyzer. An instrument that displays the *frequency* spectrum of an input signal, usually *amplitude* vertical vs. *frequency* horizontal.

structural health monitoring (SHM). A fleet management concept that allows evaluation of the structural integrity of an aircraft throughout its life cycle based on measured data. SHM uses one of many technologies to monitor aircraft structural capabilities, including integrated NDI methods (algorithms, instruments, software procedures).²

synchronous. Of or relating to *vibration* features which occur at an integer multiple of the rotational frequency of a given shaft. See **asynchronous**.

transducer. A device that converts some mechanical quantity into an electrical signal. See also *sensor*.

true negative. A *fault* is not indicated by the *digital source collector* nor found to exist by inspection.²

true positive. A *fault* is indicated by the *digital source collector* and found to exist by inspection.²

usage monitoring system (UMS). Equipment, techniques, and procedures by which selected aspects of service (flight) history can be determined.²

velocity. Rate of change of displacement with time, usually along a specific axis; it may refer to angular motion as well as to uniaxial motion. Measured in inches per second (IPS) and is most accurate from above 1000 krpm to below 60 krpm.

vibration. Mechanical oscillation or motion about a reference point of equilibrium.

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. The result of processing sampled data by applying an algorithm to achieve a single value that relates to the health of particular component *failure* modes. Primary VHM indicators will be those that can be monitored directly for the purposes of generating *alerts*. Secondary VHM indicators are those that can be used in the diagnostic process after an *alert* is generated but are unsuitable for direct *alert* generation. A VHM indicator may be further processed with other VHM indicators to give a further indicator.

VHM indicator generation rate. The rate at which each *VHM indicator* value is acquired. This is usually a function of the data recording and 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.

Health and Usage Monitoring Systems Toolkit

1. AR 7062: Airworthiness Qualification of Aircraft Systems (U.S. Army).

2. ADS-79C-HDBK: Aeronautical Design Standard Handbook for Condition Based Maintenance Systems for US Army Aircraft Systems (U.S. Army).

3. Victor Giurgiutiu, Paul Grabill, Dariusz Wroblewski, and Lem Grant, *Helicopter Health Monitoring and Failure Prevention Through Vibration Management Enhancement Program*, 54th Meeting of the Society for Machinery Failure Prevention Technology (Virginia Beach, VA, May 1-4, 2000) http://www.me.sc.edu/research/lamss/pdf/journals/23_hhmsgpybmrp_ijov_4_2001.pdf.



1 Health and Usage Monitoring Systems



Courtesy of Era Helicopters, LLC

1 Health and Usage Monitoring Systems

Since their introduction into the aviation world, health and usage monitoring systems (HUMS) have gained traction and expanded from the offshore oil and gas industry to the military, unmanned aerial systems, and commercial and business operations. HUMS are designed to automatically monitor the health of mechanical components in a helicopter, as well as usage of the airframe and its dynamic components. HUMS enable aircraft to record structural and transmission usage, transmission vibrations, rotor track and balance information, and engine power assurance data. HUMS not only monitor the health of rotating components such as gearboxes, bearings, shafts, engines, and rotors through vibration, they can also record parametric data from the aircraft's bus for usage and event analysis. Subtle changes in vibration are recorded in flight, visualized on the HUMS ground station computer, and evaluated by technicians. The intelligence gained from the use of HUMS allows aircraft maintainers and fleet operators to make informed decisions about flying and maintaining their aircraft. As a result, HUMS have been shown to enhance safety, decrease maintenance burden, increase availability and readiness, and reduce operating and support costs.

1.1 Benefits of HUMS

A HUMS program can greatly enhance a Safety Management System (SMS). Implementation of these systems has been shown to improve

aircraft airworthiness. Proponents of HUMS include the Federal Aviation Administration, the Civil Aviation Authority, and the United States military.

As HUMS programs have developed and evolved over the past decades, the benefits of these systems have included more than just increased safety. While monitoring critical components promotes safety and increases confidence in the reliability of the aircraft, HUMS also allow for more efficient maintenance planning and use of parts.⁴ With a better understanding of when a part will fail, the maintainer can replace that part at the optimum time - before failure is imminent, but not while the part has significant remaining useful life.

The US Army in particular has made a significant investment in HUMS, building a large condition-based maintenance (CBM) program and equipping over 2,500 helicopters with onboard systems. The US Army currently utilizes HUMS on four different helicopter platforms, with the goal of moving from reactive maintenance and time-based inspection and overhaul to proactive maintenance and on-condition inspection and overhaul. The program has proven extremely successful, as can be seen by reviewing the benefits listed below.

1.1.1 Safety Benefits

HUMS improve safety. There are numerous examples in aviation today where a fault was detected early enough to avoid an emergency landing, or possibly even a catastrophic failure during flight. Safety benefits of HUMS include, but are not limited to:

- Accurate identification of faults prior to catastrophic failure
- Informed decision-making
- Risk mitigation and avoidance
- Lower risk of failure in flight
- Lower risk of emergency landings

1.1.2 Maintenance Benefits

HUMS enable failures to be identified in advance, so that plans can be made to avert hardware failure and system damage. The ability to monitor the condition of system components allows for a more efficient maintenance regimen. Maintenance benefits of HUMS include, but are not limited to:

- More efficient maintenance, as unscheduled events can be pushed to align with scheduled actions so the aircraft is making money instead of waiting for a parts shipment
- Elimination of the need for portable equipment installation and reduction of the need for additional maintenance flights due to onboard rotor track and balance capability
- Troubleshooting and diagnosis of potential faults through proper use of the system.
- Deferment or elimination of certain maintenance inspection intervals as HUMS mature
- Diagnosis of problems before they cause collateral damage

1.1.3 Readiness Benefits

For commercial fleet operators and military units alike, aircraft readiness is extremely important. HUMS lead to increased aircraft readiness and availability. Readiness benefits of HUMS include, but are not limited to:

- Demonstrable reduction in downtime for unscheduled maintenance events
- Proactive maintenance, allowing aircraft downtime to be a scheduled and anticipated event rather than an unexpected inconvenience
- Immediate recognition of a seemingly insignificant problem, before it turns into a significant one, allowing for better planning for the operation of an aircraft

1.1.4 Operations and Support Cost Benefits

Repair costs can be reduced by identifying a faulted component and performing maintenance before collateral damage is inflicted. Further, the ability to replace or repair a part before it breaks will result in increased operational time and consequently increased revenue. For example, the US Army's H-60 platform has several gearboxes that share an oil system. Before HUMS, when a chip event occurred in one of the gearboxes, all connected gearboxes were removed. With HUMS, the offending gearbox can be quickly identified and removed, saving significant resources. Operations and support cost benefits include, but are not limited to:

