DESIGN OF A NOVEL INTELLIGENT DATA MANAGEMENT TOOL FOR HEALTH AND USAGE MONITORING SYSTEMS – DESIGN REQUIREMENTS

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Abstract

The utilisation of Health and Usage Monitoring Systems (HUMS) for rotorcraft applications is critical to meet the stringent requirements of rotorcraft airworthiness. The implementation of HUMS systems for automated monitoring and automated inspection has improved safety and reduced maintenance costs associated with fleet management. A HUMS system provides the status of functionality and structural integrity for diagnosis and prognosis of the aircraft components. It encompasses structural & operational health monitoring and usage monitoring of components to provide diagnostic and prognostic analyses. This paper aims to provide a discussion of the design requirements which have been formulated to design a novel HUMS Intelligent Data Management Tool (IDMT) for the Multi-Role Helicopter (MRH) rotorcraft platform. The investigation of HUMS technologies for civil, military & MRH rotorcraft platforms provided the basis to stipulate the high-level design requirements. A parametrical categorisation of the design requirements led to the stipulation of the specific HUMS design parameters based on a holistic analysis. The design parameters will be utilised for integrated HUMS & FMS software development. It is envisaged that the HUMS IDMT will be integrated with the Fleet Management System (FMS) tool to aid the maintenance personnel via increasing efficiency of the current fleet management maintenance practices. Future research work will focus on the formulation and implementation of detailed design requirements & integrated system requirements specifications for HUMS & FMS software.

1 Introduction

The utilisation of Health and Usage Monitoring Systems (HUMS) for rotorcraft applications is critical to meet the stringent requirements of rotorcraft airworthiness. The implementation of HUMS systems for automated monitoring and automated inspection has improved safety and reduced maintenance costs associated with fleet management. A HUMS system provides the status of functionality and structural integrity for diagnosis and prognosis of the aircraft components. It encompasses structural & operational health monitoring and usage monitoring of components to provide diagnostic and prognostic analyses [1].

The present status and issues which affect the credibility of the HUMS system design and implementation [2, 3] are as follows: (a) Increased incidence of false alarm rates; (b) Abundance and ambiguity of data present; and (c) high cost of implementation. Tools and techniques need to be developed for successful implementation of HUMS systems in relation to the performance levels, regulatory requirements and technology. A holistic multidisciplinary design approach to HUMS system is needed to address the disparate requirements of aerospace design and airworthiness stipulations [2, 4].

This paper aims to provide a discussion of the design requirements which have been formulated to design a novel HUMS Intelligent Data Management Tool (IDMT) for the Multi-Role Helicopter (MRH) rotorcraft platform. The investigation of HUMS technologies for civil, military & MRH rotorcraft platforms provided the basis to stipulate the high-level design requirements. A parametrical categorisation of the design requirements led to the stipulation of the specific HUMS design parameters based on a holistic analysis. The design parameters will be utilised for integrated HUMS & FMS software development.

The HUMS IDMT will be integrated with the Fleet Management System (FMS) tool to aid the maintenance personnel via increasing efficiency of the current fleet management maintenance practices.

2 HUMS Technology – Civil Rotorcraft

HUMS technology for civil rotorcraft platforms is based on commercially available off-the-shelf systems for installation. The civil application of HUMS for North Sea operations formed the baseline standards for the development of future HUMS systems for civil & military rotorcraft platforms. Some of the HUMS technologies identified are specialised systems for specific civil rotorcraft application. The HUMS technologies for civil rotorcraft platforms are identified from which the high-level design requirements were stipulated (
Table 1).

3 HUMS Technology – Military Rotorcraft

The HUMS technologies developed for military rotorcraft platforms are investigated. Military HUMS systems are designed to operate in extreme & varying environmental conditions. Some of the HUMS technologies identified are specialised systems for specific military rotorcraft application. The various HUMS technologies implemented for military rotorcraft platforms are identified from which the high-level design requirements were stipulated (Table 2).

