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Rotorcraft Health Management Issues and Challenges

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Abstract

This paper presents an overview of health management issues and challenges that are specific to rotorcraft. Rotorcraft form a unique subset of air vehicles in that their propulsion system is used not only for propulsion, but also serves as the primary source of lift and maneuvering of the vehicle. No other air vehicle relies on the propulsion system to provide these functions through a transmission system with single critical load paths without duplication or redundancy. As such, health management of the power train is a critical and unique part of any rotorcraft health management system. This paper focuses specifically on the issues and challenges related to the dynamic mechanical components in the main power train. This includes the transmission and main rotor mechanisms. This paper will review standard practices used for rotorcraft health management, lessons learned from fielded trials, and future challenges.

Introduction

Helicopter transmission integrity is important to helicopter safety because helicopters depend on the power train for propulsion, lift, and flight maneuvering. A study of 1168 helicopter accidents from 1990 to 1996 found that after human-factors related causes of accidents, the next most frequent causes of accidents were due to various system and structural failures (Aviation Safety 1998). In 1999, of the world total of 192 turbine helicopter accidents, 28 were directly due to mechanical failures with the most common in the drive train of the propulsion system (Learmount 2000). In order to reduce helicopter accidents, this study recommended the design of Health and Usage Monitoring Systems (HUMS) capable of predicting impending equipment failure for on-condition maintenance, and more advanced systems capable of warning pilots of imminent equipment failure. In order to make these predictions, the system must provide health monitoring of the transmission components and must also demonstrate a high level of reliability to minimize false alarms.

Liu and Pines (2005) recently studied U.S. civil rotorcraft accidents caused by vehicle failure or malfunction during the period from 1998 to 2004. It was a continuation of a study performed by NASA that covered the period from 1963 to 1997. Results showed that the ratio of the number of accidents caused by vehicle factors to the total number of accidents during the period of 1998 to 2004 had been reduced by more than one half in comparison to the earlier accident data. Pilot error continues to be the major cause of all rotorcraft accidents, but the results also indicate that failure or malfunction of the propulsion system remains the primary reason for vehicle factor related accidents.

Rotorcraft health monitoring systems, while historically focused on safety, can also provide economic benefits for rotorcraft operators. Figure 1 shows the potential benefit of diagnostics and predictive maintenance of critical mechanical systems. Such benefits were demonstrated on a flight trial program at Petroleum Helicopters in the form of reduced insurance cost through enhanced safety, lower operating costs, increased aircraft availability and improved operating efficiency (Cronkhite 1998). The service life of critical components was extended if the actual usage, measured by load exposure via usage monitoring, was low compared to the predicted usage, and, therefore, reduced operating costs by 10 percent. Health monitoring also provided a safety benefit when actual usage was more severe than predicted, as illustrated in figure 1.