- Increased useful life and efficiency by recommending changes to system components such as shaft alignment or gearbox design. Frequently, one damaged part will go unnoticed, eventually resulting in a severe malfunction and the need to replace an entire gearbox.
- Identification of certain problems that warrant grounding the aircraft immediately, thereby preventing further damage, and resulting in a cost savings through averting damage to components other than the root cause
- Extension of the life of an aircraft's avionics and airframe by reducing overall vibration on the aircraft
- Decreasing the maintenance burden on the soldier
- Increasing platform availability and readiness
- Enhancing safety
- Reducing operational and support costs

1.1.5 Other Intrinsic Benefits

The following are additional benefits reported through a HUMS program:

- Increased pilot confidence
- Ability to more effectively plan maintenance actions over the long-term
- Ability to monitor health of an entire fleet, regardless of physical location
- As the program matures, the potential to predict when certain faults will occur, based on historical data and specific aircraft data

1.1.6 Evidence of Benefits of HUMS

As early as 2000, the benefits of HUMS were becoming apparent. For that year, the US Joint Helicopter Safety Analysis Team (JHSAT) found that part/system failures caused approximately 26% of the helicopter accidents in 2000. The JHSAT also reported that 24 (47%) of the part/system failure accidents might have been mitigated by the use of HUMS or equivalent systems.⁵ This means that potentially detectable part/system failures accounted for nearly 50% of the accidents caused by part/system failures. HUMS is not just a maintenance tool - it has the potential to prevent accidents and save lives.

The US Army recently performed a detailed study of the benefits associated with HUMS for US Army helicopter platforms. The study covered more than 500 aircraft and several hundred thousand flight hours. The US Army's CBM program, which utilizes HUMS on four different platforms, has four primary objectives:

To quantitatively measure the progress of these goals, the US Army developed six operating metrics, including readiness, maintenance test flight (MTF) hours, mission abort rate, maintenance man hours (MMH), parts cost per flying hour, and combat power. As a result of these six metrics, the US Army can see the benefits of CBM in a quantitative form.

After only six months of analysis, analysts began to discover the benefits of the CBM program. A study of UH-60A/L Black Hawk helicopters produced statistically-significant results based on available data. Non-mission capable for maintenance (NMCM) rates were reduced by 5.3% for the sample data set, indicating improved readiness and availability. The next metric developed was maintenance test flight (MTF) hours. For the AH-64D Apache, analysts found a reduction of 1.44 MTF hours per 100 flight hours for the sample data set. These results clearly show the significant and direct effect that a well-designed health monitoring program has on improving rotorcraft reliability and reducing the cost of a maintenance program.⁶

Since the US Army began analyzing the effectiveness of the CBM program, many more impressive statistics have emerged. Analysts discovered 12-22% decrease in parts cost per flight hour for HUMS-equipped helicopters from 2007-2009. The US Army experienced a 3.8-12.4% total NMCM reduction, and 5-8% increases in readiness across various platforms. Three Class A mishaps have been avoided, and the US Army predicts that 11-12 additional Class A mishaps will be avoided over the next 10 years. In terms of reducing the maintenance burden, there is a test flight reduction of 1-4%, and over 125 maintenance procedures have been improved or eliminated.⁷

1.2 History

HUMS have evolved over time from portable rotor smoothing systems. The early systems (1970s) used vibration sensors and a method, such as the use of a strobe light, to capture phase information.

A similar method was used to balance industrial rotating machinery. Maintenance personnel would use the vibration and phase information to determine where to add weight and how much weight was needed in order to balance the machinery. In the 1980s, hand-held computers were developed to generate rotor smoothing algorithms based on a linear model using the pitch links, rotor weights and trim tab solutions. Chadwick-Helmuth and Scientific-Atlanta developed systems using this technology in their 8500 and RADS systems, respectively. The notion of an entire helicopter drivetrain vibration monitoring system emerged in the mid-80s. The first HUMS were developed for helicopters in the offshore oil and gas industry to help reduce accidents. Following a series of helicopter accidents in the North Sea, the United Kingdom (UK) Civil Aviation Authority's (CAA's) Helicopter Airworthiness Requirements Panel (HARP) issued a report that concluded the risk to helicopters operating in the North Sea was far above acceptable levels. Several steps were recommended by HARP in order to mitigate the risks. One of the recommendations was to install permanent vibration monitoring equipment. Two simultaneous projects were launched to develop helicopter vibration monitoring systems to meet the demand that was recommended by HART. One project was a partnership between Stewart Hughes Limited and Teledyne while the other was headed by Meggitt Avionics. The two companies continued to develop their products over the years and, in 1999, the CAA made HUMS mandatory for all heavy rotorcraft registered in the UK. HUMS were initially designed to increase safety, but it quickly became apparent that these systems, which were capable of describing the actual condition of critical dynamic components, had considerable maintenance and cost savings potential.⁸

1.3 Deliverables to Internal Stakeholders

Research and statistics show that HUMS and VHM have significantly reduced the accident rate in rotorcraft since their introduction into North Sea operations in the early 1990s. As a result of this success, the CAA mandated HUMS (CAP 753) in aircraft that carry nine or more passengers. Studies have also concluded that these systems were capable of successfully detecting approximately 70% of the failure modes that occurred on components that the system was designed to monitor. Other benefits include:

- Predicted maintenance actions
- Reduced unscheduled maintenance
- Reduced aircraft downtime
- Reduced labor expense
- Increased reliability
- Improved maintenance planning
- Increased component life

1.4 Coordination with Other Programs

As with any equipment, all systems have their individual strengths and weaknesses. One way to compliment the data is to compare the vibration data with flight data. If a company maintains both HUMS and FDM (FOQA) programs, new light can be shed by aligning the time stamps for a deeper insight into possible causes of detected events or alerts. Also, data from HUMS will reveal trends and patterns. In the case that preventable occurrences are detected that may not be sufficiently covered by the aircraft maintenance manuals, an addition or customization of maintenance practices into the company's system of manuals can be a good solution.

The use of HUMS combined with other aircraft systems (for example, engine data, FDR and CVR, etc.) offers a more comprehensive view of the complete health and operation of aircraft, and can be beneficially combined with:

- FOQA programs
- Training programs
- Accident/Incident investigations
- Predictive maintenance programs
- Inspection programs

4. Irebert R. Delgado, Paula J. Dempsey, and Donald L. Simon, *A Survey of Current Rotorcraft Propulsion Health Monitoring Technologies*, NASA/TM - 2012-217420, January 2012.

5. US Joint Helicopter Safety Analysis Team, *Year 2000 Report to the International Helicopter Safety Team*, Sept. 2007.

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7. Chris Smith, *US Army Condition Based Maintenance*, presented at the American Helicopter Society 67th Annual Forum (Virginia Beach, VA, May 4, 2011).

