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Rotorcraft Health and Usage Monitoring Systems - A Literature Survey

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Dear Colleague:

This technical report, **Rotorcraft Health and Usage Monitoring Systems - A Literature Survey (FAA/RD-91/6)**, describes the results of an extensive literature search of health and usage monitoring (HUMS) technology. Based on an analysis of over 1,000 abstracts, this report describes 20 systems and the abstracts of 90 papers pertinent to rotorcraft HUMS.

This document is part of an effort to establish a foundation of knowledge and information to support FAA rotorcraft certification requirements. This document has been prepared at the request of the FAA's Rotorcraft Certification Directorate in response to that office's expectations for increased HUMs related requirements. The rotorcraft industry is developing a number of techniques, methodologies, and associated equipment related to monitoring the health and usage of critical flight components. The increased application of artificial intelligence technology and expert systems has significant promise in increasing accuracy and effectiveness. Military applications of such diagnostics and related "black box" equipment to reduce maintenance requirements and increase aircraft flight availability could potentially benefit civilian operators in their challenge to stay in the "black" economically.

In continuing to meet their responsibility for the certification of aircraft and equipment they contain, the FAA expects to develop detailed certification addressing aircraft and equipment that incorporate HUMS. The immediate goal of the FAA is to gain a better understanding of what industry is developing in the HUMS area. The goal of this report was the identification of the firms involved, key people, and the degree of technology maturity which may allow for some airworthiness credit to be given.

Robert D Smith

for James I. McDaniel
Program Manager
Vertical Flight Program Office

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16. Abstract

The rotorcraft industry is developing a number of techniques, methodologies, and associated equipment for monitoring health and usage of critical rotorcraft flight components. Industry is planning to incorporate this technology on a number of new aircraft. The Federal Aviation Administration (FAA) has the responsibility for certification of these aircraft and the equipment they contain. This effort is concerned with the health and usage equipment. To best accomplish the certification of these equipment, the FAA expects to develop detailed certification criteria addressing specific issues of concern.

In the near-term, the FAA objective is to develop a better understanding of what is being developed by industry (with emphasis on United States industry), what firms are involved, who are the key people involved, what parts of this technology are mature to the point that some airworthiness credit may be appropriate, and what parts of this technology are not yet mature. With information such as this, the issues that need to be address via certification criteria can be determined quickly.

This effort is principally intended to provide support in reaching the FAA's near-term objectives. This report describes the results of an extensive literature search of health and usage monitoring technology. Over 1,000 abstracts were reviewed and analyzed. The report contains a description of 20 systems and abstracts of 90 papers pertinent to health and usage monitoring.

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TABLE OF CONTENTS

		Page
1.0	Introduction	1
1.1	Literature Search	1
1.1.1	Purpose	1
1.1.2	Requirement	1
1.1.3	Technical Approach	1
1.1.4	Data Sources	2
1.1.5	Literature Search Products	2
1.2	Industry Survey	2
1.2.1	Purpose	2
1.2.2	Requirement	2
1.2.3	Technical Approach	2
1.2.4	Data Sources	3
1.2.5	Industry Survey Products	3
2.0	Overview	5
2.1	Search Methods	5
2.2	Document Retrieval	6
3.0	Health and Usage Monitoring Systems	7
3.1	Engine Performance Assurance Monitoring System (EPAMS) - Howell Instruments, Fort Worth, TX	7
3.2	Helicopter Pilot's Emergency Situation Advisor (H/PESA) - Honeywell, Defense Avionics Division	8
3.3	Engine Diagnostic Expert System (HELIX) - Sikorsky Aircraft Division, United Technologies Corporation	8
3.4	Intelligent Fault Isolation Procedures (IFIP) - Sikorsky Aircraft Division, United Technologies Corporation	8
3.5	Aircraft Integrated Monitoring System (AIMS) and Integrated Health and Usage Monitoring System (IHUMS) - Bristow Helicopters Ltd. and Plessey Avionics, London, UK	9
3.6	Power Analyzer and Recorder (PAR) - Teledyne Avionics, Charlottesville, VA	9
3.7	Rotor Track and Balance System (ROTABS) - Vibro-Meter Company, Torrance, CA	9
3.8	COMPASS - Rolls-Royce/SD-SCICON, UK	9
3.9	Expert Maintenance Troubleshooter (XMAN) - Systems Control Technology, Inc., Palo Alto, CA	10
3.10	Advanced Avionic Architecture Maintenance/ Diagnostic Assessment (AAM/DA) - Bell Helicopter Textron, Fort Worth, TX	10
3.11	Engineering Technical Analysis and Design System (ETADS) - Bell Helicopter Textron, Fort Worth, TX	10
3.12	Intelligent Maintenance Expediter and Training Aid System (IMETS) - Bell Helicopter Textron, Fort Worth, TX	10
3.13	Vibration, Structural, Life, and Engine Diagnostic System (VSLED) - Bell Helicopter Textron, Fort Worth, TX	11

3.14 Light Helicopter - Integrated Diagnostics (LH ID) - Bell Helicopter Textron, Inc., Fort Worth, TX....11
3.15 Generic Integrated Maintenance and Diagnostics (GIMADS) Program - General Dynamics (Prime Contractor), Bell Helicopter Textron (Subcontractor)....11
3.16 TRENDKEY - Trendkey Inc., West Chester, PA....12
3.17 Thrust Management System (TMS) - Safe Flight Instruments, White Plains, NY....12
3.18 Engine Monitoring System Computer (EMSC) - AMETEK Aerospace Products, Wilmington, MA....12
3.19 Computer Aided Diagnostic System (CADS) - Teknowledge Inc.; LCdr. Thomas J. Gadzala, Naval Postgraduate School, Monterey, CA....12
3.20 Enhanced Diagnostic System (EDS) - McDonnell Douglas Helicopter Co., Mesa, AZ....13

4.0 Technologies....15
4.1 Integrated Diagnostics....15
4.2 Artificial Intelligence....16
4.3 Debris Monitoring....16
4.4 Vibration Analysis....17

5.0 Conclusions....19

List of Acronyms....21

Appendix A Documents Index....A-1

Appendix B Health and Usage Monitoring Systems Summary....B-1

1.0 INTRODUCTION

This report describes the work performed on the Federal Aviation Administration (FAA) Health and Usage Monitoring Systems Certification Requirements project. This report includes a brief description of 20 health and usage monitoring systems. It further includes abstracts of 90 documents pertinent to health and usage monitoring technology. These 90 documents are organized into 4 categories that are related to applications.

The overall goal of the effort described herein was the development of information to support FAA rotorcraft certification requirements. The technical effort was divided into two tasks: a literature search and an industry survey of ongoing efforts involving technology for monitoring both health and usage of critical rotorcraft flight components.

1.1 LITERATURE SEARCH

1.1.1 Purpose

The purpose of this task was to conduct a technical literature search of health and usage monitoring technology. The search concentrated on military and civilian efforts in the development of automatic systems to monitor the performance and calculate the health of helicopter systems. The ultimate goal was to provide the information necessary to develop certification requirements for health and usage monitoring equipment.

1.1.2 Requirement

The requirement addressed in this first task was to assist the FAA in developing a better understanding of what is being developed by industry to support helicopter engine and airframe health and usage monitoring. An assessment was made of the maturity of these systems to support airworthiness accreditation and certification.

1.1.3 Technical Approach

An extensive literature search of military and civilian libraries was conducted to define a list of existing and developing health and usage monitoring systems for helicopter and fixed-wing aircraft. Utilizing the resources of the National Technical Information Service (NTIS) and other technical databases, computer assisted searches were performed using a "key word in context" approach to locate abstracts on technical papers describing these systems. The abstracts of over 1,000 reports were analyzed, and a determination was made on which documents should be reviewed in their entirety. These documents were then ordered and reviewed in detail. A list was compiled of all systems, manufacturers, key personnel, and technical evaluations of the maturity of each system. This list was used as the starting point for the industry survey.

1.1.4 Data Sources

Data sources included the following:

a. NTIS,
b. SCT technical library,
c. DIALOG (an on-line database search service), and
d. Trade journals on health usage and monitoring systems.

1.1.5 Literature Search Products

A comprehensive list of articles, publications, technical descriptions, and technical evaluations pertinent to helicopter health and usage monitoring systems is being provided to the FAA. An evaluation of the applicability of each system is also provided.

1.2 INDUSTRY SURVEY

1.2.1 Purpose

The purpose of the industry survey task was to determine which industrial firms are participating in the development of health and usage monitoring systems and to collect additional information on specific health and usage monitoring systems under development.

1.2.2 Requirement

The requirement for the industry survey task was to conduct a comprehensive search of military and industrial sources of health and usage monitoring systems. The search included obtaining information such as who are the participating firms, who are the key personnel, what aspects of the technology are mature and what are the key issues that need to be addressed to develop certification criteria.

1.2.3 Technical Approach

The list of firms developed in the literature survey task was used as the initial source of locating industrial sources. A questionnaire on the relevant issues surrounding health and usage monitoring systems was created. The questionnaire was reviewed and approved by the FAA prior to being mailed. The questionnaire results are analyzed and compiled in a separate report for FAA use.

1.2.4 Data Sources

The data sources used consisted of industrial firms participating in the development of health and usage monitoring systems. These firms were identified in the literature survey task and through secondary contacts.

1.2.5 Industry Survey Products

A listing of company names, addresses, key personnel, phone numbers, and a description of the health and usage monitoring work being accomplished is being provided to the FAA.

2.0 OVERVIEW

This report covers the results of the health and usage monitoring literature search. It describes the search methods, the results of the search, and summarizes the analysis of the documents that were reviewed in detail. A list of acronyms that are used throughout this report and in the documents is included at the end of this report. Appendix A is a copy of the library index which is included with the documents. Appendix B is a chart summarizing the various diagnostic and health monitoring systems that have been researched. Some of these systems have already been developed and have transitioned to field use, others have not made it past the prototype stage, and some are still in development.

The majority of the systems that were reviewed addressed engine monitoring or engine and drive-train monitoring. Very few papers were found that addressed integrated diagnostics from the point of view of monitoring and diagnosing total air-vehicle performance or health. Most systems monitored only a single parametric function, such as vibration, oil analysis, engine health, etc.

The selection of documents was not limited to helicopter systems, because a significant amount of work has been accomplished in fixed-wing aircraft diagnostic systems as well as air-breathing and rocket engine systems.

In particular, there is a wealth of information on diagnostic systems within the space shuttle main engine development effort. The space shuttle main engine is the first operational liquid rocket engine developed for reuse. Because of the potential for catastrophic consequences associated with a failure during ground testing and in-flight operation, there has been considerable emphasis on the development of sophisticated monitoring systems. Therefore, several documents are included that report on efforts in this area.

The increased application of artificial intelligence technology, in particular the use of expert systems, shows considerable promise as new monitoring and diagnostic applications are developed. Several of the articles that were reviewed predict that artificial intelligence technology has the potential to deliver significant advances in productivity and accuracy in monitoring systems.

2.1 SEARCH METHODS

In addition to manual library searches and review of periodicals and trade journals, use was made of automated library searches. These automated services facilitate the search of large databases using a common set of key words and phrases. Two major services

were used: NTIS and DIALOG. The American Institute of Aeronautics and Astronautics library was also a major source for acquiring copies of the documents. Numerous commercial publications such as Rotor and Wing International, Avionics, Aviation Equipment Maintenance, Aerospace Engineering, and the Helicopter Association International's 1990 Helicopter Annual were also used.

Over 1,000 abstracts were reviewed on the NTIS and DIALOG systems using a combination of keywords and acronyms from the following list:

Condition Monitoring	Helicopter	EDS
Diagnostics	Integrated Diagnostics	EMS
Diagnostic Systems	Prognostics	FDR
Engine Monitoring	Rotorcraft	HUMS
Engine Trending	Trending	ITEMS
Expert Systems	Usage Monitoring	OCM
Health Monitoring		TEMS

In addition to the selected keywords, the computer search was refined by limiting the documents to those published in the United States or published later than 1985. Without narrowing the search in this manner, the analysts were presented with thousands of documents to review, many of which had little relationship to the desired subject.

2.2 DOCUMENT RETRIEVAL

As a result of the literature survey, 90 documents, which are catalogued in appendix A, have been acquired. The index in appendix A contains an abstract for each document.

Many of the documents contain information on more than one aspect of monitoring systems or address more than one area. For ease of review, the documents have been divided into the following five subject categories:

- Helicopter Diagnostics,
- Other Aircraft Diagnostics,
- Rocket Engine Diagnostics,
- Technology, and
- General.

3.0 HEALTH AND USAGE MONITORING SYSTEMS

There is a distinct difference between health monitoring and usage monitoring systems. Although both rely on the collection of parametric data, the health monitoring system performs the analytical task of making a determination relative to the performance of the system and its ability tc continue to perform the intended function. A usage monitoring system, on the other hand, merely measures the consumption of life by one or more component in terms of total time accumulated, time at a certain pressure or temperature, number of thermal cycles, or some other calculable parameter. Usage monitoring data is normally provided to a ground processing system and is used to predict scheduled maintenance or the removal of a component when it reaches the end of its useful life.