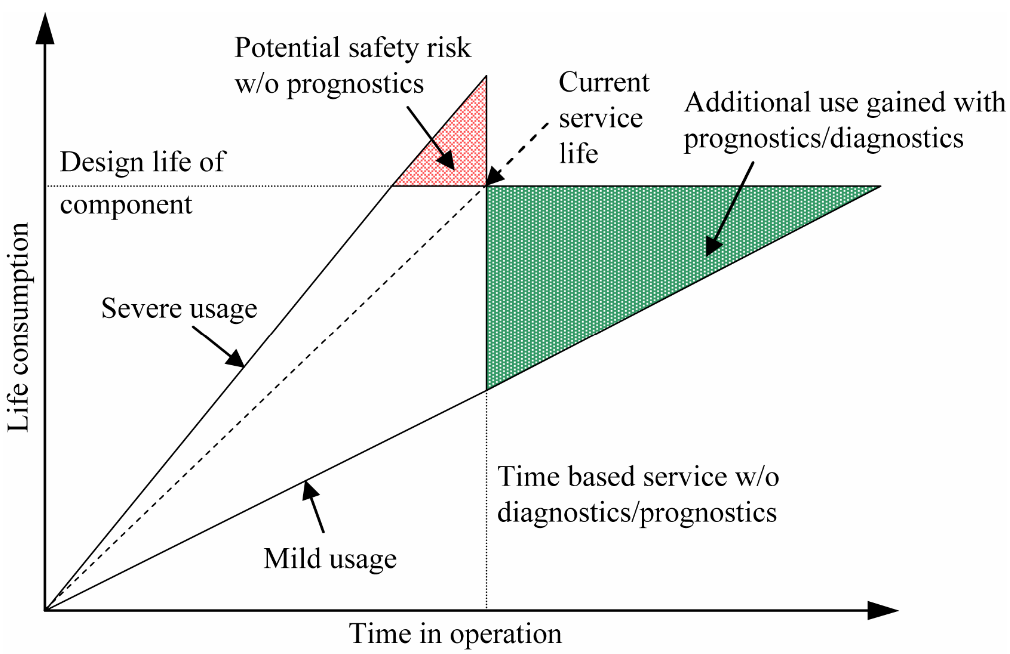

Figure 1.—Economic and Safety Benefits of Diagnostics and Prognostics (Romero et al. 1996).

One major independent study has concluded that: “HUMS was probably the most significant isolated safety improvement of the last decade,” (Hokstad et al., 1999). Although commercially available HUMS are providing significant safety benefits when installed on rotorcraft, the fault detection success rate of today’s helicopter health monitoring systems through vibration analysis is still in need of improvements. HUMS experience documented by the CAA (UK Civil Aviation Authority) in 1997, and informally updated in 2002, shows a success rate of 70 percent in detecting defects (McColl, 1997).

This paper will provide an overview of today’s rotorcraft health monitoring technologies for detecting anomalies in dynamic mechanical systems. Standard practices in acquiring and processing vibration data will be discussed first, to provide the reader with general knowledge of how useful information is extracted. Then, lessons learned from systems currently installed on rotorcraft will be discussed. This will include the difficulties encountered when trying to optimize the detection of damaged components with minimum false alarms, and difficulties in assessing vibration diagnostic performance. Future challenges to overcome in developing more advanced HUMS will then be outlined. These include prognostic capabilities for HUMS that not only indicate that damage has occurred, but also assess the magnitude of damage and the remaining useful life of critical components. These will allow helicopter operators to obtain maintenance credits, increase the time between expensive overhauls, and facilitate using HUMS as a practical tool for on-condition maintenance.

Standard Practices

Over the past several decades, a number of diagnostic techniques have been developed to detect damage and abnormal conditions of the dynamic mechanical components in rotorcraft propulsion systems. A majority of the technology developed focuses on the gears, bearings and driveshafts of the main transmission system. Other areas addressed include main rotor balance indication and correction, and, more recently, the planet carrier of the final reduction stage in the main transmission. Brief overviews of these technologies are given below.

Vibration-Based Methods

Vibration-based methods are the most common diagnostic tool used in HUMS for distinguishing the nature of damage in helicopter transmissions. Using vibration data collected from gearbox accelerometers, algorithms are developed to detect when gear and bearing damage has occurred. Damage in gears and bearings produce changes in the vibration signatures of the helicopter. Over the past 25 years, numerous vibration-based algorithms for mechanical component damage detection in transmissions have been developed. The traditional methods of vibration based gear feature detection and extraction methods in rotating equipment, discussed in detail by Zakrajsek (1989), are typically based on some statistical measurement of vibration energy. The primary differences are based on which of the characteristic frequencies are included, excluded, or used as a reference. There are six distinct elements of analyzing vibration signals for transmission health monitoring: 1) time series signal acquisition, 2) signal separation, 3) synchronous averaging, 4) feature detection and extraction, 5) interpretation of results, and 6) prognosis (Decker, 2002).

Time Series Signal Acquisition Techniques

Time series signal acquisition is typically done on the ground with the main rotor engaged, or while airborne. In a series of flight studies, Huff, Mosher, Tumer, et al. (2000 to 2004) reported extensively on steady-state maneuvering influences on signal stationarity in two helicopter models (i.e., an AH-1 Cobra, and OH-58 Kiowa). Stationarity refers to the extent to which the statistical properties of the vibration data remain invariant over time. They found that the forward climb regime produced the most stationary vibration signal in a rotorcraft. They also reported several methods for data collection (Barszcz et al., 2004), including the use of multi-axis accelerometers, and potential real-time screening of time series data using state-space methods (Mosher et al., 2004).