8. Johan Wiig, *Optimization of Fault Diagnosis in Helicopter Health and Usage Monitoring Systems*, Thesis, Ecole Nationale Supérieure d'Arts et Métiers, December 11, 2006.



2 HUMS Components and Processes



Courtesy of Era Helicopters, LLC

2 HUMS Components and Processes

2.1 HUMS Components

The basic components in all HUMS systems are very similar, differing only in the location, quantity, type of sensors, and the complexity of the particular system requirements. Systems are made up of a combination of accelerometers of various design and function (for example, ICP, high temperature, etc.), velocimeters, magnetic pickups, photocells, some type of acquisition unit (the brain and storage unit), and a ground station for analysis.

- The basic vibration health monitoring (VHM) system will consist of the equipment shown in Table 2.1 and focus on external vibration readings only, along with rotor track and balance capabilities.
- A more complete health and usage monitoring system will have the equipment of a VHM system in addition to being connected to the engine data collection units (DCU) for a more comprehensive look at the aircraft's and engine's internal health, including various temperatures, component cycles, and pressures.
- More advanced yet are the inclusion of the airframe flight data recorders (FDRs) and cockpit voice recorders (CVRs) for a complete picture of the flight activity as well as the aircraft health.

Table 2.1 CAP 753 Requirements for VHM Indicators for Measurement and Recording

Assembly	Component Type	HUMS Indicators for Measurement and Recording
Engine	Power turbine Gas generator	Vibration spectrum during run-up SO1, SO2 of the gas generator and power turbine
Engine-to-main gearbox input drive shafts	Shafts	Imbalance Misalignment (monitored from the engine and gearbox)
Main gearbox	Gears Shafts Bearings	SO1, SO2 of shafts Gear meshing frequencies Gear tooth indicators Bearing wear indicators Modulation of web tone epicyclic gear indicators
Accessory gearbox	Gears Shafts Bearings	SO1, SO2 of shafts Gear meshing frequencies Gear tooth indicators Bearing wear indicators
Tail rotor drive shaft	Shafts Hanger bearings	Imbalance Misalignment Bearing wear
Intermediate and tail gearboxes	Gears Shafts Bearings	SO1, SO2 of shafts Gear meshing frequencies Gear tooth indicators
Oil Cooler/NOTAR-style circulation control fan	Oil cooler/Circulation control blower Drive shaft	SO1, SO2 Bearing wear
Main rotor		Blade track and balance Swashplate bearing wear indicators
Tail rotor/Fenestron		Blade track and balance Swashplate bearing wear indicators

Notes:

- 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 HUMS Processes

As with the equipment hardware, all basic processes are very similar in operation. The major difference is the way the data is managed and analyzed.

Some operators are contractually required to manage their program in a particular manner, some have regulatory requirements, and others have no requirements and manage their programs as desired in-house. These processes also vary based upon the size of the fleet as well as the frequency of downloads and the manner in which the data is handled once downloaded. When beginning a HUMS program, it may be helpful to create or reference a HUMS manual or guidance document with defined processes that also describes well-known faults and prescribed maintenance action for well-known faults.

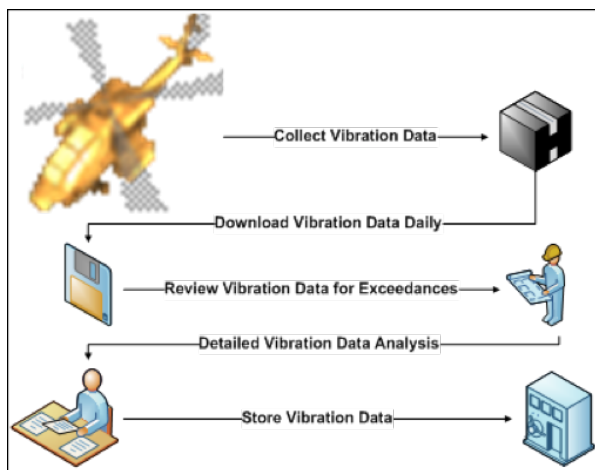


Figure 2.1 HUMS Processes

2.2.1 Basic HUMS Operation

As per CAP 753, the minimum requirements in equipment design for data management are as follows: The ground station should be capable of displaying the status of HUMS data after each download, identifying any primary indicators that are higher than their established thresholds. The recent history of both primary and secondary 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 instructions for continued

airworthiness 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.

2.2.2 Data Acquisition and Transfer

The process of acquiring data from the various sensors and transferring it to a ground station for analysis is accomplished through a variety of methods. The process involves the capture, extraction, processing, and analysis of HUMS data through manual methods (for example, hand-carried, ground-station, equipment, physical media), automated methods (for example, satellite, radio, wireless), or a combination of both.

It is important to download HUMS data regularly at a predetermined download interval. The download interval is determined by the flight data manager. The download interval may be as frequent as after every flight or only when the onboard storage medium is full. However, downloading the data at the end of each flight day should be considered as the program standard.

2.2.3 Data Analysis

After download, the data should be reviewed by the maintainer on the flight line for advisories and threshold exceedances, followed by detailed analysis by a trained HUMS analyst or engineer. The analyst should be looking for threshold exceedances as well as data

trending. This is best accomplished by trending historical vibration data from an aircraft against itself as well as the rest of the fleet. The analyst examines the data for lesser-known faults, probable faults,



or data anomalies, and alerts the maintainer if thorough analysis deems a component potentially faulty/dangerous.

Thresholds are limits set in order to quantify the degree of possible degradation. There are two types of thresholds. A fixed threshold is predetermined, often calculated based on data averaged from the operation of “healthy” components. For a learned threshold, although a hard limit is preset, the system will calculate and set a threshold based on data from a set running period. Thresholds are typically labeled advisory, caution, and warning, each of which represents a different severity level of alerts (advisory is not always used). These are frequently color-coded.

Simply looking at a single value and trying to diagnose a machine fault can prove to be impossible. Looking at the overall trend across time can illustrate fluctuations in the vibration levels. These clues can lead to the right track for investigation.

Rate-of-change: One of the key elements in identifying mechanical problems is to take note of changes in the vibration patterns. These changes can identify the beginning of the issue and also offer further clues as to why the event occurred.

2.2.4 Validating Data

Any time that a measurement is taken, there is a chance for error. When a HUMS system generates an alert, an effort must be made to ensure that the data is valid. The constant vibrations to which the airframes are subjected, combined with harsh operating environments, can contribute to occasional erroneous HUMS readings. To be effective, HUMS should be an interactive data exchange where maintenance records, pilot and mechanic discrepancies, vibration readings, oil analysis, visual verification, etc. are collectively utilized in order to come to an accurate conclusion and recommend appropriate corrective action.