Health monitoring systems, often referred to as diagnostic systems, fall into several categories. They may be in-flight monitors or ground-based processors of data that are collected in flight. They may be systems that advise the operator (pilot) or maintenance technician of the status of the system and/or recommend action to be taken. In some instances, health monitoring systems are used to control the operation of the system (i.e., limit operation or shut the system down). The majority of health monitoring systems on manned vehicles normally perform in the former mode of operation, that is, advise the operator of a failure, impending failure, or recommended action. The action is left to the operator.

Appendix B is a list of health and usage monitoring systems that have been reviewed as part of this study. The chart includes the major characteristics of each system and indicates whether they pertain to helicopter or fixed-wing, usage or health monitoring, airborne or ground systems, and wheter or not they utilize artificial intelligence technology. The cahrt also includes a subjective evaluation of the maturity of each system. The following paragraphs give a brief summary of each of the major systems that were surveyed.

3.1 ENGINE PERFORMANCE ASSURANCE MONITORING SYSTEM (EPAMS) - HOWELL INSTRUMENTS, FORT WORTH, TX

EPAMS is a mature system that is flying on a variety of fixed-wing and rotary, military and civilian, foreign and domestic aircraft. As the name implies, it is primarily a monitoring and data collection system. It accumulates life usage, including exceedence history and provides a trending base for ground analysis. It is used to support on-condition maintenance and engine life management. An additional vibration option is available. As a proven device, it has seen wide application.

3.2 HELICOPTER PILOT'S EMERGENCY SITUATION ADVISOR (H/PESA) - HONEYWELL, DEFENSE AVIONICS DIVISION

H/PESA, a development/demonstrator system, is an emergency advisory system that not only displays information, but analyzes, evaluates, and recommends actions to the operator (pilot). H/PESA uses expert systems technology. The expert system interprets the state of the system (helicopter) and records it in a knowledge base. Hypotheses are formed summarizing the state of the system. Typical hypotheses could include "engine failure imminent" or "tail rotor failure." From these hypotheses, the next step is for the expert system to recommend a "survival plan" for recovering from the emergency. This inferencing process is iterated to examine all states of the system and correlate them with "survival plans" according to a predefined set of rules. The final step would be a single survival plan that would be recommended to the operator. This is the type of system that requires considerable research, testing, prototyping, and development. It will require significant interaction between developers, engineers, and operators before it is commonplace in future aircraft.

3.3 ENGINE DIAGNOSTIC EXPERT SYSTEM (HELIX) - SIKORSKY AIRCRAFT DIVISION, UNITED TECHNOLOGIES CORPORATION

HELIX is a developmental program that diagnoses failures in the engine from sensor data, using the knowledge of the system's functions in its database. Information on this program is limited; however, additional information was requested from Sikorsky during the industry survey.

3.4 INTELLIGENT FAULT ISOLATION PROCEDURES (IFIP) - SIKORSKY AIRCRAFT DIVISION, UNITED TECHNOLOGIES CORPORATION

Sikorsky identifies IFIP as a follow-on program to HELIX. General information indicates that IFIP will be capable of guiding maintenance personnel through a diagnostic procedure to the faulty component by bringing to bear encoded knowledge about the system's normal function, as well as probabilities of failure, previous field experience, and component interactions. Sikorsky claims that fielded applications have shown as much as a 40 percent reduction in the manhours required to fault isolate, thus improving availability and supportability. In conjunction with IFIP, Sikorsky has developed a portable maintenance aid (PMA) to improve maintainability and supportability. The PMA combines an expert system with the aircraft log book, maintenance records, and the technical manual.

3.5 AIRCRAFT INTEGRATED MONITORING SYSTEM (AIMS) AND INTEGRATED HEALTH AND USAGE MONITORING SYSTEM (IHUMS) - BRISTOW HELICOPTERS LTD. AND PLESSEY AVIONICS, LONDON, UK

AIMS and IHUMS comprise a joint effort by BHL and Plessey Avionics to develop a system specifically for helicopters that satisfies the new British CAA legislation on flight data recorders which becomes mandatory in February 1991. The result of this effort will be a system which integrates both health and usage monitoring to meet CAA requirements. This work, although being done in the UK, is pertinent to the FAA health and usage monitoring project.

3.6 POWER ANALYZER AND RECORDER (PAR) - TELEDYNE AVIONICS, CHARLOTTESVILLE, VA

This is a mature unit that is in use on fixed-wing aircraft and helicopters. Its primary purpose is to compute power assurance checks, detect/record/advise operators of exceedences, and act as a usage monitor. It records engine parameters, including torque, rotor speed, airspeed, fuel flow, temperature, and altitude. Although it is not in the category of a diagnostic system, it is a relatively inexpensive device that could be used to provide necessary information when cost is a factor.

3.7 ROTOR TRACK AND BALANCE SYSTEM (ROTABS) - VIBRO-METER COMPANY, TORRANCE, CA

ROTABS is a computer-based program designed to optimize helicopter rotor setup in order to minimize damaging vibration. The ROTABS system is comprised of three modules: sensor array, signal acquisition and processing, and a laptop microcomputer. After completion of data acquisition, the system computes the best possible set of maintenance actions based on modelled rule-based criteria and past experiences. The result of these computations is a set of maintenance instructions to the technician.

3.8 COMPASS - ROLLS-ROYCE/SD-SCICON, UK

COMPASS is a system developed by Rolls-Royce and SD-SCICON to provide upline operators with a software shell to perform engine trending and diagnosis. COMPASS provides the user with a variety of data displays and performs data smoothing and trending functions. It is designed to be able to run software from various engine manufacturers under one common system. COMPASS is currently in use with Lufthansa, British Airways, and TWA.

3.9 EXPERT MAINTENANCE TROUBLESHOOTER (XMAN) - SYSTEMS CONTROL TECHNOLOGY, INC., PALO ALTO, CA

XMAN is a personal computer-based application of an expert maintenance and diagnostics tool for the flight line mechanic. It integrates performance and maintenance history data from multiple databases to diagnose detected malfunctions. As a ground-based system, it relies on data from an on-board processor as well as other data sources, including maintenance history files, oil analysis data, and engine configuration data. The system implements the fault isolation trees that are provided by the engine manufacturers and derives facts from the various databases to fault isolate reported malfunctions. It has been fielded on the A-10 TF-34 engine and the AV8B F404 engine.

3.10 ADVANCED AVIONIC ARCHITECTURE MAINTENANCE/DIAGNOSTIC ASSESSMENT (AAM/DA) - BELL HELICOPTER TEXTRON, FORT WORTH, TX

AAM/DA is an Army program to establish maintenance and diagnostic design criteria for future advanced avionic architectures. Specific design criteria will be defined for helicopter condition monitoring and fault detection/isolation. The intent is to influence the design early so that maintenance data processing requirements and capabilities for airborne and ground modes will be incorporated. This effort is based on the Tri-Service Joint Integrated Avionic Working Group (JIAWG) definitions of common modules and common avionic baselines (CAB). The results of this analysis will be used to guide condition monitoring and fault detection isolation design efforts within the military community.

3.11 ENGINEERING TECHNICAL ANALYSIS AND DESIGN SYSTEM (ETADS) - BELL HELICOPTER TEXTRON, FORT WORTH, TX

ETADS is a concurrent engineering tool development program with the overall goal of providing engineers with tools to quickly and accurately produce designs for diagnostics systems. It is included in this study because of Bell's use of the system to develop a library structure in order to capture the wealth of diagnostics data produced and collected by Bell Helicopter Textron. This will permit the previously collected data to be quickly accessed by design engineers. FAA engineers should be aware of this database as they work through the certification process for helicopter diagnostic applications.

3.12 INTELLIGENT MAINTENANCE EXPEDITER AND TRAINING AID SYSTEM (IMETS) - BELL HELICOPTER TEXTRON, FORT WORTH, TX

IMETS is a Bell Helicopter Textron in-house research and development program to develop a personal computer tool that contains expert knowledge about fault diagnosis in helicopter systems. The goal is to reduce maintenance time by providing

fault location more rapidly and by providing a list of tools and equipment required for repairs. As a diagnostic aid, it is designed to provide better diagnostics that will ultimately result in fewer cases of maintenance error. This ground system will require data collection from airborne processors or other test equipment.

3.13 VIBRATION, STRUCTURAL, LIFE, AND ENGINE DIAGNOSTIC SYSTEM (VSLED) - BELL HELICOPTER TEXTRON, FORT WORTH, TX

VSLED is a developmental system that is part of the central integrated checkout (CIC) system on the V-22 tiltrotor aircraft. The name suggests the functions that it performs, i.e., monitors vibration and temperatures, keeps tabs on structural life, and records events in the engine. It was designed to support on-condition maintenance (OCM) as a diagnostic tool for the first line mechanic. As a state-of-the-art system, it communicates on the V-22's dual-redundant 1553 data bus. It processes and stores data from three separate sources: the data bus, the full authority digital electronic controls (FADECs), and the aircraft's nacelle interface units. The future of the V-22 will perhaps dictate the future of VSLED; however, the system has practical application on future helicopter systems also.

3.14 LIGHT HELICOPTER - INTEGRATED DIAGNOSTICS (LH ID) - BELL HELICOPTER TEXTRON, INC., FORT WORTH, TX

LH ID is a development program for the Army's next generation light helicopter. The integrated diagnostics will use advanced avionic architectures to develop a cost effective system that meets supportability requirements and goals. The final design will address four major areas: an aircraft condition monitoring system, an aircraft management subsystem, a mission equipment package diagnostics subsystem, and an aircraft prognostics function. This is being developed in Bell Helicopter Textron's laboratories in Fort Worth, TX. This program warrants further investigation as it develops.

3.15 GENERIC INTEGRATED MAINTENANCE AND DIAGNOSTICS (GIMADS) PROGRAM - GENERAL DYNAMICS (PRIME CONTRACTOR), BELL HELICOPTER TEXTRON (SUBCONTRACTOR)

GIMADS is an ongoing development effort sponsored by the Air Force Aircraft Systems Division at Wright-Patterson Air Force Base, OH. There are eight contractors participating in this program to develop and institutionalize a step-by-step structured system engineering time-phased process for integrated diagnostics. As a design effort, it will include consideration of the latest technologies, innovative design approaches, integrated logistics support and verification and proof of concept. The results will be a Mil-Standard that delineates the

process and an Air Force Guide Specification. It will be applicable to helicopter and fixed-wing diagnostic systems.

3.16 TRENDKEY - TRENDKEY, INC., WEST CHESTER, PA

TRENDKEY is basically an instrument that is advertised as a pilot's helper, a systems monitor, a fuel management system, an air data computer, and as backup instrumentation. It is included in this survey because of its monitoring function and ability to measure and record exceedences. Although not a particularly sophisticated device, it also is an economic alternative in the low-cost aircraft market to provide a limited degree of system monitoring.

3.17 THRUST MANAGEMENT SYSTEM (TMS) - SAFE FLIGHT INSTRUMENTS, WHITE PLAINS, NY

TMS is an on-board computer that accepts information from existing air data systems, engine instruments, mode logic, and accessory computers and it provides outputs to instruments, annunciators, and automatic throttles. The TMS is programmed with the certified engine operating envelope and provides cockpit advice when the envelope is exceeded. The pilot receives power setting guidance on his flight director slow-fast indicator. If autothrottles are installed, TMS can implement power setting information by driving throttles directly.

3.18 ENGINE MONITORING SYSTEM COMPUTER (EMSC) - AMETEK AEROSPACE PRODUCTS, WILMINGTON, MA

The EMSC is in operation on more than 1,000 F-16 aircraft. The system processes information for exceedence monitoring and fault isolation. It supports vibration analysis, trend monitoring, and parts life tracking. Engine parameters, in addition to cockpit advisory notices and flightline go/no-go indications, are provided to the ground mechanic through a data display and transfer unit. This is a mature system and has applicability to helicopter operations.

3.19 COMPUTER AIDED DIAGNOSTIC SYSTEM (CADS) - TEKNOWLEDGE, INC.; LCDR. THOMAS J. GADZALA, NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA

CADS is the result of a study undertaken to demonstrate the feasibility of applying expert system technology to the Navy's H-46 helicopter maintenance process. A microcomputer-based prototype known as a computer-aided diagnostic system (CADS) was developed for this purpose. The prototype CADS was developed utilizing the M.1 knowledge-based system development tool by Teknowledge, Inc. There is no indication at this time that the system has gone beyond the prototype stage.

3.20 ENHANCED DIAGNOSTIC SYSTEM (EDS) - MCDONNELL DOUGLAS HELICOPTER CO., MESA, AZ

EDS is McDonnell Douglas' system for structural monitoring on the AH-46 helicopter. Although it is a multi-functional system, one of the primary purposes of EDS is to obtain operational loads data. The system functions in two modes: 1) on-board recording and diagnostics, and 2) ground analysis. The referenced document primarily addresses the structural monitoring aspects of the system.

4.0 TECHNOLOGIES

Advances in the areas of avionics, propulsion, sensors, and computer technology have had significant impact on the development of health usage and monitoring systems. We have come a long way from hanging analog reading devices on aircraft systems and copying down data for later analysis. New sensor technology has made use of fiber optics, micro-miniature components, strain gages, and laser technology common place in collecting data. Improvements in cooling, shock mounting, and rugged packaging have permitted placing sensors and processors in previously inaccessable places on the aircraft. Perhaps the most significant advances have been in the speed of processors and the increase in on-board data storage. The combination of all of these factors has facilitated in-situ capture, processing, and recording of diagnostic data. The operational impact ranges from the in-flight collection of data for ground processing to immediate pilot notification of subsystem performance and, in the ultimate case, to actual control of a subsystem base on real-time analysis.