Table 1. HUMS Technology (Civil Rotorcraft) – Design Requirements & Application Platforms

HUMS Technology (Civil Rotorcraft)	High-Level Design Requirements	Application Platforms
North Sea HUMS: The North Sea HUMS is a first generation HUMS which includes a comprehensive ground station (UNIX operating system with remote desktop capabilities) for processing the flight data. The aerial system provides monitoring of drive system vibration (rotor system, engine & gear box), monitoring of flight regime & engine performance and processing of flight data & cockpit voice recording. The data transfer to the ground station is via a Personal Computer Memory Card International Association (PCMCIA).	• Collation and processing of vibration, performance & flight data; and • Analysis of data for diagnostics and prognostics.	The North Sea HUMS has been implemented on civil versions of Boeing Chinook CH-47 and Eurocopter Super Puma AS332 [4-6].
Eurocopter HUMS: The EuroHUMS is a customised version of the North Sea HUMS. It comprises of the aerial and ground system. The aerial system covers health monitoring (defect detection of dynamic components), usage monitoring (mechanical component life) and continuous status monitoring (rotorcraft systems). The ground station system utilises the collated information for provision of diagnostic and prognostic support. A PCMCIA card is utilised to transfer data to the ground station.	• Acquisition of flight data in accordance with regulations for health, usage and status monitoring; and • Analysis of data for diagnostics and prognostics for maintenance.	The EuroHUMS has been implemented on civil and military versions of Eurocopter AS332 Super Puma [6-9].
Aircraft Recording & Monitoring Systems: The ARMS comprises of aerial and ground systems. The aerial system utilises sensors and accelerometers to obtain flight data from engines, airframe and drivetrain. Vibration information is collated for major components.	• Acquisition and processing of flight data from engines, airframe & drivetrain; and	The ARMS has been implemented on both the civil & military versions of the Eurocopter AS332 Super Puma/EC155 [6, 10, 11].

The data is transferred to the ground station system utilising a PCMCIA card. The ground station system utilises the collated data to establish basic signatures and trends for rotorcraft components and systems. A maintenance report containing all parameter exceedances encountered during the flight with corresponding corrective actions and maintenance schedules is generated.	• Analysis of data for diagnostics and prognostics to generate maintenance schedules.	
VXP HUMS: The system provides integrated aerial and ground system technologies. The VXP HUMS system comprises of aerial and ground systems. The aerial system consists of VXP acquisition and display units. The VXP HUMS system obtains data from the vibration, tachometer and optical blade tracker sensors located on the rotorcraft. The acquisition and display units utilise customised software to provide on-board diagnostics to generate a Monitor Report. The data is transferred to the ground station system utilising a PCMCIA card. The ground station system utilises an IBM compatible personal computer for detailed diagnostics and prognostics analyses. The maintenance schedules are generated accordingly. The open system architecture of VXP HUMS systems allows third parties to provide options for communicating HUMS data to the ground station system.	• Acquisition and processing of usage/exceedances data for on-board diagnostics to generate a Monitor Report; and • Detailed analysis of flight data for diagnostics & prognostics to generate maintenance schedules.	The VXP HUMS system is implemented on the civil versions of Sikorsky S-61N/L, S-76A++, S-76C/C+, Bell 206L/412/407/427/430, Agusta A109 and Eurocopter AS-365N1/2/3 [12].
Bell Agusta 609 HUMS: The BA609 HUMS system (directly derived from the Generic HUMS) comprises of aerial and ground station systems. The aerial system monitors the rotorcraft for component usage & exceedances and monitors drivetrain components for condition indices. Data is transferred to the ground station system utilising a PCMCIA card. The ground station system utilises the collated data to conduct survey of the operational status of rotorcraft/fleet for efficient component health trend identification and maintenance planning.	• Acquisition and processing of flight data for component exceedances, usage & condition indices (for drivetrain components); and • Analysis of data for efficient diagnostics & prognostics for maintenance planning.	The BA609 HUMS is a HUMS system designed specifically for implementation on the civil BA609 [13, 14].