When a component is flagged by the HUMS, a good starting point is to ask the following questions:

- Can I view the component from another sensor?
- Do adjacent components confirm heightened readings?

- Do I have additional supporting evidence?

The next step is for the maintainer to perform a manual check on the potentially faulted component. To aid in eliminating potential false alerts, inspect:

- Connectors for security, corrosion, or damaged or missing pins
- Wiring for chafed insulation and for good continuity
- Accelerometers for secure mounting and physical damage

Once valid HUMS alerts are identified, supporting evidence must be pursued related to the particular indication. This may be somewhat limited at the field level, as many of the monitored components may be internal. However, there are several courses of action that can be effective, for example:

- Verify proper lubrication
- Verify proper hardware/torque levels
- Inspect for evidence of missing balance weights
- Inspect for damage/misalignment
- Inspect vibration dampers for serviceability
- Inspect for cracks in the localized area
- Double-check any maintenance recently performed in that area
- Inspect chip detectors
- Strain oil in search of contaminants
- Send oil samples for analysis
- Conduct borescope inspection

Once additional data has been gathered, the maintainer may remove the component and document (with pictures) any noticeable faults. The next step is to send the component to an overhaul/teardown facility/OEM for analysis. Communication about the status of removed components is critical for the enhancement of your HUMS (this includes removed components that were not flagged by the HUMS). It is vital that the analysts be provided feedback on the status of the component and if any faults are found. If any faults are found, the analysts should screen the fleet for similar fault signatures. Furthermore, the analyst should maintain a database of faulted components and associated data.

2.2.5 Training

Training should be applied appropriately depending on the operator's particular needs. At a minimum, the field technicians must have a good understanding of the basic principles in regards to CBM. They should be able to manipulate the data as required and deliver that first level of analysis, that is so critical, at the aircraft. The data should be reviewed and appropriate action taken before release for flight. If the operator has an in-house HUMS department, these analysts should understand the same principles as the technicians at the aircraft and be given additional tools and

training in order to provide a deeper analysis and effective trending. In addition, the analysts should have access to a strong support group from the HUMS provider and aircraft manufacturer.

Most OEMs offer training with the purchase of their systems. This training consists of basic operation and maintenance, rotor track and balance, and basic fault isolation and interpretation. In addition, several courses are available today for more advanced diagnostics. Depending on the size and scope of an operation, developing in-house courseware may be appropriate.



3 HUMS Required Resources



Courtesy of Era Helicopters, LLC

3 HUMS Required Resources

3.1 Personnel Requirements

The number of personnel required to manage a HUMS program will vary tremendously depending on the size of the organization and fleet, type and mix of vibration equipment, and aircraft type and fleet mix. At a minimum, an operator requires trained maintainers that understand how to interpret the flight line functions of the vibration equipment used, up to and including:

- Aircraft advisories
- Threshold exceedances
- Rotor track and balance
- Spectrum analysis
- Equipment condition testing

Detailed vibration analysis may be accomplished by various methods including:

- Trained in-house engineer/analyst
- OEM analysis service
- Equipment manufacture analysis service

As with any program, HUMS start from the top down, and management support is essential to ensure buy-in throughout the organization.

Table 3.1 HUMS Personnel Requirements

Position	Responsibilities
Manager	<ul style="list-style-type: none"> • Provide/coordinate support for field technicians in all aspects of the systems that are utilized within the company • Develop and enforce procedures. Findings should contribute to improvements in the company's maintenance programs • Monitor the efficiency of HUMS technicians and provide or arrange training when necessary • Perform data checks to ensure that data is being properly captured, systems are fully functional, alerts are properly identified, and that the flight plan is compatible with the system • Test new software, provide feedback to OEM for improvement • Monitor fleet trending, compile case histories, report findings
Analysts/ Engineers	<ul style="list-style-type: none"> • Provide support to field technicians • Perform data processing and management • Interpret fault codes • Analyze data, identify patterns, provide solutions • Catalogue daily activities for reliability reporting
Field Technicians	<ul style="list-style-type: none"> • Extract data, upload and download • Perform rotor track and balance • Troubleshoot system faults and vibration alerts • Must have a general understanding of analysis in order to effectively review the daily data and take appropriate action (first line of defense) • Their eyes, ears, and communication skills are key to the HUMS team
Support	<ul style="list-style-type: none"> • General troubleshooting • Threshold evaluation/adjustment • System software support/updates • Advanced analysis and diagnostics • On-site assistance • Complete data management (e-mail notifications, weekly reports) • It is crucial to have access to OEM engineers and analysts when your internal resources have been exhausted
Information Technology (IT)	<ul style="list-style-type: none"> • Configure computers to function properly depending on specific system requirements and operating locations • Maintain/improve network connectivity between bases and headquarters • Troubleshoot software compatibility issues • Manage data integrity and security, login profiles, and user permissions

3.2 IT Requirements

IT requirements vary as much as equipment options. The following are basic IT requirements for supporting a HUMS program:

- ▶ Program-specific software for installation on system display unit or ground station with capabilities for:
 - Rotor track and balance
 - Vibration data downloads
 - Vibration threshold exceedances
 - Vibration alerts
 - Basic trending
 - Spectrum analysis
 - System built-in tests (BIT)
- ▶ Data storage required for long- and short-term data storage. Options include:
 - Local data server
 - OEM data server
 - Vibration equipment manufacturer's data server
- ▶ Analysis program for detailed analysis. Options include:
 - Web-based analysis program
 - Analysis software for use on local computer

3.3 Equipment Requirements

3.3.1 Airborne Equipment

The following airborne equipment is needed to implement a health and usage monitoring system:

- Digital source collector (DSC)
- Accelerometers
- Tachometers
- Bus interface
- Blade tracker
- Onboard data storage device

3.3.2 Ground-based Equipment

Necessary ground-based equipment includes a computer and software to provide data storage and support data analysis. The ground-based software imports the data from the aircraft, performs any required post-processing, and displays the flight data in a user-friendly environment with graphics. The ground-based software should provide the means to accurately assess the health of all aircraft. It should be intuitive and usable without extensive training.





Courtesy of Era Helicopters, LLC

4 HUMS Concepts

Vibration is an indicator of condition. It is natural for even the smoothest of machines to vibrate. Therefore, each will have an acceptable range. In the event that the vibration levels increase or vary considerably, a mechanical issue is often the cause. Causes of vibration can be attributed to anything from the original part design to unfavorable operating conditions or even poor maintenance practices. Vibration indications often appear before defects can be detected by traditional means. This can serve as a guard against “substandard” components, possibly prompting investigations into particular production batch numbers. Vibration indications are a tool that can detect flaws outside of the normal scheduled inspection intervals. This detection ability enhances mechanical integrity by complimenting the numerous prescribed inspections, maintenance actions, and service limits in the aircraft’s maintenance manuals. Vibration indications help guard against a failure of maintenance procedures, continually monitoring for patterns that would justify procedural alterations.