Complex Signal Separation

Signal separation is often necessary in order to isolate a time series that can be associated with a specific gear or bearing component. Due to the fact that the transmission's gears are phase-locked, this can often be accomplished by appropriate signal averaging as discussed below. However, in complex mechanisms, such as the planetary gear assembly, this requires specialized algorithms, due to the fact that the vibration signal from a damaged planet gear is easily masked by the other non-damaged planet gears meshing at the same frequency. Mosher (2005) recently reported a new method that shows promise for overcoming this barrier.

Time Synchronous Averaging

Synchronous averaging refers to techniques for extracting periodic waveforms from additive noise by averaging vibration signals over several revolutions of the shaft (Stewart, 1977 and Decker and Zakrajsek, 1999). This can be done in either the time or frequency domains. However, the typical signal time synchronous average is obtained by taking the average of the signal in the time domain with each record starting at the same point in the cycle as derived from the once per revolution signal. The desired signal, which is synchronous with the shaft speed, will intensify relative to the non-periodic signals. This time synchronous average signal is used as a basis for gear vibration-based feature extraction methods. Hochmann (2005) shows that the rule of thumb in estimating amount of attenuation in synchronous averaging (reciprocal of square root of N, where N = number of averages) although representative for non-coherent components of a signal, is not representative of the coherent, non-synchronous part of the signal. Hochmann developed a method for computing the attenuation of coherent components of the signal for one-dimensional data. Several statistical and filtering operations can be used on the time synchronous averaged signal (Dempsey, 2000 and Mosher et al., 2002).

Feature Detection and Extraction

Feature detection and extraction refers to using a signal processing technique to extract useful information from the vibration signal that can indicate damage and differentiate between damage to different components. As discussed by Larder (1997), no one signal processing technique is effective for all types of defect signatures. Spectrum analysis techniques in the frequency domain can work well if a defect can be identified at low frequencies, but may not work well if the defect shows up in the mid and high frequency bands. To quote from Pipe (2003), "Key to the performance of a HUM system is that appropriate vibration analysis techniques are employed for the range of fault detection capability claimed."

Planet Carrier Monitoring

A flight critical component of many rotorcraft is the planet carrier in the final reduction stage of the transmission. In a planetary transmission system, the planet gears rotate about a shaft fixed to a single structural piece called the planet carrier. The planetary carrier transmits torque directly to the main rotor. Unlike other aircraft propulsion systems, there is no inherent redundancy for the planet carrier, and in-flight failure has the potential for total loss of vehicle and crew. Not only would the vehicle experience loss of power, it would also lose maneuvering and auto rotation ability. Several cases of cracked planetary carriers were found on US Army UH-60A Black Hawk helicopters in 2002, causing a fleet grounding of all non-mission critical flights (Champagne et al., 2004). The possible consequences that could have resulted if this fault were not identified led the Army to investigate tools to detect planetary carrier cracks well in advance of catastrophic failure. Garga et al. (2005) developed a technique to detect the planetary carrier crack based on the change in vibration pattern of the planetary carrier as a result of the reduced stiffness of the carrier post with the crack. This method applies an energy ratio technique to time synchronized data tracked on the rotational speed of the planet carrier. The method was applied to aircraft vibration data and test cell data with undamaged and damaged planetary carriers. Results showed that the method was most effective when applied to the higher planetary frequencies and at high torque levels.

Increasing the torque level results in an increasing change in stiffness and vibration of the cracked planetary carrier, and, as a result, is much easier to differentiate from a nominal signal.

Transmission Bearing Health Monitoring

The average rotorcraft power train contains over 70 rolling element bearings. Although bearings usually have a high tolerance for operating while damaged, detection of the damage is in many cases difficult due to the masking of the bearing vibration by other components in the system. In addition, wide variability of vibration data from similar bearings across a fleet of aircraft adds to the complexity of detecting specific damage in its early stages. Collateral damage caused by debris from a degraded bearing can result in system failure even before the terminal failure of the bearing itself. Randall (2001) provides a summary of diagnostics developed for bearings in helicopter gearboxes. Chin et al. (2005) developed a technique of comparative data analysis to evaluate the health of a number of bearings in a fleet of 30 aircraft equipped with a HUMS system. The technique developed is a post-processing tool that performs a statistical comparison of bearing fault indicators of all similar bearings in a fleet. Results to date isolated a damaged input thrust bearing on an intermediate gearbox on one of the helicopters in the fleet.