Table 2. HUMS Technology (Military Rotorcraft) – Design Requirements & Application Platforms

HUMS Technology (Military Rotorcraft)	High-Level Design Requirements	Application Platforms
Integrated HUMS: The aerial system monitors the engine performance, RTB, drive train and airframe usage & exceedances. The Data Acquisition and Processing Unit (DAPU) collates & processes data (usage, flight, load factor and tail rotor servo) utilising sensors (RTB & transmission). Additionally, it acquires pertinent data from the CV/FDR. The monitoring data is stored on PCMCIA and is available for display on the Pilot Interface Panel (PIP). Post flight data is transferred from Card Quick Access Recorder (CQAR) to ground station by the PCMCIA. The ground station system utilises a Windows NT/Unix based Graphical User Interaface (GUI) to support processing and compilation of flight data for operations, maintenance & logistics. It covers exceedance detection, diagnostic checks and component usage tracking. It archives flight data and history of components and assemblies for maintenance.	• Provision for collation and processing of usage, flight, load and rotor data; and • Provision for analysis of data for diagnostics and prognostics.	The IHUMS system has been implemented on civil and military rotorcraft platforms which include Eurocopter AS332/AS365, Sikorsky S-76/S-61 and Bell 212/214 [6, 15].

Integrated Mechanical Diagnostics HUMS: The IMD HUMS comprises of the aerial system and ground system. The aerial system collects, processes, analyses and stores data obtained from sensors. The Main Processing Unit (MPU), the principal aerial component, analyses the input data for exceedances, flight regimes & events, performs various diagnostic algorithms and stores the data to an onboard data cartridge (PCMCIA card). It also collates the pertinent data from the CV/FDR. The acquired flight data is stored on a Data Transfer Unit (DTU) and transferred to the ground system utilising a PCMCIA card. The ground station system is a Windows NT-based client-server system used to provide an interface to configuration & maintenance functions. It provides data acquisition capabilities from the aerial system utilising a PC card to perform diagnostics/prognostics and maintenance actions.	• Provision for health, usage and exceedance monitoring of rotorcraft system assembly/structure; and • Provision for transfer, storage, analysis and processing of data for diagnostics & prognostics and maintenance actions.	The IMD HUMS system has been implemented on civil and military rotorcraft platforms which include Sikorsky S-92/S-76/H-60/H-53 and Bell AH-1/UH-1 [6, 16-23].
Generic HUMS: The GenHUMS functions cover health monitoring of engine, transmission, rotor and airframe system. Additionally, it covers usage monitoring of engine & airframe and conducts RTB functions. The aerial system of GenHUMS comprises of Data Acquisition and Processing Unit (DAPU), Cockpit Control Unit (CCU), Cockpit Interface Panel (CIP), Data Transfer System (DTS) and Optical Blade Tracker (OBT). The DAPU acquires and processes data from all sensors and stores the data on a Data Transfer Device (DTD – PCMCIA card) which is a part of the DTS. It also displays relevant exceedances, alerts and data on the CCU. The OBT measures track/lead-lag data utilising special tracker photo-diodes for RTB. The CV/FDR provides data collection and incident/mishap recording of audio data, rotorcraft flight & system parameters for post-incident analysis. The HUMS Ground Station (HGS) provides analysis of rotorcraft system health and usage monitoring parameters utilising PC-based workstation. The HGS data analysis covers fleetwide data, changing/resetting of component thresholds for damage diagnosis & prognosis and RTB & vibration data for creating standard reports.	• Acquisition and processing of data from sensors to cover health monitoring (engine, transmission, rotor and airframe system), usage monitoring (engine & airframe) & RTB; and • Provision for data analysis of health, usage & RTB to perform diagnostics and prognostic analyses on ground station for maintenance.	The GenHUMS system has been implemented on the military Chinook, Puma, Sea King and Lynx rotorcraft platforms [6, 14, 22, 24-27].
Total Health and Usage Management System: It comprises of aerial and ground systems. The aerial system utilises sensors to conduct in-flight diagnostics of power-plant, vibration & RTB analysis, regime recognition, power assurance, load/stress and other flight critical systems monitoring. Additionally, it provides in-flight processing and diagnostics capability. Data is transferred to the ground station system utilising a PCMCIA card. The ground station system provides diagnostics and prognostics utilising expert system, neural networks and fuzzy logic solutions. Additionally, it provides support tools for data mining & archiving, vibration analysis, web link support and an option of a workstation for mission debriefing. The T-HUMS open system architecture allows for adaptability to rotary and fixed wing aircraft. It provides viable upgrade configuration for interfaces, sensor packages and various other configurations.	• In-flight acquisition, processing and diagnostics of flight data; • Open architecture for adaptability on different platforms and configurations; and • Analysis of data for diagnostics and prognostics utilising expert system and classification algorithms (neural networks, fuzzy logic).	The T-HUMS has been implemented on the military CH-53, AH-64 Apache and the UH-60 Blackhawk [6, 28].