Typical helicopter vibrations include:

- Rotors (main, tail): Low-frequency vibrations travel throughout the airframe
- Power train (driveshaft, gearbox): Medium-frequency vibrations must be closer to detect
- Bearings: High-frequency vibrations travel very small distances

Sources of vibration can include:

- Mass unbalance
- Misalignment
- Eccentricity
- Distortion
- Looseness
- Wear
- Interference
- Friction
- Gear contact
- Resonance
- Aerodynamic forces
- Operational circumstances

Effects of sustained levels of excessive vibration can include:

- Fatigue cracks
- Component or structural failures
- Accelerated component wear
- Increased unscheduled removals
- Fretting and chaffing
- Corrosion and looseness at riveted joints
- Electrical component failures
- Passenger and crew discomfort and fatigue
- Rough ride, excessive noise in cabin

HUMS deploy both proactive and reactive methods to anticipate drivetrain failure. Proactive methods include usage spectrum analysis such as load cycle calculation, allowing remaining component safe life to be estimated based on the actual stress a component has been under for the duration of its service. The reactive approach is based on detecting propagating component failure at an early stage, before seizure occurs. This method relies on a sensor network covering engines and transmission systems. For the current generation HUMS, this sensor network is mainly limited to vibration sensors and angular shaft speed sensors.

During operation, the HUMS airborne segment gathers data from its sensor network and stores this data in a storage unit (black box) or acquisition unit. Most HUMS perform diagnostics and reporting between flights. This is achieved by transferring the data, by means of a storage medium, to a stationary computer, known as the ground station. The ground station contains complex algorithms developed by the equipment manufacturer to sort the data and display the data in a readable format. The data is then analyzed by

the maintainer or the analyst to determine the condition of a particular component based on predetermined parameters. These parameters may include various triggers, alarms, alerts or limits established by the OEM or simply comparing the particular airframe against itself and the rest of the fleet. These programs also offer the following for a complete CBM program:

- Main rotor track and balance solutions
- Tail rotor track and balance solutions
- Driveshaft balance solutions
- Vibration absorber tuning solutions
- Airframe signature analysis
- Spectral analysis
- Aircraft flight monitor data
- Vibration equipment health indicators

4.1 Rotor Track and Balance

Rotor track and balance, or rotor smoothing, is a routine maintenance task that involves a calculated system of adjustments to pitch links, blade weights, and trim tabs. These adjustments are designed to reduce vibrations at the fundamental (once-per-revolution) rotor frequency. A reduction in rotor vibration adds a significant amount of “smoothness” to the aircraft while in flight. In addition, proper smoothing will increase the longevity of the aircraft. The procedure for rotor smoothing is typically performed in multiple flight modes, including flat pitch ground running at 100% (FPG100), hover, and several pre-defined, steady, level flight airspeeds. The slightest adjustment can change both the dynamic balance as well as the aerodynamic response of each individual blade. Rotor track and balance is a vital process for maintaining an aircraft’s health. A correctly adjusted rotor system will raise pilot comfort levels and increase the lifetime of time-based components prior to replacement.

Rotor smoothing is typically performed with the use of accelerometers mounted in the cockpit. The accelerometers are synchronized with a tachometer and a tracking device such as a camera or a strobe. The goal is for each blade to trace the same path through the air as it rotates about the hub. HUMS collect the accelerometer, track, and phase information and use a linear model or a neural network to provide solutions that will effectively reduce the vibrations and/or blade track split.

HUMS provide the maintainer with a rotor smoothing solution that gives precise instructions on what type of adjustment to perform (weight, pitch link, tab bend, elastomeric wedge), where to perform the adjustment, and what magnitude of adjustment is required. Since HUMS are continuously collecting data, there is no need to perform dedicated rotor track and balance flights. A helicopter can be flown on its normal mission, and rotor smoothing adjustments can be performed upon its return to home base. The adjustments can be confirmed by normal flight operations during subsequent flights. The exception to this method is when maintenance has been performed on the rotor system; in this situation, it may be advantageous to perform dedicated rotor track and balance.

4.2 Dynamic Component Monitoring⁹

The monitoring and condition assessment of dynamic components is the most advanced and arguably the most beneficial aspect of HUMS. Raw accelerometer data is acquired by an onboard digital source collector (DSC) during predetermined flight regimes. The length of data and the rate at which the data is being sampled is dictated by operational and design parameters of the aircraft and the amount of processing required. For example, in order to monitor a gear, the rotational velocity or frequency of its attached shaft must be considered. As general guidance, collect no fewer than five samples per tooth of the gear being monitored. Performing this calculation for the fastest rotating gear will provide the minimal sampling rate for that gear. The length of data is dictated by the amount of processing required to achieve a satisfactory signal-to-noise ratio.

HUMS data used for dynamic component monitoring is generally acquired during steady-state conditions of the aircraft. These regimes can include: on ground with 100% velocity of the rotor system at zero angle pitch, in ground-effect hover, out of ground-effect hover, and steady-state cruise. These regimes can be triggered automatically if the DSC has a data bus interface, or manually by the aircraft crew. Parametric data for usage monitoring should be acquired constantly. Because the amount of parametric data collected can become extremely large, the data should be sampled at the lowest rate possible. In most current HUMS that collect parametric data, the

parametric data is saved and processed at a later time.

Accelerometer data is often processed on the DSC. Intermediate processing, such as fast Fourier transforms (FFTs), synchronous time averaging (STA), or spectral averaging, is performed. Condition indicators (CIs) are then calculated from the results of the intermediate processing.

The effectiveness of HUMS is directly tied to the effectiveness of its CIs. The CIs must have a maximum amount of true positives (correctly identified faulted components) and a minimum amount of false positives (components identified as faulted when they are in fact healthy) in order for the users to have confidence in the system. HUMS are never likely to catch all faulted dynamic components, but they can achieve a high degree of accuracy as the CIs are refined. Until HUMS can confidently and consistently identify a specific failure, they should not replace any other safety measures that are in place. It should be clearly stated in the HUMS user's manual which components are consistently identifiable.

4.2.1 Sensors

HUMS sensors should have high reliability and high accuracy. A HUMS sensor should be adequately rated for the fault it is designed to detect. For example, if a fault is detectable at a frequency of 18,000 Hz, the sensor should be rated to at least 18,000 Hz.