The use of artificial intelligence techniques, particularly expert systems, will continue to expand in both airborne and ground diagnostic systems. Several of the new technologies are discussed in the following paragraphs to give the reader an idea of what is taking place as one considers the certification of new diagnostic and monitoring systems.

4.1 INTEGRATED DIAGNOSTICS

Historically, diagnosis of electrical, mechanical, and propulsion subsystems has been accomplished at the subsystem level, and only for that subsystem. That kind of approach has naturally led to the proliferation of different types of diagnostic systems and, often, duplication of effort. Avionics subsystems were the first to integrate diagnostic functions among the various avionic subsystems such as communications, navigation, weapons delivery, electronics countermeasures, etc. The results of avionics diagnostics were presented on avionics status panels, and later, as the data bus concept developed, the information was recorded and analyzed in on-board processors. With the advent of integrated flight controls, digital engine electronic controls, and fly-by-wire aircraft such as the F-16, all of the diagnostic information has become available on a common data bus. An integrated approach to diagnostics implies that each of the aircraft subsystems generate critical information that is important not only to the pilot, but to the maintainers of the aircraft. New aircraft such as the Advanced Tactical Fighter and the Stealth Bomber take into account the fact that diagnostics are a function that envelopes the entire aircraft, and health and usage monitoring systems are being developed in that light.

Aircraft now in the design and development cycle will address diagnostics from a systems approach. The challenge is integrating diagnostics on existing aircraft. That is perhaps beyond the scope of this study, but the technology associated with integrated diagnostics will surely need to be addressed in the certification process for new diagnostic systems.

4.2 ARTIFICIAL INTELLIGENCE

A new area of interest in engine monitoring is the use of one aspect of artificial intelligence, expert systems. As mentioned in the above paragraph, the use of a computer to diagnose trouble in avionics systems is well established. The use of automatic test equipment (ATE) and built-in test equipment (BITE) is widespread throughout avionics systems. The use of expert systems involves capturing the "expert" knowledge of human engineers and troubleshooters and committing that knowledge to a set of rules that can be quantified and stored in the computer. The rules must emulate the knowledge of a wide range of human experts and function with the speed of today's modern computers. The expert system receives data from the sensors in an aircraft or subsystem, stores the data, converts the data to knowledge or facts describing the condition of the subsystem, and applies the rules of the "expert" to determine or recommend an action. Most of today's expert systems applications keep the human "expert" in the loop. As expert systems continue to be developed and gain confidence, their use will rapidly expand to all areas of diagnostics and maintenance. The particular advantage of these systems is their ability to absorb vast amounts of input facts and make a consistently accurate decision in a split second. Artificial intelligence technology, most notably the use of expert systems, will play an increasing role in the development of health and usage monitoring systems.

4.3 DEBRIS MONITORING

The role played by particulate analysis of lubricating fluids in engines has been limited in the past to analyzing the oil on the ground, after the fact. The oil analysis results were normally used in conjunction with other indicators to assess the condition of mechanical systems. Recent developments allow, for the first time, microprocessor-based on-board systems to detect and collect significant data during system operation. While the role of the quantitative debris monitor (QDM) remains essentially the same, the speed and accuracy at which it can accomplish its function permits the correlation of seemingly unrelated symptoms to confirm an impending or actual failure. The reliance on real-time debris monitoring technology as an input to integrated diagnostic systems will also increase as new aircraft systems are designed.

4.4 VIBRATION ANALYSIS

As with debris monitoring technology, the improvements in sensors and on-board processing capability provide one more source of data for the diagnostic systems. In the area of vibration, digital processing can precisely measure engine, drive-train, and accessory vibration. Previous analog systems with one or more fixed data bands were subject to uncertainty as to whether the data was real or a false alarm. Digital systems virtually eliminate that ambiguity. Structural integrity programs will surely benefit from the results of improvements in this area of technology. The benefits of inputting this type of data into integrated diagnostics systems will include more accurate ordering of spare parts, more operational spare engines, and a reduced number of spares. As an additional data input to a diagnostic system, vibration monitoring information will support the on-condition maintenance concept. This type of information will certainly reduce the number of catastrophic failures and the resultant damage associated with secondary failures.

5.0 CONCLUSIONS

The purpose of this task was to conduct a technical literature search of health and usage monitoring technology. Over 1,000 abstracts were reviewed and 90 documents were selected related to health and usage monitoring systems. Those areas that offer significant relevance in new and developing diagnostic systems have been highlighted.

The most obvious conclusion is that future helicopter diagnostic systems will not be limited to individual subsystems. They will most likely address the aircraft as a system and report on the status or condition of all subsystems. More processing will be conducted on the aircraft as new sensors, processing capability, and storage are added to the airframe. More data will be collected and passed on to ground processors for further analysis, trending, comparison with fleet "norms," and for use in ground troubleshooting. Artificial intelligence (expert systems) will continue to grow in importance and use, both in aircraft and ground systems.

LIST OF ACRONYMS

AAM/DA	Advanced Avionic Architecture Maintenance/Diagnostic Assessment (Bell)
ACAP	Advanced Composite Aircraft Program
AIAA	American Institute of Aeronautics and Astronautics
AIMS	Aircraft Integrated Monitoring System (Bristow, Plessey Avionics)
ARIA	Advanced Reconfigurable Integrated Architecture
ART2	Adaptive Resonance Theory
ASEE	American Society for Engineering Education
ASME	American Society of Mechanical Engineers
ATE	Automatic Test Equipment
BITE	Built-In Test Equipment
BUCS	Backup Control System
CAA	Civil Aviation Authority
CAB	Common Avionic Baseline
CADS	Computer Aided Diagnostic System (Gadzala, NPG)
CALS	Computer-Aided Acquisition and Logistic Support
CAM	Content Addressable Memory
CERWAT	Center of Excellence for Rotary-Wing Aircraft Technology (Georgia Institute of Technology)
CIC	Central Integrated Checkout System
CMS	Condition Monitoring System
CVR/FDR	Cockpit Voice Recorder/Flight Data Recorder
DALT	Density Altitude
DARPA	Defense Advanced Research Projects Agency
D&CM	Diagnostic and Condition Monitoring
EDS	Enhanced Diagnostic System (McDonnell Douglas)
EGT	Exhaust Gas Temperature
EISE	Extendable Integrated Support Environment
EMS	Emergency Medical Service
EMSC	Engine Monitoring System Computer (Ametek)
EPAMS	Engine Performance Assurance Monitoring System (Howell Instruments)
ETADS	Engineering Technical Analysis and Design System (Bell)
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Electronic Control
FCM	Flight Condition Monitoring
FDR	Flight Data Recorder
GIMADS	Generic Integrated Maintenance and Diagnostics (General Dynamics)
HARP	Helicopter Airworthiness Review Panel (CAA)
HHC	Higher Harmonic Control
HMS	Health Monitoring System
H/PESA	Helicopter Pilot's Emergency Situation Advisor (Honeywell)
HELIX	Engine Diagnostic Expert System (Sikorsky)
HUMS	Health and Usage Monitoring System
IFIP	Intelligent Fault Isolation Procedures (Sikorsky)
IHUMS	Integrated Health and Usage Monitoring System (Bristow, Plessy Avionics)

IMETS	Intelligent Maintenance Expediter and Training Aid System (Bell)
INTERFACE	Integrated Reliable Fault-Tolerant Control for Engines
ITEMS	Integrated Turbine Engine Monitoring System
JIAWG	Joint Integrated Avionic Working Group
LH ID	Light Helicopter - Integrated Diagnostics (Bell)
LHX	Light Helicopter Experimental Program
LRU	Line Replacement Unit
N1	Turbine Engine Gas Producer Speed
N2	Power Turbine Speed
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NEOF	No Evidence of Failure
Np/Nr	Propeller Speed/Rotor Speed
NTIS	National Technical Information Service
OAT	Outside Air Temperature
OCM	On-Condition Maintenance
PALT	Pressure Altitude
PAR	Power Analyzer and Recorder (Teledyne)
PC	Personal Computer
PI	Parameter Identification
PMA	Portable Maintenance Aid
QDM	Quantitative Debris Monitor
RAF	Royal Air Force
ROTABS	Rotor Track and Balance System (Vibro-Meter)
SAE	Society of Automative Engineers
SCT	Systems Control Technology, Inc.
SFC	Specific Fuel Consumption
SSME	Space Shuttle Main Engine
TEMS	Turbine Engine Monitoring Systems
TMS	Thrust Management System (Safe Flight Instruments)
VLSI	Very Large Scale Integration
VSLED	Vibration, Structural, Life, and Engine Diagnostic System (Bell)
VTOL	Vertical Takeoff and Landing
VTRS	Visual Technology Research Simulator
XMAN	Expert Maintenance Troubleshooter (SCT)

APPENDIX A
DOCUMENTS INDEX

A.1 HELICOPTER DIAGNOSTICS

DOC. NUMBER: 1

TITLE: AIMS for Helicopters

AUTHOR: D. Jesse, Bristow Helicopters Limited
D.W. Barr, Plessey Avionics

PUBLISHER: DLR, Institut fur Flugfuhrung - Proceedings of 15th AIMS Symposium

DATE: September 1989

DOC. TYPE: Symposium Paper

ABSTRACT: Helicopters differ from fixed-wing aircraft in that most of the flight safety critical components cannot be duplicated. In order to improve flight safety and to reduce operating costs, an AIMS system specifically designed for helicopters is needed. This joint paper between Bristow Helicopters Ltd. and Plessey Avionics considers the current progress on HUM systems, and the need to satisfy the new Civil Aviation Authority (CAA) legislation on flight data recorders for helicopters which becomes mandatory in February 1991. The result is a joint development programme which integrates both functions and provides proven hardware in time for the legislation, and is of practical use to the operators.

DOC. NUMBER: 2

TITLE: Airborne Integrated Monitoring System

AUTHOR: A.H. Neubauer, Jr., Teledyne Controls

PUBLISHER: Unknown

DATE: Unknown

DOC. TYPE: Conference Paper

ABSTRACT: This paper addresses the goals and issues associated with on-board monitoring techniques and suggests approaches for dealing with them. Both input and output signal interface goals will be discussed, along with the microprocessor and memory devices necessary to implement a viable monitoring system.

The major goal for input and output interfaces is to achieve a workable system that operates completely in the digital domain. Although this is not always practical, the achievement of such a goal will reduce system complexity and aircraft wiring. For memory and recording, the goal is to implement cost effective, solid-state, nonvolatile devices that can provide error free and long lasting storage of data while withstanding the hostile environment. The goal for computer technology is to make maximum use of existing devices but to retain the flexibility necessary to accept new, high capacity devices as they come on the market.

The central integrated checkout system being implemented on the V-22 Osprey tiltrotor aircraft will be used as the example of current technology.

DOC. NUMBER: 3

TITLE: Another Day with an EMS Mechanic

AUTHOR: D.L. Bonney, St. Louis Helicopter Airways

PUBLISHER: Journal of Air Medical Transport

DATE: December 1989

DOC. TYPE: Journal Article

ABSTRACT: This article chronicles a typical workday for an emergency medical service (EMS) mechanic. He performs one zone of the Approved Aircraft Inspection Program on a BO-105 Messerschmitt-Bolkow Blohn helicopter.

DOC. NUMBER: 4

TITLE: Application of Constraint Suspension Techniques to Diagnosis in Helicopter Caution/Warning Systems

AUTHOR: G. Glenn, McDonnell Douglas Helicopter Company

PUBLISHER: American Helicopter Society - National Specialists Meeting

DATE: April 1988

DOC. TYPE: Conference Paper

ABSTRACT: This paper describes research done at McDonnell Douglas Helicopter Company in applying artificial intelligence techniques to the task of advising a helicopter crew of events taking place in their aircraft subsystems.

As part of the U.S. Army Apache EDS contract, a demonstrator system was developed that is capable of simulating multiplex bus traffic of caution/warning related data, and invoking a diagnostic module upon detection of an abnormal condition. Problem indicators are prioritized based on severity and displayed on a simulated up-front cockpit display and multifunction display. The demonstrator attempts to provide a diagnosis, where possible, and also provides advice about actions to be performed in response to critical situations. Severe problems are announced using an aural annunciator with digitally sampled stored messages. The diagnostic module utilizes a technique called candidate generation via constraint suspension to prune the list of suspected components while diagnosing a failure. Constraint suspension is a form of model-based reasoning that allows faults to be diagnosed by modeling the intended correct behavior of the system and comparing the outputs of the model with the true behavior of the system. This technique, which was first investigated by Randall Davis at the Massachusetts Institute of Technology under DARPA funding, shows potential for use as a diagnostic tool in ground-based as well as airborne systems.

DOC. NUMBER: 5

TITLE: Automatic Engine Monitoring Field Installation and Reliability Evaluation Report

AUTHOR: B.M. Battles, Bell Helicopter Textron

PUBLISHER: Helicopter Association International

DATE: July 1989

DOC. TYPE: Project Report

ABSTRACT: This report concludes an evaluation of automatic engine monitoring equipment, which began in November 1985. The final phase of the project was a field installation and reliability evaluation, during which equipment was installed in operational aircraft. Semco Instruments was the only monitor manufacturer that met all the HAI requirements. Six attachments to the report summary give information on the operators and their aircraft, the field installations, the performance of each system, the systems' functions and parameters, the operators' comments, and other ancillary operators' comments beyond the scope of the evaluation.