Vibration Management Enhancement Program: The VMEP HUMS system comprises of aerial and ground systems. The aerial system consists of Vibration Management Unit (VMU) and sensors (tachometers and accelerometers distributed throughout the rotorcraft's drive train). The VMU measures and processes vibration and other parametric information in flight. The VMU front panel provides flight specific status information for the aircrew. The flight data is transferred to the ground station system via a MIL-STD 1553B serial data bus. The ground station system comprises of supporting software for detailed engineering analysis on a PC based Windows platform – PC Ground Based System (PC-GBS). The PC-GBS software provides multi-level operator interface for specific data to isolate potential faults. It displays recommended maintenance actions on-board the rotorcraft & fleet status to the maintenance manager. The flight information is automatically downloaded to the VMEP web-based infrastructure tool when it is attached to the PC-GBS for provision of data archiving, software configuration management and management reports.	• Acquisition, processing and automated on-board diagnostics for RTB & rotorcraft system assembly; and • Analysis of flight data for diagnostics & prognostics to generate maintenance/management reports and data archiving.	The VMEP HUMS system is implemented on the military versions of AH-64 Apache, UH-60/MH-60 Black Hawk, CH-47 Chinook, OH-58 Kiowa and Bell 412 [22, 25, 29-31].
Merlin HUMS: The aerial and ground systems are configured to address the differences between the Merlin HUMS & GenHUMS system architectures. The ground station system for Merlin HUMS (Enhanced Health and Usage Diagnostic System – EHUDS) incorporates complete asset and maintenance tracking capability. The Merlin Mk1 HUMS evaluates four parameters from each of the transmission vibration signals for a single drive train component. Comparatively, the GenHUMS evaluates fifty CIs defined for transmission vibration. The Design Authority (DA) restricts Merlin HUMS configuration to a minimum, robust & reliable set of CI parameters to reduce extensive qualification requirements for each CI algorithm and associated software.	• Provision for extensive health monitoring (engine), usage monitoring (standard/enhanced structural, transmission, engine), transmission vibration monitoring (standard & enhanced), quantitative debris monitoring & RTB; and • Provision for complete asset and maintenance tracking capability with minimum, robust & reliable set of CIs for software development.	The Merlin HUMS system has been implemented on the EH101 military rotorcraft platform [26, 27].
Longbow Apache HUMS System: The system comprises of aerial and ground systems. The aerial system capabilities include RTB; engine & transmission vibration monitoring; engine performance, airframe & exceedance monitoring; aircraft, transmission, engine & structural usage monitoring; and avionics diagnostics & voice recording. Data is transferred to the portable PC ground station utilising a PCMCIA card or MIL-STD-1553B databus. The ground station system utilises Logistics Integrated Maintenance Support System (LIMSS) to provide the maintainer with Interactive Electronic Technical Manaul (IETM) on a portable computer – the Soldiers Portable On-system Repair Tool (SPORT). It utilises a fault diagnosis and ambiguity reduction program to interpret fault data and automatically directs the maintainer to the appropriate section of the technical manual. Maintenance schedules are generated accordingly.	• Acquisition, transfer & processing of usage, exceedance and monitoring of rotorcraft system assembly; • Analysis of flight data for diagnostics & prognostics to generate maintenance schedules; and • Individual level software based repair analysis.	The Longbow Apache HUMS system is designed specifically for implementation on the military AH-64D Apache [14, 32].
Bell CH-146 Griffon HUMS System: The system comprises of aerial and ground systems. The aerial system comprises of the Main Data Acquisition Unit (MDAU), CV/FDR and sensors/accelerometers. The MDAU acquires pertinent flight data via sensors and CV/FDR which is processed and stored for	• Acquisition, transfer and processing of flight data for RTB diagnostics, usage, exceedances and monitoring of rotorcraft	The Bell CH-146 Griffon HUMS system is designed specifically for implementation on the military Bell CH-146 Griffon [33].