Gearbox Vibration Database

In early 1996 the Rotorcraft Industry Technology Association (RITA), in cooperation with representatives from Department of Defense, NASA and the Federal Aviation Administration (FAA) put together a "National HUMS Technology Roadmap." This roadmap defined the existing HUMS efforts, the state of HUMS technology and technology needs. One of the needs identified as the result of this exercise was advancement of diagnostics algorithms, damage and failure detection. The objective was to enhance the effectiveness of diagnostics algorithms in detection and isolation of fault in helicopter drive train. Early on the need for a central data repository for vibration data and existing diagnostics algorithms was identified. Sikorsky took the lead in developing a database storing the existing diagnostics algorithms and vibration data collected from multiple gearboxes for analysis. The database enables the user to apply different raw data to multiple algorithms and compare the results.

Metrics Evaluation Tool

In another effort, Boeing investigated the evaluation of diagnostics algorithms, identified metrics, criteria for threshold setting and impact on the detection and false alarm rate. The result of the study was compiled in a report, "Monitor the Monitors, RITA Metrics Document." The Metrics Document formulates a set of criteria that can be used by the rotorcraft industry and HUMS suppliers to evaluate and rate the performance and effectiveness of diagnostic algorithms. In a subsequent effort, Boeing developed a conceptual design for a tool adopting the analytical methods and metrics identified in the RITA metrics document. The tool, referred to as the Metrics Evaluation Tool, is a client- server application that extracts the data from the RITA Database. A paper by Safa-Bakhsh et al. (2003) describes the development of a Metrics Evaluation Tool for this purpose. The paper provides an overview of features to be evaluated using probability of detection and false alarm metrics as well as diagnostic accuracy metrics. Unfortunately, as of the date of this paper, a complete database of existing vibration algorithms and their capabilities or limitations is not available. This is due, in large part, to the limited amount of transmission seeded fault data that are available for full assessment and validation of vibration algorithm performance.

Environmental Effects on Vibration Methods

In addition to evaluating the performance of vibration features to detecting damage, it is equally important to verify the sensitivity of the features to typical environmental effects. The effects of speed and load have also been studied and will be required for utilizing HUMS for on-condition maintenance in varying flight regimes. Preliminary work performed by Decker (2002), Dempsey (2001), and Mosher et al. (2002) have evaluated gear diagnostic features under varying load, speed and flight conditions.

Condition Indicators in Certified HUMS

Providing clear information to the end user regarding the health of the transmission from the features extracted is a difficult process. All major HUMS currently certified for civil helicopters compute a number of condition indicators from vibration to characterization of the health of the component. In the Goodrich HUMS, selected condition indicators are fused into a Health Indicator (HI) to give an overall assessment of the state of the component. When the HI exceeds some threshold, the component is deemed to be in warning (perform additional analysis) or alarm (component is faulted and requires maintenance) (Bechhoefer et al., 2003).

Acoustic Emissions

As discussed by Evans (2003), although many component defects exhibit “classic” vibration signatures, new defect indications still occur and require expert interpretation and/or physical investigation is usually necessary to detect incipient failures that would otherwise remain undetected. One of the new technologies that is being developed is the use of acoustic emission data to detect the very early stages of crack initiation and propagation. As the crack tip advances through the material, the grains “snap” which creates a stress wave that propagates through the steel. In simple four point bending tests, this stress wave is measurable. As damage progresses, the number of events grows exponentially. A review of the literature suggests that this technology should be applicable to both crack and pitting damage on both gears and bearings (Tam and Mba, 2004 and Mba, 2005). They also report that this technology has the potential to be used for prognosis (Tam et al., 2004 and Tam et al., 2005) In addition, Li and Choi (2002) are using fracture mechanics and gear dynamic modeling codes to train forward neural networks to estimate crack sizes of vibration and acoustic emission data.