HUMS sensors should be strategically placed on all critical drivetrain components and other components of high interest. Tachometers should be placed on shafts when dynamic balancing is being conducted, or when velocity needs to be recorded. Accelerometers mounted on dynamic components should have a clear energy transfer path from the specific component being monitored to the sensor. Also, the sensor should be oriented such that the sensitive axis is aligned with the predominant axis of vibration.

HUMS sensors should be regularly checked to ensure proper functionality. A system BIT (built-in test) should be performed at each power-on to ensure proper functionality of the circuitry. This should apply to both the DSC and the accelerometers. Problems with wiring, connections, or sensors can result in condition

indicators giving false or incorrect readings. In order to avoid this, data quality checks should be applied to the collected data during normal data acquisitions.

4.2.2 Gear Condition Monitoring

Gear condition monitoring is typically accomplished by calculating the synchronous time average (STA) of the gear. The STA is calculated by dividing the raw accelerometer data into single revolution data segments at the frequency of the gear of interest using a tachometer signal. The segments are resampled to get the same amount of points in each segment. The segments are then averaged together and become the STA. The STA contains the vibration signature of the shaft coincident to the gear of interest, and averages out the asynchronous vibration. Data should be acquired for gear diagnostics at steady-state regimes when the gear has the most torque applied to it. Gear condition indicators that have been proven by government and commercial operators of laboratory test stands are:

- Residual kurtosis
- Residual RMS
- Sideband modulation
- Narrowband crest factor
- Gear distributed fault
- G2-1
- Residual peak-to-peak
- Energy operator
- Sideband index
- Sideband level factor
- FM4 and FM4*
- Energy ratio
- M6A and M6A*
- M8A and M8A*
- NA4 and NA4*
- NA4 reset
- Amplitude modulation
- Phase modulation
- Instantaneous frequency
- NB4 and NB4*
- NP4

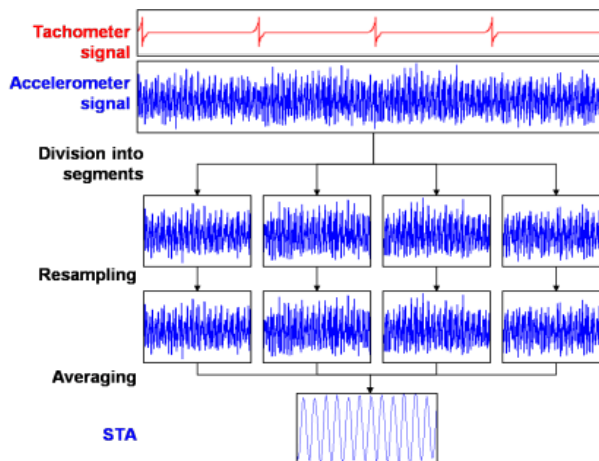


Figure 4.1
Synchronous Time Average (STA) Calculation

4.2.3 Bearing Condition Monitoring

Bearing CIs are usually applied to the asynchronous frequency domain (AFD) of the accelerometer data or the spectrum of the enveloped signal. The AFD is calculated by averaging several windowed FFTs of the raw accelerometer data. The enveloped signal, also known as the amplitude demodulated signal, attempts to extract the impulse vibration fault signature from the raw accelerometer data. Bearing faults are typically associated with the rolling elements, races, and cage of the bearing, and their resulting fundamental fault frequencies. Faults can also appear in energy bands, usually in higher frequencies.

4.2.4 Shaft Condition Monitoring

The condition monitoring of shafts is mathematically much simpler than gear or bearing diagnostics. Shaft CIs are simply calculated from the harmonics of the shaft operating speed. The shaft CIs can be calculated from both the STA and the AFD. Some shafts also require dynamic balancing. This is performed using the same methods as rotor smoothing.

4.3 Usage Monitoring and Structural Health Monitoring

Usage monitoring involves tracking specific aspects of an aircraft's flight history. Due to the ability of HUMS to accurately detect and measure flight regimes, fatigue damage management can be refined. The baseline "worst case" usage

spectrum can be refined over time for each aircraft using the aircraft-specific usage profile. Also, individual component fatigue damage assessment estimates can be based on aircraft-specific flight history instead of the “worst case design estimate.”¹⁰

Structural health monitoring (SHM) is designed to track and evaluate the structural integrity of an aircraft throughout its life cycle. SHM detects structural damage and degradation that occur as a result of the aircraft's service environment and age, including cracks, corrosion, and other damage. The purpose of SHM is to identify

damage that is often undetectable by the human eye, and to prevent propagation of damage through early detection and remediation. Similar to dynamic component monitoring, SHM is achieved through direct sensor measurement. Both accelerometers and strain gauges can be used to determine the health of structural components. These methods are currently in their infancy and are not widely developed or used in HUMS.

9. ADS-79C-HDBK: Aeronautical Design Standard Handbook for Condition Based Maintenance Systems for US Army Aircraft Systems (U.S. Army).

10. ADS-79C-HDBK, pp. 13-14.



A

List of Available Attachments



Courtesy of Era Helicopters, LLC

Appendix A List of Available Attachments

Appendix A contains a list of available attachments to this document. To view the attachments, click on the link or visit the [IHST website](#).

Table A.1 List of Available Attachments

	Title	Author	Date
A	AC 27-1B : Certification of Normal Category Rotorcraft	Federal Aviation Administration, United States	Sep 2008
B	AC 29-2C : Certification of Transport Category Rotorcraft	Federal Aviation Administration, United States	Sep 2008
C	ADS-79C-HDBK : Aeronautical Design Standard Handbook for Condition Based Maintenance Systems for US Army Aircraft Systems	United States Army	Jan 2012
D	CAP 753 : Helicopter Vibration Health Monitoring (VHM) - Guidance Material for Operators Utilising VHM in Rotor and Rotor Drive Systems of Helicopters	Civil Aviation Authority, United Kingdom	Aug 2012
E	Comparison of HUMS Benefits - A Readiness Approach . Presented at the American Helicopter Society 65th Annual Forum, Grapevine, TX, May 27-29, 2009	Joshua C. Hasty, Kennedy W. Speaks, Joshua S. Kennedy	May 2009
F	Helicopter Health Monitoring and Failure Prevention Through Vibration Management Enhancement Program . Presented at the 54th meeting of the Society of Machinery Failure Prevention Technology, Virginia Beach, VA, May 1-4, 2000	Victor Giurgiutiu, Paul Grabill, Dariusz Wroblewski, Lem Grant	May 2000
G	JAR-OPS 3 : Commercial Air Transportation (Helicopters)	Joint Aviation Authorities (JAA) Europe	Jul 2007
H	Optimization of Fault Diagnosis in Helicopter Health and Usage Monitoring Systems . Thesis, Ecole Nationale Supérieure d'Arts et Métiers, December 11, 2006	Johan Wiig	Dec 2006
I	US Army Condition Based Maintenance . Presented at the American Helicopter Society 67th Annual Forum, Virginia Beach, VA, May 4, 2011	Chris Smith	May 2011
J	Year 2000 Report to the International Helicopter Safety Team.	US Joint Helicopter Safety Analysis Team	Sep 2007

B

HUMS Equipment Providers



Courtesy of Era Helicopters, LLC

Appendix B HUMS Equipment Providers

Appendix B contains a list of health and usage monitoring systems (HUMS) equipment providers.