further diagnostics and prognostics. The data is transferred to the ground station utilising a PCMCIA card. The ground station system utilises the information for diagnostics and prognostics purposes. Maintenance schedules are generated accordingly.	system assembly; and • Analysis of flight data for diagnostics & prognostics to generate maintenance schedules.	
Sikorsky JUH-60A HUMS System: The system comprises of aerial and ground systems. The aerial system comprises of the Flight Loads Monitoring System (FLMS) and the Multi-purpose Display Unit. The FLMS consists of three subsystems: a) Rotor Data System (RDS); b) Fuselage Data System (FDS); and c) HUMS computer. The RDS comprises of sensors and signal conditioning located on the rotating portion of the main rotor assembly for data collation. The FDS comprises of sensors and signal conditioning located on the non-rotating portion of the rotorcraft for data collation. The on-board HUMS computer collates data from the RDS & FDS, conducts data analysis and archives data on digital storage media. The multi-purpose display unit displays the HUMS status and control. The data is transferred to the ground station utilising an air to ground telemetry antenna. The ground station system utilises the information for diagnostics and prognostics purposes. Maintenance schedules are generated accordingly.	• Acquisition and processing of rotor system assembly, fuselage & flight data; and • Analysis of flight data for diagnostics & prognostics to generate maintenance schedules	The Sikorsky JUH-60A HUMS system is designed specifically for implementation on the military Sikorsky JUH-60A [34].

4 HUMS Technology – MRH

The MRH technology provides the basis to formulate the specific HUMS technology design requirements for identification of the monitoring, diagnostics & prognostics requirements. The monitoring is governed by the systems to be analysed for health, usage and status. A description of the MRH HUMS technology from which the high-level design requirements were stipulated are presented in Table 3.

Table 3. MRH HUMS Technology & Design Requirements

MRH HUMS Technology	High-Level Design Requirements
The HUMS technology on the MRH comprises of the Ground Management System (GMS) and Diagnostic System (DS). The GMS provides the required information to initiate/perform the appropriate maintenance activities. It is a software support tool to manage the maintenance activities associated with the rotorcraft platform. Additionally, the GMS provides Flight Condition Recognition (FCR) capability for 29 flight conditions utilising a FCR buffer. It computes usage for rotorcraft components & assembly. The on-board DS conducts the required diagnostic & prognostic functions for maintenance. It provides preventive maintenance (prognostic information for failure prediction); and corrective maintenance (failure detection & isolation). These capabilities are achieved by Built-In-Test (BIT) functions and failure isolation [35, 36]. The MRH HUMS system is implemented in accordance with the ADF regulations – Australian Air Publication (AAP) 7001.054 Airworthiness Design Manual [37].	• Provision of a ground system to analyse acquired on-board data for maintenance actions; • Provision of an on-board system to provide preventative/corrective maintenance actions; • Monitoring of health, usage & status to achieve the availability targets; and • Provision of FCR capability to determine rotorcraft component & assembly usage.

5 Design Requirements

The investigations of HUMS technologies for civil, military & MRH rotorcraft platforms provided the basis to stipulate the high-level design requirements for the HUMS IDMT. The design requirements were collated & categorised parametrically for inputs to the HUMS software development. The detailed design requirements will be specified and implemented in future research work.

5.1 Design Parameters

The high-level design parameters are identified based on the results of civil, military & MRH HUMS technology analysis. The design requirements are parametrically categorised to stipulate the design parameters comprising of diagnostics & prognostics (aerial & ground systems), data management and open system architecture.