Data Fusion

One technique that has shown great promise for improving current HUMS performance is to integrate two measurement technologies, oil debris analysis and vibration, instead of relying only on vibration-based features. There are a number of on-line oil debris monitoring systems that can detect metallic debris in an oil flow line due to surface degradation of oil wetted components. Some of these systems can also determine particle size of the debris detected (Roylance and Hunt, 1999). Results from testing in NASA Glenn drive train test facilities show the potential for integrating oil and vibration results in a health monitoring system with improved damage detection and decision-making capabilities as compared to using individual measurement technologies (Dempsey, 2004).

Auto Rotor Imbalance Detection and Rotor Smoothing

A critical maintenance action specific to rotorcraft is reducing rotor imbalance related vibration. Maintaining smooth rotor operation is desirable for not only pilot and passenger comfort, but also critical to reducing excessive loading to the life-limited dynamic components of the rotor. Traditional methods of rotor smoothing require costly dedicated maintenance flights in which the pilot must fly specific flight regimes to obtain data for rotor adjustments. Many current HUMS installations automatically collect data from normal operational flights, and are used in conjunction with an automatic flight regime recognition system to obtain data for maintenance actions. Branhof et al. (2005) developed a new technique of automated rotor smoothing using continuous vibration measurements. Results demonstrated that rotor smoothing adjustments can be determined and applied based on continuous data to keep aircraft smooth in the flight regimes they spend most of their time. With continuous data collection, rotor smoothing data can be collected on every flight without pilot input or using regime recognition instrumentation. With this collection of continuous rotor smoothing data, adjustments can be applied to the aircraft at the discretion of the maintenance crew without special maintenance test flights. Some variability in the continuous vibration data was seen when the method was flight tested on an AH-64 Apache helicopter; however, the resulting rotor smoothing adjustments reduced the vibration to within goals where the aircraft flies the most.

Lessons Learned

A number of the technologies discussed in the previous section have been incorporated into industry and government developed on-board rotorcraft HUMS systems. The following paragraphs summarize results of fielding these systems, and subsequent lessons learned.

Eurocopter reports an assessment of their experience in HUMS development over the past 10 years in a paper by Pouradier and Trouvé (2001). Several shortfalls of today's HUMS are identified as well as ideas to correct them. As shown in table 1, the reasons for the shortfalls, such as system complexity, or damage never or inconsistently detected, summarize the challenges to improving the performance of current HUMS. This table also indicates the diagnostic system will be used as a maintenance tool, and for this reason it must provide the end user with a facile decision making tool for assessing system health.

TABLE 1.—EUROCOPTER'S LIST OF SHORTFALLS
(Pouradier and Trouve, 2001).

Shortfalls/Unforeseen Difficulties	Reasons identified	Eurocopter's answer
Integration with operator's maintenance and logistic organization	1. System complexity 2. New operator skills	• Adaptation of organizations • Training • Improved documentation • Support from aircraft manufacturer
Limited maintenance credits • Limited maintenance alleviation • Time Between Overhauls unchanged	Performance • Lack of evidence of performance • Incomplete defect coverage • Limited prognosis performance Regulation Requirements more demanding than those for maintenance tools	Performance • Cooperation with operators on database gathering/analysis • Research activity to increase defect coverage and prognosis performance • Economic benefit of structural usage monitoring to be assessed Regulation Consider HUMS a maintenance tool
Some mechanical damage is still missed • Monitoring of epicyclic stages to be improved • Some damage is never or is inconsistently detected	Performance • Incomplete defect coverage	Performance • Research activity to increase defect coverage • Techniques other than vibration analysis to be considered
Operating cost higher than anticipated • Decision making sometimes difficult	Performance • Limited diagnosis perform-ance because of not "defect specific" monitoring techniques	Performance • Improved diagnostic procedures • Research activity to improve diagnosis performance
Acquisition cost • Most of the Civil applications in the North Sea sector • HUMS mostly installed on heavy aircraft	Technology • Not enough standardization • Difficulty in retrofitting HUMS in aircraft with analogue avionics • Rapid obsolescence • Regulation • High integrity requirement	Technology • Standardization • Integration into digital avionics systems Regulation • Consider HUMS a maintenance tool
Support cost higher than anticipated • Long maturing process • Help for diagnostics • Threshold adjustment • Continuous development	Performance • Monitoring techniques not "defect specific" • Regulation • High integrity requirement	Performance • Streamlining ongoing development activity through support contracts • Improved diagnostic procedures • Research activity Regulation • Consider HUMS a maintenance tool

A paper by Heather (2003), presents an update on fielded experience for over 300 Smiths Aerospace HUMS in service. Although safety is the major benefit, the following maintenance and improved operational benefit have also been obtained.