Table B.1 HUMS Equipment Providers

Company Name	Website	Description
Eurocopter	www.eurocopter.com	Their Modular Aircraft Recording Monitoring System (M'ARMS) is the HUMS installed on several Eurocopter models. Benefits include improved safety and early detection of impending mechanical failures. It also allows cockpit voice and video recording, as well as usage and quick-access recording.
GE Aviation	www.geaviation.com	Their Integrated Vehicle Health Management (IVHM) technology is available for both rotary- and fixed-wing platforms. They recently acquired Smiths Aerospace, formerly Stewart Hughes.
Goodrich	www.goodrich.com	A primary supplier of HUMS for military and commercial aviation. Provides both the Integrated Mechanical Diagnostics - Health and Usage Management System (IMD - HUMS) and the Integrated Vehicle Health Management System (IVHMS), both of which provide advanced diagnostic information to maintainers. These products contribute to increased safety and enhanced maintenance planning.
Honeywell	www.honeywell.com	Best known for their VXP Health Monitoring System, which is fully certified and designed to support future upgrades. Benefits of this system include more effective maintenance, the latest advancements in technology, proven reliability, and excellent customer support.

C HUMS Analysis and Case Studies



Courtesy of Era Helicopters, LLC

Appendix C HUMS Analysis and Case Studies

Appendix C describes the types of HUMS analysis currently available and presents three case studies pertaining to the use of health and usage monitoring systems (HUMS):

- Gear Fault Detection
- Sprag Clutch Monitoring
- Gearbox Generator Bearing Fault

Types of HUMS Analysis

There are several types of analysis available with today's equipment. Some are practically automated while others are more hands-on. The best analysis is a combination of the two. While all programs are required to have a means of flight line analysis (for example, warning, caution, and nominal indications), which is a very important part of your program, this should not be used as your primary source of analysis. Detailed daily analysis should be performed by a trained analyst, comparing daily data against historical data for that airframe against itself as well as the fleet.

Flight line analysis is a way for the maintainers to see the post-flight status of monitored components and be alerted to any sudden changes in component health. This is accomplished through the use of

predetermined threshold limit triggers, alarms, and alerts. Flight line analysis also provides a way to determine equipment health.

After data is reviewed by the maintainer and it is determined that no maintenance actions are required, the data should be transferred to a qualified analyst for detailed component condition analysis. The analyst may be an employee of the operator or contracted through an analysis service. This process should be completed daily.

The benefits of detailed analysis are:

- Historical trending airframe/fleet
- Post maintenance condition change
- Identification of slight but steady degradation of components
- Identification of premature equipment failures
- Predictive maintenance
- Improved parts scheduling
- Decreased AOG charges
- Decreased aircraft downtime

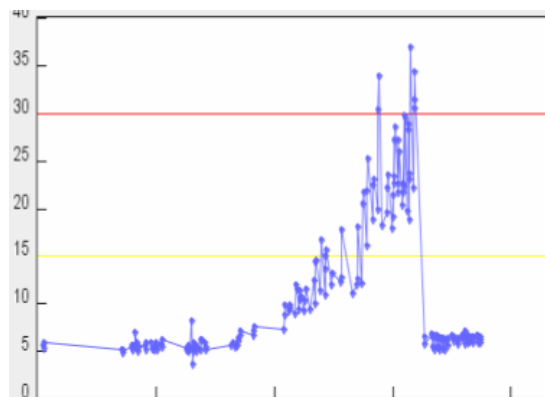
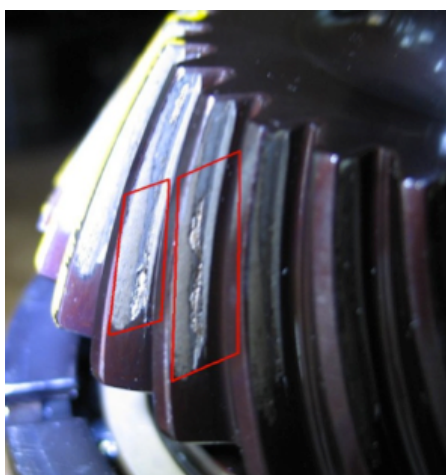
Case Study 1: Gear Fault Detection

Title: Identification of an AH-64 Nose Gearbox Gear Fault

Date: January 2009

Problem: The subject gearbox was removed from service due to a review of the HUMS data by the aircraft crew revealing a 'red' condition indicator. The AH-64 is equipped with a Honeywell Modernized Signal Processing Unit (MSPU). The nose gearbox is outfitted with a triply redundant diagnostic system, which includes a chip detector, a temperature sensor, and an accelerometer tied to the MSPU. A teardown analysis of the gearbox revealed severe damage to both the input pinion and output bevel gears. Neither the chip detector nor the temperature sensor revealed a fault in the gearbox.

Approach: The condition indicators successfully identified and classified the fault. No other action was required to improve the diagnostics of the HUMS.



Results: The significance of the subject case is the fact that neither the chip detector nor the temperature sensor detected the severe fault. If the HUMS data had been ignored, it is likely that the helicopter would have eventually experienced a chip indication or suffered a catastrophic loss of the gearbox, which, in either case, would have resulted in a precautionary landing or accident. Because the HUMS were able to correctly identify the fault, a precautionary landing was avoided, along with the subsequent recovery effort. The aircraft crew was also able to avoid unnecessary aircraft unavailability by performing proactive maintenance.

Reference: Lance J. Antolick, Jeremy S. Branning, Daniel R. Wade, and Paula J. Dempsey, *Evaluation of Gear Condition Indicator Performance on Rotorcraft Fleet*, presented at the American Helicopter Society 66th Annual Forum (Phoenix, AZ, May 11-14, 2010).