5.1.1 Diagnostics & Prognostics – Aerial System

The aerial system is required to provide automated on-board diagnostics & prognostics for various rotorcraft systems & subsystems from collated flight data. The analysed data is to be utilised for preventative maintenance (failure prediction) & corrective maintenance (failure detection & isolation). Additionally, the aerial system will provide health, usage & status monitoring to generate a Monitor Report.

The HUMS IDMT will determine usage monitoring of the rotorcraft based on the recognised flight conditions experienced by the rotorcraft to output a usage/Monitor report.

5.1.2 Diagnostics & Prognostics – Ground System

The ground system is required to provide diagnostics & prognostics capability for maintenance scheduling. The acquired flight data is to be analysed by expert systems and classification algorithms (neural networks, data mining, fuzzy logic) for diagnostics & prognostics. The ground system will provide complete asset and maintenance tracking capability by a set of condition indicators for diagnostics & prognostics of rotorcraft components & assembly.

The ground system is also required to provide individual software based repair analysis for efficient mission planning of the rotorcraft fleet. It will generate TEs with appropriate information and provide diagnostics/prognostics of the failure. Accordingly, it will generate maintenance & management reports.

The HUMS IDMT will provide flight condition recognition capability to determine rotorcraft component & assembly usage utilising classification algorithms.

5.1.3 Data Management

The data management covers data acquisition, processing, storage and transfer.

- <u>Acquisition & Processing</u>: Acquisition & processing of flight data is required for diagnostics and prognostics analyses. On-board hardware and software will be required to obtain the rotorcraft component & assembly flight data (vibration, performance, health/usage/status, RTB).

- <u>Data Storage & Transfer</u>: Data storage capability is required to archive data for long/short term to generate fleet statistics & diagnostics/prognostics reports. Data transfer capability is required between aerial & ground systems and other ground station/ground management system (GMS) systems. It is also required to provide import/export of data through support software tools/GMS interface for diagnostics and prognostics analyses. Data storage and transfer will be provided utilising a data transfer device with a specified memory capacity.

5.1.4 Open System Architecture

An open system architecture is required for adaptability of HUMS system modules to different rotorcraft platforms & configurations. It is also required for third parties to communicate HUMS data to the ground station system. The open system architecture is required to facilitate technology insertion and interoperability [38].

6 Results & Discussion

The HUMS technologies were investigated for its characteristics and capabilities to identify the design requirements for the development of

HUMS IDMT. The investigations covered civil and military HUMS including the MRH platform for technology status update.
The investigation results were collated to establish a set of HUMS design requirements. The detailed design requirements will be specified and implemented in future research work.

6.1 HUMS Technology Status

The investigations on HUMS technology status covered the identification of several off-the-shelf HUMS technology systems for installations on civil & military rotorcraft. The spectrum of systems investigated provided the operators & maintainers with health, usage and status information for diagnostic & prognostic analyses for maintenance purposes.

The investigations categorised the various systems based on system specific capabilities. It covered various platforms and degree of capability. In addition, the military technology covered the operational environment and the MRH HUMS system.

6.2 Design Requirements

The investigations on HUMS technologies for civil, military and MRH platforms provided the basis to identify the high-level generic design requirements for development of HUMS IDMT. The design requirements identified for the HUMS technologies were categorised into a set of comprehensive requirements from a parametric perspective. It comprises of design parameters to address diagnostics & prognostics (aerial & ground systems), data management and open system architecture.

The aerial system provided diagnostics and prognostics for preventive and corrective maintenance actions while the ground system provided further analyses for maintenance scheduling. In addition, the ground system provided inputs for maintenance planning and generation of maintenance & management reports. Data management requirements addressed the acquisition, processing, storage and transfer of data. An open system architecture is to be adopted to facilitate interoperability to other types of platforms and usage by third parties.
The identified design parameters provide the platform for establishment of a framework to develop the HUMS IDMT.

7 Concluding Remarks

The HUMS technologies for present civil, military and MRH rotorcraft platforms were adequately identified. The investigations provided the basis to stipulate a comprehensive set of high-level design requirements.

Future research work will focus on the formulation and implementation of detailed design requirements & integrated system requirements specifications for HUMS & FMS software.