- Accurate record of helicopter usage for maintenance and lifing
- Reduced consequential damage from a mechanical fault due to timely removal of component based on HUMS data
- Accurate recording of aircraft exceedances
- Improved aircraft troubleshooting
- Reduction of unscheduled maintenance
- Maintenance credits and extension of component life
- Fleet health verification through mining aircraft health data.

In particular, the Canadian Forces had a formal Maintenance Credit program developed by their OEM (Augustin and Bradley, 2004) for the CH-146 Griffon fleet. Many benefits were established, and the use of HUMS became second nature to the pilots and maintainers of this fleet of 100 aircraft. In addition, a review of 180 HUMS-related maintenance actions yielded the following results:

- 41 percent allowed the determination of an appropriate level of maintenance following an exceedance
- 19 percent allowed for installation condition improvements so as to preclude accelerated wearing of components
- 17 percent precluded the need for additional troubleshooting flights by having the second source of data available
- 12 percent precluded expensive ($100,000 plus) component replacement as result of an exceedance
- 11 percent possibly prevented serious faults from loose mounts, shifted hubs, worn tail shaft bearings, tail rotor pitch links and main rotor components

Another rotorcraft health management system being field tested on a several aircraft platforms has also yielded important maintenance information and lessons learned. The Integrated Mechanical Diagnostics Health and Usage Management System (IMD-HUMS) is a commercial system developed by the U.S. Navy and the Goodrich Corporation to be a common health management system for all Navy and Marine helicopters. The IMD-HUMS performs automatic rotor track and balance data collection to reduce aircraft vibrations caused by unbalanced rotor system. The IMD-HUMS also performs automated monitoring of all major dynamic components of the main drive train and tail rotor, and automated engine performance monitoring. In addition, IMD-HUMS performs usage and exceedances monitoring on critical structural components.

The U.S. Army and the Goodrich Corporation have undertaken a battalion-level demonstration of the Goodrich Integrated Mechanical Diagnostics Health and Usage Monitoring System (IMD HUMS). A paper by Dora et al. (2004) addresses the status of the demonstration. The paper identifies significant benefits of the system due to maintenance man-hour reductions (on the order of 58 percent reduction compared to current practices and automatic detection of drive train faults (Dora et al. 2004).

Little (2005) provides an overview of results from a recently completed operational test and evaluation program on three U.S. Marine CH53E helicopters. Results showed the IMD-HUMS system was able to detect a number of mechanical anomalies, including improperly balanced tail drive shafts, degraded main rotor damper bearings, and degraded engine performance which, if not detected, may have resulted in engine turbine section failure. Wright (2005) also gives an overview of current results from installing the IMD-HUMS system in 2003 on 30 U.S. Army UH-60L Black Hawk helicopters stationed in Mosul, Iraq. The installed IMD-HUMS units were able to detect prematurely worn generator shaft and adaptors on several units. It was also able to pinpoint tail rotor vibration problems to the tail rotor gearbox on one unit, which, upon inspection, had severely corroded components. The system also identified a number of sensor failures that were not apparent under routine inspections. Overall, the IMD-HUMS system has provided more specific diagnostic information on high vibration signals than previously available with standard techniques. Wright indicates that setting accurate threshold levels for the various health indicators in the system is underway, and will be completed mid 2005.