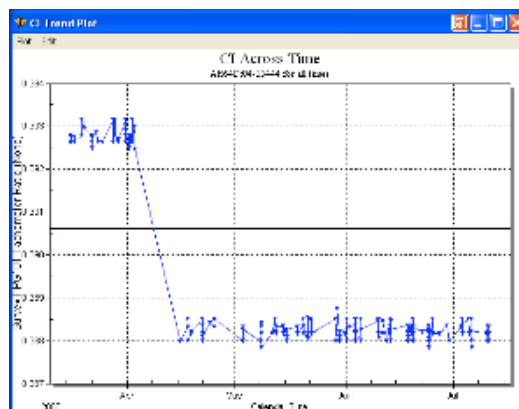
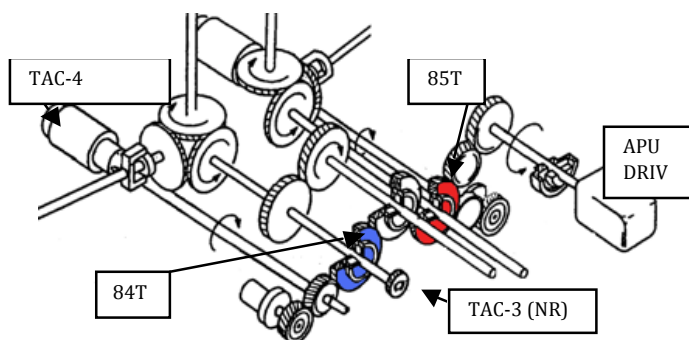
Case Study 2: Sprag Clutch Monitoring

Title: Sprag Clutch Failure Prevention on the Apache Main Transmission

Date: January 2008

Problem: The AH-64D helicopter main transmission contains two overrunning sprag clutches that allow the accessory section to be powered by either the auxiliary power unit (APU) or the engines. The transmission has an 85-tooth accessory drive spur gear installed on the right-hand side and an 84-tooth accessory drive idler spur gear installed on the left-hand side. During the transition from APU power to engine power, the primary clutch on the 85-tooth gear is engaged while the secondary clutch on the 84-tooth gear continues to overrun. If, for some reason, the primary clutch does not engage, the secondary clutch will engage and drive the accessory section. A failure of both clutches would leave the aircraft without AC power and result in loss of control to the hydraulic systems. The flight crew originally had no method for determining if the primary clutch had failed and the aircraft was operating on the secondary clutch.

Approach: The US Army's AH-64D fleet is equipped with a Modernized Signal Processing Unit (MSPU) as a means for implementing the condition-based maintenance (CBM) program. The MSPU records data from a variety of sensors, including accelerometers and tachometers. A method for determining which clutch is currently engaged was developed by calculating the NR and NGEN tachometer ratios.



Results: After the software change was applied to the MSPU, three aircraft were eventually identified to be running on their secondary clutch by the new condition indicator. In the first two cases, physical inspection revealed that two 84-tooth gears were installed in the transmission, rather than one 85-tooth gear and one 84-tooth gear. Due to the installation error, both clutches were found to have excessive wear. The clutches had used 90% of their useful life in only 4% operational time. This discovery resulted in the prevention of a potentially catastrophic dual clutch failure.

Benefits: As a result of this discovery, three Class A mishaps were potentially averted. Improvements have also been made to the manufacturing process in order to ensure the correct gears are installed in the transmission.

Reference: Jonathan Keller, Damian Carr, Frances Love, Paul Grabill, Hieu Ngo and Perumal Shanthakumaran, *AH-64D Main Transmission Accessory Drive Spur Gear Installation Fault Detections*, Journal of Intelligent Manufacturing, Volume 23, Number 2 (2012), pp. 205-211.

Case Study 3: Gearbox Generator Bearing Fault

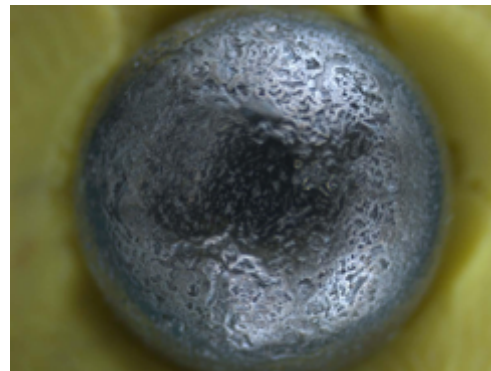
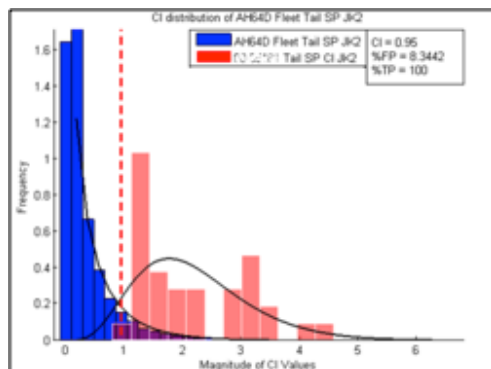
Title: Identification of UH-60L Accessory Gearbox Drive Bearing Faults

Date: September 2012

Problem: The UH-60L uses the Goodrich Integrated Vehicle Health Management System (IVHMS). This particular case involved the ability of the IVHMS to predict remaining useful life (RUL) of the UH-60 accessory module generator bearings. Accessory gearbox (AGB) generator bearings present a special circumstance for RUL estimates - although the bearings could continue to operate for some time, ferrous debris causes an illumination of the gearbox chip light. Excessive chip events require the replacement of the gearbox, meaning the RUL of a bearing that "makes metal" is effectively zero hours, and prompts a precautionary landing. An improved diagnostic for the AGB generator bearings will result in increased aircraft readiness, improved mission planning, and a reduction in mission aborts.

Approach: In order to develop improved mechanical diagnostics and refined thresholds for the AGB, HUMS analysts followed a five-step methodology: 1) physics of failure analysis, 2) detection of algorithm development, 3) fault correlation data mining, 4) fault validation, 5) inspection/teardown analysis, and 6) electronic and embedded diagnostics.

The ability to predict a chip event before it occurs, and to separate out healthy aircraft from aircraft with an impending chip, greatly enhances safety. Three teardown analyses were performed to confirm the presence of an AGB generator bearing fault and correlate the fault to existing condition indicators. New thresholds were developed, based on the teardown analysis results and data mining of the UH-60 fleet data.



Results: When the newly-defined thresholds were applied to the fleet, a faulted AGB was immediately identified. The unit, deployed at a forward operating base in Afghanistan, was contacted by the US Army CBM working group. Upon removal of the gearbox, the unit noted metal shavings in the oil. Early identification of this fault likely prevented a precautionary landing. This threshold setting process resulted in the capability of the IVHMS to successfully predict accessory gearbox chip events onboard the aircraft.

Reference: Daniel R. Wade and Jeremy Branning, *Application of Aeronautical Design Specification 79 to the UH-60L Accessory Gearbox Generator Drive Bearings*.

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HEALTH AND
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Courtesy of American Eurocopter

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