References

[1] Friend, S., et al., 2005, 'SH-60B HUMS experience using a satellite data link', in *Aerospace Conference, IEEE Proceedings, Big Sky, USA, March 5-12, 2005*, pp. 3445- 3453.

[2] Mukkamalla, R., Britton, M., and Sundaram, P., 2002, 'Scenario-based specification and evaluation of architectures for health monitoring of aerospace structures', in *Proceedings of the 21st Digital Avionics Systems Conference*, pp. 12E1-1 - 12E1-12.

[3] Parekh, D.K. and Sinha, A.K., 2007, 'Preliminary studies on health and usage monitoring system architecture for the NH-90 rotorcraft platform', in *American Helicopter Society 63rd Annual Forum, Virginia Beach, VA, May 1-3, 2007*, pp. 1-7.

[4] Land, J.E., 2001, 'HUMS - The benefits - past, present and future', in *Aerospace Conference, IEEE Proceedings, Big Sky, USA, March 10-17, 2001*, pp. 3083-3094.

[5] Anon., "Honeywell EVXP HUMS certified by FAA and ed by Sikorsky for S-76C++ helicopter," October 2007, http://honeywell-news.newslib.com/story/6665-3235634/.

[6] Wiig, J., 2006, 'Optimisation of fault diagnosis in helicopter health and usage monitoring systems', PhD Thesis, I'Ecole Nationale Superieure d'Arts et Metiers.

[7] Anon., "Singapore Super Puma get HUMS," July 1995, www.flightinternational.com.

[8] Anon., "HUMS maintenance safety," January 2000, http://www.eurocopter.de/site/FO/doc/rotor_j/30/pa-30-20-01.pdf.

[9] Anon., "EuroHUMS Support," n.a 2001, http://www.eurocoptersea.com/hums.htm.

[10] Anon., "Eurocopter AS332-L2, Super Puma, G-JSAR," February 2003, www.aaib.gov.uk/cms_resources/dft_avsafety_pdf_030207.pdf.

[11] Pouradier, J.-M. and Trouve, M., 2001, 'An assessment of Eurocopter experience in HUMS development and support', in *American Helicopter Society 57th Annual Forum, Washington, DC, May 9-11, 2001*, pp. 1-8.

[12] Anon., "VXP HUMS," April 2005, http://www51.honeywell.com/aero/common/documents/HUMS.pdf.

[13] Anon., "Bell Helicopter selects Smiths Aerospace Cockpit Voice and Flight Data Recorders," September 2001, http://www.geaviationsystems.com/News.

[14] Larder, B., et al., 2000, 'Smith Industries HUMS: Changing the M from Monitoring to Management', in *Aerospace Conference, IEEE Proceedings, Big Sky, USA, March 18-25, 2000*, pp. 449-455.

[15] Anon., "Integrated health and usage monitoring systems," n.a 2006, http://www.meggitt-avionics.co.uk.

[16] Hess, R., Duke, A., and Kogut, D., 2001, 'The IMD HUMS as a tool for rotorcraft health management and diagnostics', in *Aerospace Conference, IEEE Proceedings, Big Sky, USA, March 10-17, 2001*, pp. 3039-3058.

[17] Brock, L., 2001, 'Role of open systems in implementing Navy HUMS', in *American Helicopter Society 57th Annual Forum, Washington, DC, May 9-11, 2001*, pp. 1-7.

[18] Hess, R. and Patriquin, D., 2001, 'Concepts for reapplying HUMS technology across rotorcraft platforms', in *American Helicopter Society 57th Annual Forum, Washington, D.C., May 9-11, 2001*, pp. 1-8.

[19] Hess, R., et al., 2000, 'Realising an expandable open HUMS architecture', in *American Helicopter Society 56th Annual Forum, Virginia Beach, May 2-4, 2000*, pp. 1-7.

[20] Muldoon, R.C., Gill, J., and Brock, L., 1999, 'Integrated mechanical diagnostic (IMD) health and usage monitoring system (HUMS): An open system implementation case study', in *Proceedings of the 18th Digital Avionics Systems Conference, St Louis, MO, USA, October 24-29, 1999*, pp. 9.B.4-1-9.B.4-8.