DOC. NUMBER: 6

TITLE: Bell's Design Approach for Future Rotorcraft Maintenance/Diagnostics

AUTHOR: R. Franks, R. Samson, R. Patten, J. Emery; Bell Helicopter Textron

PUBLISHER: American Helicopter Society - 46th Annual Forum

DATE: May 1990

DOC. TYPE: Conference Paper

ABSTRACT: This paper describes an overview of programs under way at Bell in which advanced maintenance/diagnostics technology guidelines are being developed and applied in the engineering design process. Examples of company-sponsored work and contracted programs are described, addressing the requirements for near-term guidelines and those leading into the next century. An overview of a future specification being developed by the Air Force called GIMADS is discussed, with emphasis given to (on) the mechanical systems diagnostics portion of the specification development. Plans for incorporating "lessons learned" into Bell's computer-aided engineering activities are discussed.

Examples of programs addressing onboard maintenance/diagnostics aids are summarized, including health, usage/lifing, monitoring systems (HUMS) for commercial helicopters, and the health monitoring system to be used on the V-22 Osprey. An overview of a study contract called advanced architecture maintenance/diagnostic assessment (AAM/DA) is discussed. This program, funded by the U.S. Army Aviation Applied Technology Laboratory, is studying advanced maintenance/diagnostics requirements and the development of guidelines for incorporating maintenance/diagnostics into advanced avionics architecture.

DOC. NUMBER: 7

TITLE: CHC's High-Stakes Venture into Helicopter Maintenance

AUTHOR: H. McLean

PUBLISHER: Rotor & Wing International

DATE: April 1990

DOC. TYPE: Magazine Article

ABSTRACT: Canadian Helicopters Corporation's (CHC) maintenance arm is the Engineering Support Division. The division began as Okanagan Helicopters, the largest of the companies now part of CHC, and after a downturn in the early 1980s, the division now services customers throughout Canada and in over a dozen countries. The division's services include maintenance on the Sikorsky S-61; engine overhauls on Allison 250 series, GE CT58, Pratt & Whitney PT6, Turbomeca Arriel and others; parts for all major helicopter models; overhaul on Bell and Aerospatiale components and accessories; avionics and instrument services; precision machine shop work; nondestructive testing; and major airframe overhauls and rebuilds. International business accounts for about 45% of the division's revenues. The division is targeting the Canadian Department of National Defense for future business.

DOC. NUMBER: 8

TITLE: A Comprehensive Diagnostic System for the T800-APW-800 Engine

AUTHOR: A. Bilodeau, K.S. Collinge; Textron Lycoming

PUBLISHER: Unknown

DATE: Unknown

DOC. TYPE: Conference Paper

ABSTRACT: In responding to U.S. Army requirements to improve LHX weapon system maintenance to the greatest extent possible, Textron Lycoming created an advanced engine-mounted system for the T800-APW-800 gas turbine engine. Although named the engine monitoring system, it is much more than the name implies. It is a comprehensive diagnostic system which monitors, diagnoses, and provides maintenance and repair instructions and mission data records.

This EMS leads diagnostic technology with its ability to continuously acquire, validate, monitor, analyze, record, and manage all engine parameters. The EMS provides both flight and maintenance crew support with information on engine performance, condition, operational history, maintenance requirements, repair instructions, and logistic information. With this information, automated diagnosis, maintenance, and repair can be accomplished in a timely manner. All of this information is available to flight and maintenance crews and to fleet data collection centers.

The system minimizes false diagnosis, reducing NEOF (No Evidence Of Failure) returns to depot. This is accomplished through the combination of automatic and semi-automatic diagnosis. The EMS maximizes engine availability, maintainability, reliability, and operability while it minimizes engine life cycle costs.

DOC. NUMBER: 9

TITLE: Development of a Prototype H-46 Helicopter Diagnostic Expert System

AUTHOR: T.G. Gadzala, Naval Postgraduate School

PUBLISHER: Naval Postgraduate School

DATE: September 1987

DOC. TYPE: Master's Thesis Report

ABSTRACT: This study was undertaken to demonstrate the feasibility of applying expert system technology to the Navy's H-46 helicopter maintenance process. A microcomputer-based prototype known as a computer-aided diagnostic system (CADS) was developed for this purpose. Given a helicopter electrical or hydraulic system discrepancy, the troubleshooter interacts with CADS to find the cause. The prototype CADS was developed utilizing the M.1 knowledge-based system development tool by Teknowledge, Inc.

The complexity of helicopter systems diagnosis and inadequacies of the maintenance manuals often result in unnecessary removal of system components. The prototype CADS is intended to demonstrate that a fully developed system, containing all the formal and heuristic knowledge of H-46 diagnostic information, could eliminate these problems. Also, such a diagnostic system could provide a comprehensive, stable diagnostic knowledge base, regardless of personnel turnover.

This study includes a description of current helicopter maintenance procedures, and how the integration of CADS could improve this process. Also included are descriptions of expert systems and the M.1 knowledge-based system development tool: how they work, and their applicability to structured selection problem-solving. The development and testing strategies used for CADS are discussed in detail. Results, conclusions, and recommendations for further study are provided.

DOC. NUMBER: 10

TITLE: Development of a Structural Integrity Recording System (SIRS) for U.S. Army AH-1S Helicopters

AUTHOR: J.G. Dotson, A.W. Kolb; Technology Incorporated

PUBLISHER: Applied Technology Laboratory, AVRADCOM

DATE: May 1982

DOC. TYPE: Final Report

ABSTRACT: A follow-on research and development program to implement a structural integrity recording system for the Army AH-1S helicopter was conducted by developing a computer program to reduce recorded aircraft usage data. The program, entitled fatigue damage assessment system, was designed to run on the AVRADCOM computer. An improved lift-link-mounted strain sensor was also developed. The sensor was laboratory-tested and deemed ready for follow-on application testing in regard to monitoring helicopter gross weight, and takeoff and landing detection.

DOC. NUMBER: 11

TITLE: Diagnostic and Condition Monitoring (D&CM) System Assessment for Army Helicopter Modular Turboshaft Engines

AUTHOR: H.J. John; General Electric Company, Aircraft Engine Group

PUBLISHER: Applied Technology Laboratory, AVRADCOM

DATE: October 1980

DOC. TYPE: Final Report

ABSTRACT: Needs for and means of improving D&CM and troubleshooting to modules and LRUs for the T700-GE-700 engine in Army environment were studied. Recommendations are: (1) Do not modify existing METS for modular fault isolation. However, do computerize the acquisition of the overall engine performance data; (2) introduce the slave chip detector to the depot; (3) expand evaluation of the control system analyzer by Black Hawk companies; (4) support the development of degaussing chip detector; (5) initiate Phase I of multipurpose airborne D&CM system which combines performance, life, overtemp and chip detector monitors; and (6) continue to acquire T700 field data and develop a method to quantify D&CM payoffs such as better engine availability.

DOC. NUMBER: 12

TITLE: EH-101 Cockpit Displays: Keeping It Plain and Simple

AUTHOR: S. Coyle

PUBLISHER: Rotor & Wing International

DATE: May 1990

DOC. TYPE: Magazine Article

ABSTRACT: The electronic displays and software used in the European Helicopters Industries (EHI) EH-101 multipurpose helicopter confer several major advantages: different end uses (military versus civil) have different display output; different flight modes (start-up versus cruise) also change mode; and different applications (low altitude versus high altitude) can have different displays. The display and/or avionics can differ by installation (e.g. MIL-STD-1553B wiring versus ARINC 429 civil wiring), by switch selection, and be automatically based on sensor data. The advantages are many, including uncluttered display for swift pilot reaction to emergencies, versatility for different helicopter configurations (military versus civil), and better maintenance records.

DOC. NUMBER: 13

TITLE: Emerging New Technologies at Sikorsky Aircraft

AUTHOR: Dr R.K. Shenoy, Research and Development Planning, Sikorsky Aircraft Division, United Technologies Corp.

PUBLISHER: Vertiflite

DATE: March/April 1990

DOC. TYPE: Magazine Article

ABSTRACT: Currently Sikorsky Aircraft is adapting advances in electronics technology to make rotorcraft more reliable and competitive. Expert systems and artificial intelligence, advanced simulation, and engineering automation top the list of such emerging technologies and are briefly described in this article. In addition to these areas, to counter the improvements in detection technology, low observables are emerging as another technology of interest. Considerable investment and progress has been made at Sikorsky Aircraft in low observables technologies, which include radar signature control and infrared signature control. Due to the nature of this subject, only a few details of the radar signature control technology will be discussed.

DOC. NUMBER: 14

TITLE: An Experimenter Operator Station for Helicopter Flight Simulator Research and Training

AUTHOR: T.A. Kaye, Bell Helicopter Textron
L.M. Freeman, Aerospace Engineering, University of Alabama

PUBLISHER: AIAA

DATE: 1989

DOC. TYPE: Conference Paper

ABSTRACT: The increasing use of flight simulators for pilot training is primarily driven by economic and safety considerations. A very labor intensive research effort is usually required in order to verify the basic assumption that the skills a pilot develops in the simulator are the same as the skills required to fly the actual aircraft. Studies that demonstrate a positive transfer of learning to the pilot typically require human factors researchers to perform many repetitious and tedious tasks, particularly in the area of data acquisition and statistical analysis.

DOC. NUMBER: 15

TITLE: Expert Systems for Helicopter Pilots

AUTHOR: W. Shaneyfelt; Defense Avionics Systems Division, Honeywell

PUBLISHER: Avionics

DATE: January 1990

DOC. TYPE: Magazine Article

ABSTRACT: The helicopter pilot's emerging situation advisor (H/PESA) is a prototype demonstration of a cockpit expert emergency advisory system. The system displays, analyzes, and evaluates information, and recommends actions. In addition to factual information, the knowledge base includes rules of inference. The organization of the knowledge base was determined, in part, by execution speed. During an in-flight emergency, a pilot cannot wait for an expert system to go through a lengthy analysis. Speed gains have been achieved by organizing rules in the knowledge base into a hierarchy.

DOC. NUMBER: 16

TITLE: Fixed-Gain Versus Adaptive Higher Harmonic Control Simulation

AUTHOR: LTC K.P. Nygren; Dept. of Civil & Mechanical Eng., U.S. Military Academy
D.P. Schrage; CERWAT/School of Aerospace Eng., Georgia Inst. of Tech.

PUBLISHER: American Helicopter Society

DATE: July 1989

DOC. TYPE: Journal Paper

ABSTRACT: A computer simulation of helicopter vibration reduction using higher harmonic control (HHC) is developed by incorporation of an HHC solution procedure in the dynamic system coupler program. The simulation can model almost any HHC control and identification scheme tested to date, including stochastic control. The adequacy of fixed-gain as opposed to adaptive control has recently been in question. Both of these HHC methods are simulated in steady and constant-thrust maneuvering flight, as well as conditions of incorrect transfer matrix initialization. The results indicate fixed-gain control can adequately reduce vibrations for the helicopter modeled, as long as the flight condition is within about 20 knots of the flight conditions used to calculate gains.

DOC. NUMBER: 17

TITLE: A Full Authority Digital Electronic Control System for Multi-Engine Rotorcraft

AUTHOR: D. Petro; AVCO Lycoming Division / A.J. Gentile; Chandler Evans Inc. A.B. Foulds; Hawker Siddeley Dynamics Engineering

PUBLISHER: The City University - 11th European Rotorcraft Forum

DATE: September 1985

DOC. TYPE: Conference Paper

ABSTRACT: Conventional engine control systems for turbine-powered rotorcraft have become increasingly complex in the process of striving for optimized performance of the power plant and aircraft. Traditionally, the only method of achieving this goal was to increase the level of functional sophistication within the control through nonelectronic techniques.

Using a proposed Royal Air Force (RAF) application as an example, this paper reviews the basic requirements and need for incorporation of a full authority digital electronic control system on an existing twin-engine military helicopter. The unique selection process and component configuration are discussed, which involved international collaboration among several organizations utilizing the latest concepts in electronic technology. The technical details and functional per-formance of the digital electronic control system are described relative to fulfilling the particular requirements of a tandem rotor helicopter. Finally, operational and installation features of the engine control system, such as reliability, maintainability, diagnostics, history recording, health monitor-ing, aircraft incorporation and cost-of-ownership are summarized to ensure that the original design philosophy and goals of the program would be satisfied.

DOC. NUMBER: 18

TITLE: The Future Roles of Flight Monitors in Structural Usage Verification

AUTHOR: A.E. Thompson, Sikorsky Aircraft Division, United Technologies Corp.