Another rotorcraft health management system is currently fielded on a number of helicopters in the U.S. Army. The Vibration Management Enhancement Program (VMEP) is a health management system developed by the U.S. Army and the Intelligent Automation Corporation to provide automated track and balancing of the main rotor, and diagnostic information on the primary drive system and tail rotor drives of the helicopter. It is currently under field testing and has been installed on over 100 aircraft which include the UH60, MH60, AH64, CH47, and the Bell 412. Branhof (2005) gives an overview of the mechanical faults detected to date using the VMEP system, and illustrates how this data collected can be used to develop a true condition- based maintenance program. Since 1999, the VMEP system has developed a large database of drive train diagnostics indicators that have been recorded. Some of the faults discovered were on critical areas of the drive train, and included a swash plate bearing, hangar bearing, engine nose gearbox, oil cooler fan bearing, and tail rotor drive shaft. The damaged units were removed and disassembled to accurately document the damage for direct correlation with the damage indicator. This validation step is critical for the development of reliable threshold levels, and on-condition based maintenance. This project also developed a web-based system where statistical analysis is performed on a data warehouse of Army HUMS parameters recorded from over 100 aircraft (Brotherton et al., 2003). This system has been used effectively to let engineers set condition indicator limits and find "outlier" aircraft from remote locations such as Iraq and Kosovo.

Another paper by Draper (2003) discusses the Smiths Aerospace GenHUMS (Generic HUMS) that has been in operational service in the UK Chinook fleet since 2000. This paper reviews the lessons learned and benefits from the Chinook program and how they are being incorporated in the Sea King, Puma, and Lynx program. One of the most notable benefits from GenHUMS to date was the use of the system to perform fleet wide health check monitoring following a break up of a combiner transmission bearing (Cook, 2002). The failure vibration characteristic was converted into a HUMS condition indicator and it was possible to screen all of the other HUMS equipped aircraft within 12 hours. The screening established that no other transmissions displayed similar failure characteristics, allowing aircraft with GenHUMS installed to remain available for operations. As HUMS technology matures, fleet-wide database and analysis capabilities will continue to provide significant benefits to the rotorcraft industry.

Future Challenges

Although rotorcraft health monitoring technologies have matured significantly over the last few decades, further work is needed to achieve the full safety and economic potential of an integrated health monitoring system.

The ultimate goal of rotorcraft health management systems is to achieve true condition-based maintenance and operational quality while increasing the safety of rotorcraft to that comparable to large fixed wing aircraft. To achieve these goals, the following future challenges will need to be addressed:

- Increase the fault detection coverage from today's rate of 70 percent
- Increase the reliability of damage detection
- Decrease false alarm rates from historic average rates of about 1 per 100 flight hours by an order of magnitude and at least no worse than the current misdiagnosis rate for component removals on non HUMS-equipped helicopters
- Develop technology to accurately detect onset of failure and isolate damage, and assess severity of damage magnitude. With this, develop life prediction technologies to assess effects of the damage on the system and predict remaining useful life and maintenance actions required
- Integrate the health monitoring outputs with the maintenance processes and procedures

- Develop data management and automated techniques to obtain and process the diagnostic information with minimal specialist involvement
- Develop system models, material failure models and correlation of failure under bench fatigue, seeded fault test and operational data
- Development of a generic data collection and management scheme for analysis of operational data is required. This requirement stems from the fact that establishing the threshold, false alarm and detection rates requires a large body of data with rich statistical content
- Development of mature and verifiable techniques to detect catastrophic failures and give in-flight pilot cueing and warning in near-real time

Conclusions

This paper gives an overview of health management issues and challenges specific to rotorcraft. This paper presented a review of standard practices used for rotorcraft health management in addition to lessons learned from a number of fielded systems. In addition, this paper outlines future challenges that need to be addressed to fulfill the safety and maintainability opportunities an advanced health management system represents. Although the technologies described in this paper were developed for rotorcraft, many of these technologies could be beneficial for other aerospace platforms. Areas such as data fusion and sensor integration would indeed be useful for any application where reliability and accuracy of damage detection is critical.

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13. ABSTRACT ***(Maximum 200 words)***
This paper presents an overview of health management issues and challenges that are specific to rotorcraft. Rotorcraft form a unique subset of air vehicles in that their propulsion system is used not only for propulsion, but also serves as the primary source of lift and maneuvering of the vehicle. No other air vehicle relies on the propulsion system to provide these functions through a transmission system with single critical load paths without duplication or redundancy. As such, health management of the power train is a critical and unique part of any rotorcraft health management system. This paper focuses specifically on the issues and challenges related to the dynamic mechanical components in the main power train. This includes the transmission and main rotor mechanisms. This paper will review standard practices used for rotorcraft health management, lessons learned from fielded trials, and future challenges.

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