[21] Dora, R. and Boydstun, B., 2004, 'Utility of the IMD HUMS in an operational setting on the UH-60L Blackhawk', in *American Helicopter Society 60th Annual Forum, Baltimore, Maryland, May 7-10, 2004*, pp. 1-10.

[22] Zakrajsek, J., et al., 2006, *Rotorcraft health management issues and challenges*, pp. 15.

[23] Edsall, A., 2000, 'Technology insertion in health and usage monitoring systems: An integrator's perspective', in *American Helicopter Society 56th Annual Forum, Virginia Beach, Virginia, May 2-4, 2000*, pp. 1-10.

[24] Trammel, C., Vossler, G., and Feldmann, M., 1997, 'UK Ministry of Defence generic health and usage monitoring system (GenHUMS)', in *American Helicopter Society 53rd Annual Forum, Virginia Beach, Virginia*, pp. 9.

[25] Dempsey, P., Lewicki, D., and Le, D., 2007, 'Investigation of current methods to identify helicopter gear health', in *IEEE Aerospace Conference*, pp. 14.

[26] Cook, J., Gourlay, J., and Boardman, L., 2004, 'Contrasting approaches to the validation of helicopter HUMS - a military user's perspective', in *Aerospace Conference, IEEE Proceedings*, pp. 3748- 3755.

[27] Rushworth, P., et al., 2007, 'Benefits and pitfalls of health and usage monitoring systems and development of UK MoD policy', in *Australian International Aerospace Congress, Melbourne*, pp. 9.

[28] Anon., "Total health and usage management system for helicopters and tilt rotor aircraft," n.a 2005, http://www.rsl-electronics.com/.

[29] Grabill, P., et al., 2002, 'The US Army and National Guard Vibration Management Enhancement Program (VMEP): Data analysis and statistical results', in *American Helicopter Society 58th Annual Forum, Montreal, Canada, June 11-13, 2002*, pp. 1-19.

[30] Brotherton, T., et al., 2003, 'A testbed for data fusion for helicopter diagnostics and prognostics', in

Proceedings of the 2003 IEEE Aerospace Conference, Big Sky MT, USA, pp. 1-14.

[31]Giurgiutiu, V., et al., 2000, 'Helicopter health monitoring and failure prevention through Vibration Management Enhancement Program', in *54th Meeting of the Society for Machinery Failure Prevention Technology, Virginia Beach, VA, USA, May 1-4*, pp. 1-10.

[32]Anon., "AH-64D Longbow Apache HUMS," October 2007, http://www.janes.com/extracts/extract/jav/jav_1553.html.

[33]Augustin, M.J., Heather, A., and Rogers, H., 2001, 'Implementing HUMS in the military operational environment', in *American Helicopter Society 57th Annual Forum, Washington, DC, May 9-11, 2001*, pp. 1-9.

[34]Ellerbrock, P.J., Halmos, Z., and Shanthakumaran, P., 1999, 'Development of new health and usage monitoring system tools using a NASA/Army rotorcraft', in *American Helicopter Society 55th Annual Forum, Montreal, Canada, May 25-27, 1999*, pp. 1-12.

[35]Bertaccini, C., 2006, *Ground Management System (GMS) Specification*, SP N000G0921E01, pp. 47.

[36]Maino, B., 2003, *Diagnostics System (DS) Specification*, SP N 000 G 0918 E01, pp. 33.

[37]Parekh, D.K. and Sinha, A.K., 2008, *Health and Usage Monitoring System (System & Software - Requirements Analysis)*, Report ADCO TN-2006-06-1b, Sir Lawrence Wackett Aerospace Centre, RMIT University, Melbourne, pp. 1-43.

[38]Haas, D., Schaefer, C., and Spracklen, D., 1999, 'JAHUMS ACTD - A case study in open systems from a technology insertion perspective', in *Proceedings of the 18th Digital Avionics Systems Conference, St Louis, MO, USA, October 24-29, 1999*, pp. 9.B.5-1-9.B.5-10.

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