PUBLISHER: American Helicopter Society - National Technical Specialists Meeting

DATE: October 1988

DOC. TYPE: Conference Paper

ABSTRACT: Structural substantiation of helicopter dynamic components for fatigue has traditionally combined three elements - component strength, aircraft flight loads, and an assumed usage spectrum. While component strength and flight loads are measured, most substantiating usage spectra are based on general military or civil specifications, contractor experience, or user and pilot surveys. All of these methods are filled with assumptions and cannot begin to address the mission profile variabilities. Since helicopter dynamic component replacement times can be very sensitive to the assumed usage spectrum, it is necessary to define a "realistic mission profile". Past efforts in this direction have included detailed load/criteria studies, mission simulation flight tests, and pilot/user questionnaires. The development of flight monitors will provide major opportunities to understand aircraft usage. This paper discusses past and current limited aircraft monitoring programs at Sikorsky. It then describes future monitors under development which will provide fleet-wide continuous usage monitoring, and regime recognition algorithms which will provide rate of occurrence data for all critical flight conditions. It is emphasized that monitor data must be used cautiously. The engineer must use quality data, based on statistically significant survey programs. But most important, the traditional conservatism of the substantiation process must not be stripped away haphazardly. The reliability of a substantiation depends upon a balance of realism in the usage spectrum and conservatism in the overall substantiation process.

DOC. NUMBER: 19

TITLE: Health Monitoring of Helicopter Gearboxes

AUTHOR: D.G. Astridge, Westland Helicopters Ltd.

PUBLISHER: Aeronautic & Astronautic Assoc. of France - 8th Europ. Rotorcraft Forum

DATE: August/September 1982

DOC. TYPE: Conference Paper

ABSTRACT: The various problems posed for gearbox health monitoring are discussed, and the solutions applied to the Westland 30 helicopter are described. These embrace the transition from traditional, well-known laboratory-based techniques and subjective evaluations, to the on-line facilities of future aircraft such as the EH101 and growth versions of Westland 30.

DOC. NUMBER: 20

TITLE: The Health and Usage Monitoring of Helicopter Systems - The Next Generation

AUTHOR: J.D. Roe, D.G. Astridge; Westland Helicopters Ltd.

PUBLISHER: Reprinted by AIAA

DATE: Unknown

DOC. TYPE: Conference Paper

ABSTRACT: The paper discusses the relevance of health and usage monitoring systems to the improvement of airworthiness and life cycle costs of helicopters, addressing the findings and recommendations of the HARP report/review of helicopter airworthiness (CAP 491, CAA, June 1984). The advanced on-board maintenance processor systems currently being designed for the Westland 30 Series 300 and EH101 helicopters are described, covering sensors, interfaces, data links, processors and output devices. The functions include vibration analysis and quantitative debris monitoring systems for transmissions, power assurance checking, low cycle fatigue and thermal creep monitoring for engines, and torque and strain monitoring for complete transmissions and rotor systems. The systems include sensors and algorithms that have been developed very recently and substantiated by rig tests to deliberate failure, by development flying in arduous conditions, and by application to in-service aircraft. An overview of the development programmes leading to certification of the on-board systems will also be given. The impact of these systems on maintenance policies is also discussed.

DOC. NUMBER: 21

TITLE: Health and Usage Monitoring Techniques for Greater Safety in Helicopter Operations

AUTHOR: D.G. Astridge; Westland Helicopters Ltd., United Technologies Corp.

PUBLISHER: International Journal of Aviation Safety

DATE: September 1985

DOC. TYPE: Journal Paper

ABSTRACT: The paper discusses work being done to monitor the integrity of helicopter transmissions during operation. Health monitoring should provide early warning of surface wear modes, a clear rejection signal for surface wear modes, and means of corroborating the indications at the aircraft by maintenance personnel. For transmissions, the primary usage parameter is torque-transmitted, although in instances where rotor loads are transmitted through the gearbox casing, rotor loads and moments may need to be analyzed. Significant advances have been made in gearbox health monitoring technology, particularly in quantitative debris monitoring (i.e., the Tedeco QDM system), and in enhanced vibration signal averaging (i.e., Westland's vibration analysis techniques have demonstrated the ability to detect cracks and fracture modes before they are visible to the eye).

DOC. NUMBER: 22

TITLE: Helicopter Gear Box Condition Monitoring for Australian Navy

AUTHOR: K.F. Fraser, C.N. King; Aeronautical Research Laboratories

PUBLISHER: Reprinted by AIAA

DOC. TYPE: Conference Paper

ABSTRACT: The Aeronautical Research Laboratories has been involved for more than a decade in studies on behalf of, and in the provision of scientific advice to, the Royal Australian Navy on airworthiness matters in respect of the main rotor gear boxes for its Wessex Mk 31B and Sea King Mk 50 helicopters. Work has been undertaken in the two major areas of gear box health and fatigue life usage monitoring. The health monitoring program has included both oil/wear debris analysis and vibration analysis. Significant advances in the area of early failure detection have been achieved in the vibration work. Safe fatigue lives of all gears in the main rotor gear boxes for Wessex and Sea King have been estimated for Australian operating conditions. Prototype equipment developed at these Laboratories and currently fitted in some Sea King helicopters estimates fatigue life usage of gears during flight and is capable of monitoring actual life usage for individual gear boxes.

DOC. NUMBER: 23

TITLE: Helicopter Health and Safety

AUTHOR: G. Norris

PUBLISHER: Flight International

DATE: January 1990

DOC. TYPE: Magazine Article

ABSTRACT: The drive to improve the airworthiness of civil helicopters is being tackled on three fronts: design, technology, and operations. New helicopters are being developed which embody airliner standards of safety and system redundancy from the first set of designs. Microprocessor-based technology, principally in the area of HUMS and FDR's, is being integrated into existing helicopters. Operations are being made safer by revised regulations.

DOC. NUMBER: 24

TITLE: 10th Helicopter Health Monitoring Advisory Group (HHMAG) Meeting Minutes

AUTHOR: S.L. James, Helicopter Health Monitoring Advisory Group

PUBLISHER: Helicopter Health Monitoring Advisory Group

DATE: April 1989

DOC. TYPE: Meeting Minutes

ABSTRACT: The minutes include three briefings and two trial updates. The briefings are "AS332 Mk2 Health Monitoring" by M.R. Francois of Aerospatiale, "EH101 Health Monitoring" by Signor Bruno Maino of EHI, and "Review of Rotor System Catastrophic Failures" by Mr. Andrew of MJA Dynamics. For the AS332 trial, seventy vibration recordings and thirty-two oil debris samples were taken. The first flight of the full HUMS on-board system was delayed. For the S61 trial, the two aircraft involved in the trial would be operational in late June 1989 and the other in August 1989. Also, three thousand hours of monitoring will permit strip evidence to be correlated to SOAP analysis.

DOC. NUMBER: 25

TITLE: 11th Helicopter Health Monitoring Advisory Group (HHMAG) Meeting Minutes

AUTHOR: S.L. James; Helicopter Health Monitoring Advisory Group

PUBLISHER: Helicopter Health Monitoring Advisory Group

DATE: October 1989

DOC. TYPE: Meeting Minutes

ABSTRACT: The minutes include four briefings and updates on the S61 trial and the AS333 trial. The briefings are "Application of Expert Systems in Improving Helicopter Airworthiness" by the University of Exeter School of Engineering (condensed report also included), "HUMS: FAA Update" by J.D. Swihart of FAA Southwest Region, "ROTABS: Rotor Trim And Balance System" by T. Staub, and "RADS" by K. Pipe of Stewart Hughes.

DOC. NUMBER: 26

TITLE: Helicopter Health Monitoring from Engine to Rotor

AUTHOR: J.F. Marriott, J.F.M. Kaye; Hawker Siddeley Dynamics Engineering Ltd.

PUBLISHER: ASME - Gas Turbine and Aerospace Congress

DATE: June 1988

DOC. TYPE: Conference Paper

ABSTRACT: Recent tragic accidents have focused attention on the dangers of unmonitored helicopter dynamic assemblies. Methods are available to monitor the entire power train from the engine to the rotor. Apart from the obvious safety advantages, such systems offer the additional benefits of increased availability, a planned maintenance schedule, and a reduction in life cycle costs.

Historically, monitoring systems have evolved from isolated processing units, each performing single functions. Hawker Siddeley Dynamics Engineering Ltd., in conjunction with Stewart Hughes Ltd., is developing a modular and integrated health and usage monitoring system. After a brief discussion of health monitoring equipment evolution, this paper focuses on the practical application of the techniques required to ensure the health of the modern helicopter.

DOC. NUMBER: 27

TITLE: Helicopter Operators Forecast Steady Growth into Mid-1990s

AUTHOR: N.C. Kernstock

PUBLISHER: Aviation Week & Space Technology

DATE: February 1990

DOC. TYPE: Magazine Article

ABSTRACT: The global civil helicopter industry has experienced a rebound, although business has not yet returned to the high levels seen in the late 1970s. Four operators typify those who are achieving success by controlling the growth of existing business and their entry into new markets, as well as exploiting profitable niches. While these companies' operations encompass a wide variety of helicopter missions, three major markets are responsible for most of the growth: the oil industry, police and public service, and medical flight service.

DOC. NUMBER: 28

TITLE: Hoverview - More HUM Trials Due

AUTHOR: Helicopter World

PUBLISHER: Helicopter World

DATE: January-March 1990

DOC. TYPE: Magazine Article

ABSTRACT: A series of trials, due to start in February 1990, on North Sea helicopters represents a continuation of the UK Civil Aviation Authority's thrust to establish the utility and effectiveness of health and usage monitoring (HUM) in service. British International Helicopters (BIH) will conduct the trials on two of its Sumburgh-based S61N helicopters. The trials involve a total of 1,100 hours flying time over twelve to fifteen months. The HUM equipment will analyze data from a range of sensors to detect faults in their very early stages. Sensors include debris monitors, accelerometers, and a fixed optical tracker for accurate sensing of rotor track and lag. The on-board HUM processor can also derive high-level safety and maintenance conclusions.

DOC. NUMBER: 29

TITLE: The Integration of Health Monitoring Techniques for Helicopter Gearboxes

AUTHOR: Comm. M.J.D. Brougham; Royal Navy MoD Directorate of Helicopter Proj.
P. Gadd; Naval Aircraft Materials Laboratory, RNAY Fleetlands

PUBLISHER: The City University - 11th European Rotorcraft Forum

DATE: September 1985

DOC. TYPE: Conference Paper

ABSTRACT: This paper discusses the use of a combination of health monitoring techniques to provide comprehensive coverage of possible failure modes in a typical transmission gearbox. From experience gained in research and development work sponsored by the UK Ministry of Defense in recent years, the paper explores the relative value of conventional status parameters such as oil level, pressure and temperature, together with the newer techniques of wear debris and vibration analysis.

The use of health monitoring techniques in a matrix to provide both early warning of failure and diagnostic information is considered, as well as the effect of design features such as transmission configurations, oil filtration standards and filter bypass arrangements. The problems of data collection and processing are also discussed.

The development of the Anglo Italian EH 101 Health and Usage Monitoring System is used to illustrate the process of sensor location, validation of processor algorithms, and the planning to achieve full system certification.

DOC. NUMBER: 30

TITLE: KRASH Analysis Correlation with the Bell ACAP Full-Scale Aircraft Crash Test

AUTHOR: J.D. Cronkhite, Bell Helicopter Textron
L.T. Mazza; Aviation Applied Technology Directorate, U.S. AVSCOM

PUBLISHER: American Helicopter Society - National Technical Specialists Meeting

DATE: October 1988

DOC. TYPE: Conference Paper

ABSTRACT: The Bell ACAP aircraft, developed under the U.S. Army's Advanced Composite Airframe Program, was designed to meet the Army's stringent crash survivability requirements using the KRASH analysis combined with testing of critical energy-absorbing structural components. The full-scale aircraft was crash tested at the Impact Dynamics Facility of NASA Langley Research Center and successfully demonstrated that it provided crash protection for the occupants and fully met the ACAP crash requirements. The actual test condition was somewhat more severe than planned. Also, the onboard acceleration data was lost during the test and comparisons of the test results with the KRASH simulation had to be conducted using high speed photo motion analyses and post test measurements. For comparison purposes, the KRASH analysis was updated after the test to represent the actual test condition and to incorporate unexpected damage that had occurred to a tail gear fitting and the engine deck, but was not included in the original analysis. Comparisons of the KRASH analysis and test showed good agreement and verified that KRASH was a viable analytical tool for the design of composite airframe structures for crash impact.

DOC. NUMBER: 31

TITLE: Mastering a Complicated Beast

AUTHOR: M. Hodges, Georgia Institute of Technology

PUBLISHER: Research Horizons

DATE: Spring 1990

DOC. TYPE: Magazine Article

ABSTRACT: At the Center of Excellence for Rotary-Wing Aircraft Technology (CERWAT) at the Georgia Institute of Technology, fourteen faculty and about thirty graduate researchers address basic research questions that U.S. industrial and government laboratories are not equipped to handle. The research at CERWAT centers on four key areas: aerodynamics, aeroelasticity, structures and materials, and flight controls and mechanics. A key discipline for rotorcraft is understanding turbulant flow. From the point of view of the rotor, one must understand the motion of vortices that spin off the blade, and from the point of view of aeroelasticity, one must understand the forces exerted by the turbulent downflow on the airframe. The researchers at CERWAT make use of a laser Doppler wind tunnel in conjunction with advanced software models. The software models are spreading out into industrial use.

Another effort has been to model the reactions of the pilot. For this purpose, two types of models are in use: the linear model or autopilot, and the nonlinear "shooting" model. The nonlinear model will regress time if it crashes, and "take another shot" at controlling the aircraft. Other efforts involve modelling composite materials (e.g. a blade that twists when it stretches) and advanced control systems involving feedback.

DOC. NUMBER: 32

TITLE: MDHC's Enhanced Diagnostics System, A Unique and Comprehensive Approach to Structural Monitoring

AUTHOR: J. Harrington III, D. Chia, J. Neff; McDonnell Douglas Helicopter Company

PUBLISHER: Reprinted by AIAA

DATE: Unknown

DOC. TYPE: Conference Paper

ABSTRACT: Currently in the helicopter industry, structural component lives and inspection criteria are established by damage tolerance or safe life methods. An accurate determination of the loading spectrum of the component is required for both methodologies. Structure monitoring of aircraft through the use of flight data recorder technology could substantially reduce the uncertainties in the load spectrum used in component life analysis. McDonnell Douglas Helicopter Company has developed a multi-functional flight data recorder system for the Army's AH-64A Apache Helicopter. One of the primary functions of the EDS is to obtain operational loads data. EDS structural monitoring is unique because it uses aircraft mission subsystems data as well as strain gage data to monitor loads and aircraft usage. The purpose of this paper is to describe the EDS structural monitoring approach and to propose a methodology for using the EDS structural loads data in a comprehensive structural integrity program.

DOC. NUMBER: 33

TITLE: The Modularity of the Health and Usage Monitoring System

AUTHOR: P.D. Baker; Smiths Industries Aerospace & Defence Systems

PUBLISHER: Aeronautic & Astronautic Assoc. of France - 13th Europ. Rotorcraft Forum

DATE: September 1987

DOC. TYPE: Conference Paper

ABSTRACT: The Health and Usage Monitoring System has functional flexibility or modularity by application, while the core of the system, the Health and Usage Monitor, is modular by design and function. It is possible by these means to produce a system which is sufficiently versatile to meet the needs of the rotorcraft operator, the requirements of the rotorcraft and engine manufacturers, and those of the certifying authorities. The purpose of this paper is to outline the range of facilities and functions available at this time for health and usage monitoring.

Data can be accepted by the system from any type of sensor. These data are validated before compression and storage, for subsequent examination, or for immediate utilization in a variety of functions. The functions themselves can cover the power plant, airframe, transmission, and rotor. Experience in the development and application of the system has been gained to a greater or lesser extent in a variety of fixed- and rotary-wing aircraft, in both civil and military applications; it is this which is the basis of the paper.

DOC. NUMBER: 34

TITLE: Osprey's VSLED: Rewriting the Maintenance Manual

AUTHOR: E.W. Bassett

PUBLISHER: Rotor & Wing International

DATE: June 1988

DOC. TYPE: Magazine Article

ABSTRACT: The VSLED is the aircraft health-monitoring system under development for the V-22 Osprey. VSLED consists of an airborne unit and a sensor network. The airborne unit is built around a MIL-STD-1750 processor and two co-processors. The sophisticated and extensive sensor network puts VSLED in touch with engine and airframe components.

DOC. NUMBER: 35

TITLE: The On-Condition Qualification of the Trailing Edge Area of the UH-1H Metal Main Rotor Blade

AUTHOR: B. Dickson, Bell Helicopter Textron
R. Arden; Aviation Applied Technology Directorate, U.S. AVSCOM

PUBLISHER: American Helicopter Society - National Specialists Meeting

DATE: October 1988

DOC. TYPE: Conference Paper

ABSTRACT: A program has been conducted by Bell Helicopter Textron, Inc. (BHTI), under contract to AVSCOM engineering, to establish an on-condition replacement status for the UH-1H metal main rotor blade considering fatigue cracking along the trailing edge. Two test specimens constructed from service-returned blades were used to generate crack growth data. Innovative approaches used in the test included application of a multistep spectrum of beamwise, chordwise, and torsional loads derived from the UH-1H operational spectrum to simulate a 2-hour flight. Application of test loads included the superposition of the significant 1/rev and 7/rev chordwise loads to realistically account for the dynamic response of the blade in flight. The paper presents details of the derivation of the crack growth test load spectrum, details of the test, and crack growth data generated that were subsequently used to establish a safe inspection interval.

DOC. NUMBER: 36

TITLE: Qualification and Fleet Introduction of the AH-1T Flight Loads and Usage Monitor

AUTHOR: C.G. Schaefer, Jr.; Helicopter Loads and Dynamics, Naval Air Command

PUBLISHER: Reprinted by AIAA

DOC. TYPE: Conference Paper

ABSTRACT: The U.S. Navy is currently assessing the validity of its present fatigue methodology for rotary wing aircraft. NAVAIR is now involved in a fleet usage survey that will attempt to collect a sizable database to evaluate the current attack helicopter usage spectrum. The survey includes the design and installation of an instrumentation system that monitors flight environmental loads and operational mission usage of eight fleet Marine AH-1T (TOW) attack helicopters. This paper addresses that flight test effort, some of the problems encountered, and the introduction of the system into the fleet.

DOC. NUMBER: 37

TITLE: Qualification Testing of AH64 Fly-By-Wire Backup Control System (BUCS)

AUTHOR: S.S. Osder, McDonnell Douglas Helicopter Company

PUBLISHER: Reprinted by AIAA

DATE: Unknown

DOC. TYPE: Conference Paper

ABSTRACT: The AH64 helicopter's fly-by-wire backup control system was qualified using a combination of tests performed on the aircraft and in a closed loop validation facility. The backup fly-by-wire system concept is described and the test procedures used to qualify that system are reviewed. Some key technical issues relating to the control logic used to monitor system health and to detect the conditions requiring automatic backup control engagement are discussed.

DOC. NUMBER: 38

TITLE: Rotorcraft Trends - Part 2 Requirements and Monitoring

AUTHOR: T. Ford

PUBLISHER: Aircraft Engineering

DATE: December 1985

DOC. TYPE: Magazine Article

ABSTRACT: A CAA working group on helicopter health monitoring concluded that for future helicopter designs, the transmissions and rotor systems would benefit most from the use of health monitoring techniques. Three other areas were also identified as important areas for effective monitoring: flight control systems, structure, and engines and fuel systems. Requirements and monitoring recommendations are made for each of these five areas.

DOC. NUMBER: 39

TITLE: Sikorsky Adopts Cautious Approach to Japanese Civil Helicopter Market

AUTHOR: Unknown

PUBLISHER: Aviation Week & Space Technology

DATE: February 1990

DOC. TYPE: Magazine Article

ABSTRACT: Although the Japanese have identified a need for about 3,300 heliports and 600 helicopters over the next 20-30 years to ease the transportation network gridlock, 3 main hindrances have prompted Sikorsky Aircraft to exercise caution in pursuing the Japanese civil helicopter market. First, Japan has complex and rigid helicopter certification and flight regulations. Second, the national government recently implemented tax codes that will soon make helicopter ownership less attractive. The third and most important reason is that Japan has been experiencing, and for the foreseeable future will continue to experience, a chronic shortage of trained helicopter pilots.

DOC. NUMBER: 40

TITLE: Simulator Evaluation of Instructional and Design Features for Training Helicopter Shipboard Landing

AUTHOR: D.J. Sheppard, S.A. Jones, D.P. Westra; Essex Corporation
J.J. Madden; Naval Training Systems Center

PUBLISHER: Human Factors Society - Proceedings of 32nd Annual Meeting

DATE: 1988

DOC. TYPE: Conference Paper

ABSTRACT: The effects of four instructional issues and one simulator design feature for training helicopter shipboard landing on small ships were tested in the vertical takeoff and landing (VTOL) simulator at the visual technology research simulator (VTRS), Naval Training Systems Center. They were: (1) field of view (VTRS versus a test field of view), (2) task chaining (segmented backward chaining versus whole task training), (3) augmented cueing (augmented cueing versus no augmented cueing), (4) length of training (18, 27, and 36 trials), and (5) the timing of seastate introduction (early versus late). The experiment utilized an in-simulator transfer-of-training paradigm in which pilots who were not proficient in the helicopter shipboard landing task were trained under one of several experimental conditions, then tested on the transfer condition (that represented maximum realism) in the simulator. Thirty-two pilots each completed a total of 54 trials (36 training, 18 transfer). Pilots were tested in the transfer condition (six trials) after their 18th, 27th, and 36th training trial. Of the experimental instructional issues, task chaining had the largest effect, with better performance in all segments of the task for pilots who were trained with the backward-chaining sequence than for pilots who received whole task training. Augmented cueing did not yield the transfer performance anticipated. Seastate introduction had no effect on performance. Field of view had some marginal effects on vertical performance in the hover, with better performance for pilots who were trained with the combination VTRS field-of-view and backward-chaining. Results suggest a diminished rate of learning after 33 simulator trials (includes 27 training trials and six transfer trials of the first probe).

DOC. NUMBER: 41

TITLE: Strengthening the Weak Link of Fatigue Qualification

AUTHOR: K.M. Rotenberger, U.S. Army Aviation Systems Command

PUBLISHER: Unknown

DATE: Unknown

DOC. TYPE: Conference Paper

ABSTRACT: The "weak link" in the fatigue substantiation process is the aircraft usage spectrum. In recognition of this, the Army is conducting several programs designed to better account for the actual usage of Army helicopters. A pilot survey program was conducted for the AH-1 and UH-1 systems and produced updated spectra that incorporated new missions and tactics previously unaddressed. Many programs involving flight data recorders are currently underway. They are designed to record the data necessary to continuously define the condition of an aircraft in flight. Once incorporated, this will allow the Army to monitor and update usage spectra as necessary and thereby enhance the "weak link" of the fatigue substantiation process.

DOC. NUMBER: 42

TITLE: UH-60 Flight Data Replay and Refly System State Estimator Analysis

AUTHOR: M. Whorton, University of Alabama

PUBLISHER: AIAA - 28th Aerospace Sciences Meeting

DATE: January 1990

DOC. TYPE: Conference Paper

ABSTRACT: Research currently underway at The University of Alabama Flight Dynamics Lab investigates concepts for implementation of a ground-based UH-60 flight data replay and refly system. A variation of a linearized extended Kalman filter is implemented which utilizes a mathematical model of the UH-60 to accurately re-create a UH-60 helicopter flight based on flight measurements. Essential in this paper is the development of the UH-60 mathematical model, an experimental verification of the Kalman filter implementation, and an experimental evaluation of filter sensitivity to initial condition errors, measurement sample rate reductions, and model parameter variations. Results indicate that vehicle dynamics are represented with sufficient fidelity by the UK-A mathematical model for both filter design and piloted simulation, providing a replay and a refly capability. Experimental analysis of the Kalman filter indicates that the current filter exhibits a robust tracking ability for low measurement sample rates; demonstrates relatively fast, stable convergence in the presence of initial condition errors; yet manifests a notable performance degradation due to weight variations.

DOC. NUMBER: 43

TITLE: U.S. Army Flight Condition Monitoring

AUTHOR: R.L. Buckner, D.J. Merkley; Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVSCOM)

PUBLISHER: Unknown

DATE: Unknown

DOC. TYPE: Conference Paper

ABSTRACT: The flight condition monitoring (FCM) method of acquiring operational usage data is presented as it was developed from U.S. Army helicopter service usage programs from 1964 to present. The importance of incorporating operational usage data in fatigue design approaches, such as safe-life and damage tolerance, is discussed with emphasis on the establishment of dynamic component fatigue lives. The Army's service usage programs are critically reviewed to determine areas of sensitivity in establishing design mission spectra for rotary-wing aircraft. The feasibility of utilizing FCM with state-of-the-art microprocessor recorder technology on future in-service programs is presented with suggested unified approaches to mission spectrum development on current and future helicopter systems.

DOC. NUMBER: 44

TITLE: Vibration Analysis for Detection of Bearing and Gear Faults Within Gearboxes: An Innovative Signal Processing Approach

AUTHOR: R.C. Kemerait, G.W. Pound, L.J. Owiesny; ENSCO, Inc.

PUBLISHER: Unknown

DATE: Unknown

DOC. TYPE: Conference Paper

ABSTRACT: The principal purpose of this research was to investigate the possibility of enhancing the early detection of gear and bearing problems in helicopter gearboxes utilizing more sophisticated signal processing techniques. Additional considerations were the applicability of these improvements to routine helicopter maintenance and use as an aid for in-flight readiness. The selected research dealt with the processing of acceleration data collected from the Navy TH-1L helicopter test bed. The aircraft was strapped down with the main rotor removed for safety reasons and the tail rotor left on to load the 42 degrees gearbox being investigated. The signal processing research dealt principally with the potential improvements to be gained by utilizing the complex and cosine squared cepstrum techniques. Considerable apparent gains in performance were achieved by a combination of the traditional and unique employments of these cepstral techniques. Many other signal processing features were investigated and reported as by-products of this research.

A.2 OTHER AIRCRAFT DIAGNOSTICS

DOC. NUMBER: 45

TITLE: Allison Gas Turbine: in the Forefront of Vertical Flight Propulsion R&D

AUTHOR: L. Scipioni, Jr.; Allison Gas Turbine Division, General Motors

PUBLISHER: Vertiflite

DATE: May/June 1988

DOC. TYPE: Magazine Article

ABSTRACT: Allison Gas Turbine Division of General Motors is the major producer of light helicopter turboshaft engines. In the 1980s, several turbine engine development programs were started to address 1990s requirements. The T800, a 1200-SHP engine, is a new, small engine for the Army's Light Helicopter Experimental Program (LHX). The V-22 Osprey Tiltrotor uses the Allison T406 engine, a large turbine engine in the 6000-SHP category. The future thrust is towards lower cost and smaller, more reliable and powerful turbines. Research and development areas include: investigation of unique cycles, doubled power to weight ratio, greater than 25% reduction in SFC, increased reliability/maintainability, better affordability, improved operational capability, etc. The technologies needed to support these development areas include improved high temperature materials, smaller components, and maintainability design characteristics.

DOC. NUMBER: 46

TITLE: An Analysis of Air Force Management of Turbine Engine Monitoring Systems (TEMS)

AUTHOR: Capt. E.B. Hubbard III, Capt. G.A. Swecker; Air Force Institute of Technology, Wright Patterson AFB

PUBLISHER: Air Force Institute of Technology, Wright Patterson AFB

DATE: June 1980

DOC. TYPE: Master's Thesis Report

ABSTRACT: Turbine engine monitoring systems (TEMS) are engine health monitoring and diagnostics tools being developed and tested for use on Air Force engines in order to improve and reduce the cost of engine maintenance and management and to aid in the implementation of on-condition maintenance. Previous researchers have described the major features of TEMS, analyzed the results of development and test efforts, and identified problems which must be overcome. This study examines the problem of fragmentation which exists in the Air Force management of TEMS development and testing. The authors describe and analyze the overall Air Force management of TEMS. Management problems were identified and classified into three major areas: structure and role problems, information flow and integration problems, and leadership and command problems. Four alternative management concepts were analyzed. Based on this analysis, the authors recommend that the management structure be modified, and a TEMS task force be established to more effectively utilize TEMS for Air Force engine maintenance and management.

DOC. NUMBER: 47

TITLE: An Automated Between-Flight Visual Inspection Condition Monitoring System

AUTHOR: P.T. Coleman, E. Nemeth, J.M. Maram, A.M. Norman; Rockwell International, Rocketdyne Division

PUBLISHER: AIAA - AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference

DATE: July 1989

DOC. TYPE: Conference Paper

ABSTRACT: This paper discusses the automation of between-flight visual inspections for reusable rocket engine system maintenance. A review of current turnaround maintenance procedures and the application of automated inspection methods is discussed. In addition, the application of vision processing to images acquired by current methods of visual inspection is examined.

DOC. NUMBER: 48

TITLE: Design of Digital Self-Selecting Multivariable Controllers for Jet Engines

AUTHOR: A.H. Jones, B. Porter, A. Chrysanthou; Centre for Instrumentation and Automation, University of Salford

PUBLISHER: AIAA - AIAA/SAE/ASME/ASEE 26th Joint Propulsion Conference

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: In this paper, the tunable digital set-point tracking PI controllers for linear multivariable plants developed at Salford are extended to deal with plants with more output variables than input variables. This extension is effected by delineating the concept of asymptotic positive-real closed-loop transfer function and by using this concept in the design of self-selecting highest- or lowest-wins controllers. The effectiveness of the resulting design methodology is illustrated by designing a self-selecting lowest-wins set-point tracking PI controller for a two-input five-output turbofan jet engine.

DOC. NUMBER: 49

TITLE: Diagnostics in the Extendable Integrated Support Environment (EISE)

AUTHOR: J.R. Brink, Ph.D.; Battelle Columbus Division
P. Storey; Sacramento Air Logistics Center, MMESD

PUBLISHER: NASA Lyndon B. Johnson Space Center - SOAR '88 Workshop

DATE: November 1988

DOC. TYPE: Conference Paper

ABSTRACT: EISE is an Air Force developed real-time computer network consisting of commercially available hardware and software components to support systems level integration, modifications, and enhancements to weapons systems. The EISE approach offers substantial potential savings by eliminating unique support environments in favor of sharing common modules for the support of operational weapon systems.

An expert system is being developed that will help support diagnosing faults in this network. This is a multi-level, multi-expert diagnostic system which uses experiential knowledge relating symptoms to faults and also reasons from structural and functional models of the underlying physical model when experiential reasoning is inadequate. The individual expert systems are orchestrated by a supervisory reasoning controller, a meta-level reasoner which plans the sequence of reasoning steps to solve the given specific problem. The overall system, termed the diagnostic executive, accesses systems level performance checks and error reports, and issues remote test procedures to formulate and confirm fault hypotheses.

DOC. NUMBER: 50

TITLE: Digital Data System Expected to Benefit Defense and Industry

AUTHOR: B.D. Nordwall

PUBLISHER: Aviation Week & Space Technology

DATE: February 1990

DOC. TYPE: Magazine Article

ABSTRACT: The computer-aided acquisition and logistic support (CALS) program is a Pentagon program to shift technical weapon systems data from paper to digital storage. The first phase of the program ran from 1985 to 1989, and emphasized coordination with industry, infrastructure plans and initial standards. The second phase is scheduled from 1990 to 1995, during which a CALS test network will be established. The third phase, from 1995 to 2000, will have CALS shifting to wide-scale industrial networks. The services have designated lead weapon systems to use CALS: the LHX helicopter and the Abrams M1 tank from the Army, the A-12 advanced tactical aircraft, the V-22 Osprey and the SSN-21 Seawolf submarine from the Navy, and the Advanced Tactical Fighter from the Air Force.

The success of CALS depends on the creation of standards and technology. Creating a standard defense/industry interface poses an immediate problem. Another issue is how far to retrofit CALS, since 50-80% of existing weapon systems will still be around in 2000.

DOC. NUMBER: 51

TITLE: Engine Monitoring

AUTHOR: S. Royek, R. Casagrande, P. Emile, D. Garcia, G. Gozemba; Ametek Aerospace Products

PUBLISHER: Avionics

DATE: January 1990

DOC. TYPE: Magazine Article

ABSTRACT: The most sophisticated engine monitoring systems are on several military aircraft. Engine data is collected and analyzed, alerting the pilot to abnormal conditions. Also, vibration analysis combined with speed, temperature, pressure, engine cycles, life usage, and time/date stamping create maintenance schedules for each engine. In a U.S. Navy study of an earlier engine monitoring system, maintenance per flight hour and premature engine removals were reduced and actual flight hours were increased.

DOC. NUMBER: 52

TITLE: Evaluation of a Fault Tolerant Digital Engine Controller

AUTHOR: W.E. Wright, J.C. Hall; Advanced Technology Control Systems, GE. Dr. J.J. Deyst, Dr. R.E. Harper; Charles Stark Draper Laboratory

PUBLISHER: AIAA - AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference

DATE: July 1989

DOC. TYPE: Conference Paper

ABSTRACT: In order to address aircraft engine control reliability and redundancy issues associated with advanced aircraft, the Air Force initiated two programs known as INTERFACE I and II - L. The acronym INTERFACE is derived from Integrated reliable fault-tolerant control for engines. The Advanced Technology Controls organization of General Electric Aircraft Engines participated as a prime contractor in both INTERFACE programs. INTERFACE I incorporated a military standard 1750A 16-bit processor architecture programmed in Jovial, and INTERFACE II - L utilizes military standard 1815 Ada in combination with a 32-bit processor. Both programs produced triple redundant engine controls and feature a tightly synchronized, Byzantine resilient fault-tolerant computer architecture developed by the Charles Stark Draper Laboratory. This paper presents an evaluation of the INTERFACE I engine control, as well as preliminary evaluation of the INTERFACE II control. The results of investigations into fault-tolerant parallel processing for engine controls will also be presented.

DOC. NUMBER: 53

TITLE: Full Authority Digital Electronic Engine Control System Provides Needed Reliability

AUTHOR: D.A. Fiebig; Controls Engineering, Government Engine Business, Pratt and Whitney

PUBLISHER: AIAA - AIAA/SAE/ASME/ASEE 26th Joint Propulsion Conference

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: During the past decade the reliability of control systems for Pratt & Whitney military engines has improved by a factor of six. An operational engine of current configuration now requires the removal of a control system component for maintenance action less than once a year. This significant improvement is the result of a concentrated effort to address the elements of product quality and reliability at all stages of development including design, development, manufacture, and deployment. In addition to basic design improvements which rely on digital electronic control modes, specific design, development test and production quality improvement initiatives have contributed to the overall reliability enhancement. Such programs as environmental stress screening, combined environment reliability testing, durability testing, production readiness programs, field service evaluations, and manufacturing process reviews made significant improvements in product reliability. Throughout the next decade, significant improvements in reliability will continue to be made because of the incorporation of further digital electronic control enhancements (dual channel full authority digital electronic control systems) and the application of propulsion and power system integrity program, concurrent engineering, and total quality management initiatives for the design, development, and production programs.

DOC. NUMBER: 54

TITLE: Integrated Avionics

AUTHOR: R.E. Friday; King Radio Division, Allied Signal Corporation
M.A. Card; Bendix Avionics Division, Allied Signal Corporation

PUBLISHER: Aerospace Engineering

DATE: April 1988

DOC. TYPE: Magazine Article

ABSTRACT: The trend in avionics systems for general aviation is towards the integration of sophisticated navigation, display and flight control systems. One major hinderance to full integration has been the ranging degree of incompatibility between components that typically comprise an avionics system. Recently introduced general systems include electronic flight instrument systems, long-range navigation systems and digital flight control systems. New display systems, data transfer methods, and cockpit management tools are being developed to deal with the increased amount of data available to the flight crew. Among the technologies being investigated are flat panel displays, fly-by-wire control systems, voice command and control, high-speed bi-directional data buses, and fault tolerant data management computers.

DOC. NUMBER: 55

TITLE: Power Analyzer and Recorder (PAR)

AUTHOR: Teledyne Avionics

PUBLISHER: Teledyne Avionics

DATE: Unknown

DOC. TYPE: Product Brochure

ABSTRACT: PAR is Teledyne Avionics' power analyzer and recorder. It is a turbine engine health monitor designed to analyze and record aircraft operation and display information to the pilot. PAR continuously monitors N1, N2, Np/Nr, EGT, and Torque, and generates all Atmospherics - PALT, DALT, OAT. Data can be downloaded to a printer or PC via a RS232 communications port.

DOC. NUMBER: 56

TITLE: Reconfigurable Integrated System Architecture for Future Monitoring Systems

AUTHOR: W.A. Clearwaters; Helitune Ltd.

PUBLISHER: DLR, Institut fur Flugfuhrung - Proceedings of 15th AIMS Symposium

DATE: September 1989

DOC. TYPE: Symposium Paper

ABSTRACT: Next generation monitoring systems will require capabilities not found in current systems. In order to meet the challenges posed by these systems, Helitune has instituted the ARIA (Advanced Reconfigurable Integrated Architecture) program to capitalize on recent advances in computer technology, particularly in the areas of object oriented programming systems, VLSI, and database systems. ARIA proposes to employ the power inherent in the object paradigm to address the problems of integration and reconfiguration in future monitoring systems. ARIA also encompasses a hardware element to develop a modular, distributed hardware set and a software toolbox for the reliable implementation and maintenance of these new systems.

DOC. NUMBER: 57

TITLE: A Self Diagnostic System for Piezoelectric Sensors

AUTHOR: W.J. Atherton, Ph.D., P.M. Flanagan, Ph.D.; Cleveland State University

PUBLISHER: AIAA - AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference

DATE: July 1989

DOC. TYPE: Conference Paper

ABSTRACT: A technique for determining the mounting conditions of a piezoelectric accelerometer is presented. This technique electrically stimulates the piezoelectric element in the "diagnostic" frequency band measuring the electrical frequency response characteristics across a capacitive load impedance. The diagnostic frequency band is typically much higher than the operating bandwidth of the accelerometer. The resonant frequencies of the accelerometer are included in the diagnostic band. By monitoring the shift in these resonant frequencies via electrical stimulation techniques, certain diagnostic conditions including mounting conditions can be determined. Experimental data from a compression mode accelerometer is used to demonstrate this technique.

DOC. NUMBER: 58

TITLE: Systems Approach to Engine Monitoring

AUTHOR: G. Harris; Data Trend

PUBLISHER: Avionics

DATE: February 1986

DOC. TYPE: Magazine Article

ABSTRACT: The JET (Jet Electronics and Technology) ETM600 is an inflight engine monitoring system that provides operating parameter trend analysis graphs by means of a removable module that stores the data. The result is substantially improved maintainability and instrument calibration.

DOC. NUMBER: 59

TITLE: Trend Analysis and Diagnostic Codes for Training Purposes

AUTHOR: G. Torella; Italian Air Force Academy

PUBLISHER: AIAA - AIAA/SAE/ASME/ASEE 26th Joint Propulsion Conference

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: The importance and necessity of simulation during the training of personnel, as well as during on-condition maintenance activities, are discussed. Numerical codes have been developed for this aim and the results for trend analysis and for diagnostic calculations are presented. The paper deals with different fault situations and with engines with different configurations.

A.3 ROCKET ENGINE DIAGNOSTICS

DOC. NUMBER: 60

TITLE: Artificial Intelligence Techniques for Ground Test Monitoring of Rocket Engines

AUTHOR: M. Ali, U.K. Gupta; Center for Advanced Space Propulsion, University of Tennessee Space Institute

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: The goal of the ongoing research described in this paper is to develop an expert system which can detect anomalies in Space Shuttle Main Engine (SSME) sensor data significantly earlier than the redline algorithm currently in use. In the training of such an expert system, we have focused on two approaches which are based on low frequency and high frequency analyses of sensor data. Both approaches are being tested on data from SSME tests and their results compared with the findings of NASA and Rocketdyne experts. Our prototype implementations have detected the presence of anomalies earlier than the redline algorithms that are in use currently. It therefore appears that our approaches have the potential of detecting anomalies early enough to shut down the engine or take other corrective action before severe damage to the engine occurs.

DOC. NUMBER: 61

TITLE: Comparison of Nonlinear Smoothers and Nonlinear Estimators for Rocket Engine Health Monitoring

AUTHOR: B.K. Walker, E.T. Baumgartner; Health Monitoring Technology Center for Space Propulsion Systems, University of Cincinnati

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: A new nonlinear, real time smoothing algorithm is applied to the problem of estimating some of the parameters that describe the dynamics of a reusable space propulsion system, in particular parameters that are likely to change when engine degradations occur. The results are compared to those from a nonlinear filtering algorithm based upon the extended Kalman filter. The SSME operating at its 100 percent rated power level is used as the baseline propulsion system with the filter and smoother designs based upon a reduced order dynamic model of the SSME. The data used to drive the algorithms is generated by a high fidelity transient simulation of the SSME with small magnitude random dither signals applied to the fuel side control valves and with substantial random noise added to the measured outputs. The results indicate the smoother provides substantial improvement over the filter in terms of parameter estimation accuracy. However, both algorithms are not always able to track the correct parameter values when changes in these values representing engine degradations are introduced in the simulation that produces the data. The paper concludes with an examination of the effect of measurement biases on the parameter estimation performance of the smoother and a method to compensate these effects.

DOC. NUMBER: 62

TITLE: Condition Monitoring of Liquid Rocket Engines Using Statistical Process Control

AUTHOR: E. Royer, D. Wolting; Aerojet TechSystems Company

PUBLISHER: AIAA

DATE: July 1989

DOC. TYPE: Conference Paper and Slides

ABSTRACT: This paper discusses the application of statistical process control methodology to problems of engine performance and condition monitoring. These methods include simple X-bar, R, and cumulative sum control charts. A case study is presented, where these techniques are applied to evaluate the performance of liquid rocket engines over time. The results show that these methods can be very effective aids in analyzing flight data and in confidently developing performance predictions for future missions.

A multivariate control chart is also presented for summarizing the condition of liquid rocket engines. The method combines numerous measurements into a single statistic which characterizes overall engine status. Tests of significance based on this statistic are shown to identify faults or anomalies which would otherwise go undetected. Diagnostic procedures using multivariate methods are discussed, as are ways to reduce both Type I and Type II errors in engine condition monitoring applications.

DOC. NUMBER: 63

TITLE: Cost-Benefit Modeling for Rocket Engine Condition Monitoring Systems

AUTHOR: C.J. Meisl; Rocketdyne Division, Rockwell International

PUBLISHER: AIAA

DATE: July 1989

DOC. TYPE: Conference Paper

ABSTRACT: Condition monitoring systems (CMS) for rocket engines may contribute significantly to future decreased launch costs, due to improvements in the overall reliability of propulsion systems and streamlined pre-launch and refurbishment processes. This paper discusses a methodology for assessing the costs and benefits of rocket engine CMS for future launch vehicles. The methodology is based on net life cycle cost savings for the total vehicle and payload system. It considers the actual cost of CMS, the unreliability penalties of the CMS, and its beneficial effects on reducing operational costs and increasing overall engine reliability.

Emphasis of the work reported in this paper is on engine reliability improvements and decreased costs for a launch cycle. The reliability modeling was performed using a simulation method based on fault trees for two key component groups, i.e., turbopump and main combustion chamber with nozzle. Changes in launch cycle costs were determined using a Markov Chain approach which accounts for the cost of engine-caused launch vehicle failures. The methodologies are described, preliminary parametric results presented for reusable engines, and cost drivers discussed.

DOC. NUMBER: 64

TITLE: Cost Effectiveness Perspectives for Launch Vehicle Health Monitoring Systems

AUTHOR: R.L. Puening; Martin Marietta Astronautics Group

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: This paper describes methodologies to quantitatively determine the cost effectiveness of health monitoring systems for different types of launch vehicles and launch vehicle stages. The interaction of health monitoring with other programmatic element cost saving measures is described. Individual elements of cost saving benefits and penalties of health monitoring systems as applied to launch vehicles are assessed utilizing a health monitoring cost model spreadsheet tool developed by the author.

DOC. NUMBER: 65

TITLE: Development of a Health Monitoring Algorithm

AUTHOR: E. Nemeth, A.M. Norman Jr.; Rocketdyne Division, Rockwell International

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: An algorithm has been developed using fourteen measurements of the SSME rocket engine that in many cases provides significantly better performance (detection of damage and then shutdown) than existing redline-type algorithms.

Essentially, the algorithm has permissible zones for functions of combinations of the variables, rather than just limits on the values considered independently. The limit functions are developed ad hoc rather than using some estimation-control oriented technique.

DOC. NUMBER: 66

TITLE: Diagnostic Needs of the Space Shuttle Main Engine

AUTHOR: RR. Teeter, A.E. Tischer, R.C. Glover, B.A. Kelley; Battelle Columbus Laboratories

PUBLISHER: Battelle Columbus Laboratories

DATE: 1984

DOC. TYPE: Technical Paper

ABSTRACT: A study is being conducted for NASA on potential diagnostic system improvements to the SSME. This paper reports midterm progress including: (1) the results of a failure mode review identifying key diagnostic needs; (2) the results of a survey of diagnostic techniques that might be applied to the SSME; and (3) application to the SSME of a Battelle developed tool (the failure information propagation model) for analysis of diagnostic needs. It is concluded that opportunities for significantly improved diagnostics exist in a number of areas. Future plans are described that are directed toward development of a diagnostics strategy and design recommendations for an improved diagnostic system for the SSME.

DOC. NUMBER: 67

TITLE: An Expert System for Fault Diagnosis in a Space Shuttle Main Engine

AUTHOR: M. Ali, U. Gupta; University of Tennesse Space Institute

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: The detection and diagnosis of SSME faults in an early stage is important in order to allow enough time for fault preventive or corrective measures. Since most of the faults in a complex system like SSME develop rapidly, early detection and diagnosis of faults is critical for the survival of space vehicles. We have designed an expert system for automatic learning, detection, identification, verification, and correction of anomalous propulsion system operations. This paper describes an innovative machine learning approach which is employed for the automatic tracking of this expert system.

DOC. NUMBER: 68

TITLE: Health Monitoring System for the SSME: Fault Detection Algorithms

AUTHOR: S. Tulpule, W.S. Galinaitis; United Technologies Research Center

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: A health monitoring system (HMS) framework for the SSME has been developed by United Technologies Corporation for the NASA Lewis Research Center. As part of this effort, fault detection algorithms have been developed to detect the SSME faults with sufficient time to shut down the engine. These algorithms have been designed to provide monitoring coverage during the startup, mainstage and shutdown phases of the SSME operation. The algorithms have the capability to detect multiple SSME faults, and are based on time series, regression and clustering techniques. This paper presents a discussion of candidate algorithms suitable for fault detection, followed by a description of the algorithms selected for implementation in the HMS and the results of testing these algorithms with the SSME test stand data.

DOC. NUMBER: 69

TITLE: Health Monitoring System for the SSME: Hardware Architecture Study

AUTHOR: J.K. Kamenetz; Hamilton Standard Division of United Technologies
M.W. Hawman, S. Tulpule; United Technologies Research Center

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: This paper presents a hardware architecture for a SSME HMS. The architecture study was conducted in conjunction with a NASA sponsored program to develop a framework for SSME HMS for ground test and, potentially, flight applications. The function of the ground based HMS was two fold: protect engines during ground test and provide a test bed for HMS development. The flight system would potentially serve as a maintenance aid and as a safety feature. The requirements of the program were to use as much of the existing controller and facility instrumentation as possible and to utilize existing or near term technologies. The HMS was intended to be designed, developed, and qualified for ground use within 5 years. Fundamentally, the HMS design should not preclude flight-based operation.

The paper follows a defined conceptual design process. The requirements for both systems are both stated and analyzed. A multi-processor, distributed, VME system is envisioned for the ground test hardware. By repackaging the boards, the same concept is shown to be usable for the flight system. The paper concludes with an analysis of weight, power, and reliability with respect to variations in functionality.

DOC. NUMBER: 70

TITLE: HERMES Propulsion Subsystem On-Board Diagnostic Monitoring and Control

AUTHOR: N. Cornu, G. Gerbes; Societe Europeenne de Propulsion, Space and Defence Group

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: After a description of the HERMES propulsion requirement, physical characteristics and basic principles selected for the spacionics, this paper is intended, in a second part, to set up the objectives of the on board diagnostic monitoring and control, the monitoring concept and the monitoring method to be applied to the HERMES propulsion subsystem. The resultant measurement points with their data requirements and the new technological developments needed are described in the third part of this paper.

DOC. NUMBER: 71

TITLE: The History and Future of Safety Monitoring in Liquid Rocket Engines

AUTHOR: A. Norman, I. Cannon, L. Asch; Rockwell International, Rocketdyne Division

PUBLISHER: AIAA

DATE: July 1989

DOC. TYPE: Conference Paper

ABSTRACT: One of the major advantages of liquid rocket engines is their ability to modify operating conditions during a firing in order to prevent failures which might otherwise result in loss of the mission or damage to test facilities. The simplest and most common form of modification is shutdown, but transitioning to a more benign condition for a detected problem is likely to become more common in future engines as new and more powerful control hardware and software become available. In order to take advantage of this capability, monitoring systems must be able to detect unsafe conditions and signal the control system to take the appropriate actions. This paper will discuss the history and development of these safety monitoring systems to the present day, what can be expected in the foreseeable future, and how past history can affect these expectations.

DOC. NUMBER: 72

TITLE: Integrated Health Monitoring Approaches and Concepts for Expendable and Reusable Space Launch Vehicles

AUTHOR: J.G. Johnson; General Dynamics Space Systems Division

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: To support the high launch rates that are projected for space launch vehicles in the 1990s and to reduce current launch system operations costs, test and checkout tasks will have to be accomplished in a more cost-effective and operationally efficient manner. This paper will determine health monitoring approaches and concepts for expendable and reusable space launch vehicles, and provide a definition and architecture for integrated health monitoring. Expendable space launch vehicle flight history data is also presented to further understand the types of anomalies that have occurred on past space launch systems. A vehicle data architecture is also presented for reviewing data and obtaining the maximum amount of information that is available onboard a space launch vehicle system. Information is also presented concerning the technology issues for a fully integrated health monitoring system, as well as the evolutionary trend that is occurring between the ground support equipment and airborne areas.

DOC. NUMBER: 73

TITLE: Neural Network Approach to Space Shuttle Main Engine Health Monitoring

AUTHOR: B. Whitehead, H. Ferber, M. Ali; Center for Advanced Space Propulsion, University of Tennesse Space Institute

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: A neural network was trained to distinguish anomalies in SSME sensor data from noisy normal steady-state sensor data. Power spectra of successive windows of individual sensor data were presented to a neural network using Kohonen's topological feature map training algorithm. The trained network for each sensor was then tested to determine if it would detect anomalies in the sensor data, and if so, the time at which the anomaly would be detected. Power spectra from a few hundred seconds of actual test data from NASA tests 901-364 and 904-044 were used to test the network. In both cases, the neural network detected the onset of anomalous engine behavior at approximately the same time within each test as the onset times reported by NASA and Rocketdyne experts in their post-test analyses.

DOC. NUMBER: 74

TITLE: Neural Network Pattern Recognizer for Detection of Failure Modes in the SSME

AUTHOR: H. Luce, R. Govind; NASA, Health Monitoring Technology Center, University of Cincinnati

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: A system for diagnosis of emergent performance degradations and failure modes in the SSME is described. This system looks at the SSME as a collection of subassemblies, and uses time signature data, from sets of parameters arising from sensors local to each subassembly, to compose patterns to be analyzed. A hybrid architecture is used: The first processing layer consists of ART2 (adaptive resonance theory) neural networks, one ART2 network per subassembly; the second layer consists of CAM (content addressable memory) networks, one per subassembly; and the final layer is a backpropagation neural network, which processes data from all of the CAM networks. A prototype system, encompassing only the high pressure fuel turbopump, is presented. The long-term goal of this work is to create a system using the above architecture to ensure that the SSME remains in a state of "health," by creating a feedback loop incorporating operating parameter controls, subassemblies, sensors, and the neural network system.

DOC. NUMBER: 75

TITLE: Prelaunch Expert System for Space Shuttle Propulsion System Health Monitoring

AUTHOR: J. Engle, D. Bogart, J. Marinuzzi; Rockwell International Corporation, Space Transportation Systems Division

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: The prelaunch expert system is a ground-based real-time expert system used to monitor sensors for each Space Shuttle subsystem and identify launch commit criteria violations, their causes, and suggested courses of action. This expert system will reduce the workload and enhance the performance of engineers who monitor large amounts of data and will speed up their reaction time to potential problems. In addition, it can preserve valuable Shuttle program knowledge that might otherwise be lost with the retirement or transfer of senior personnel. The building of the system was driven by the needs of the mission support community and has therefore found a high degree of acceptance among its intended end users.

DOC. NUMBER: 76

TITLE: Progress Toward an Automated Visual Inspection System

AUHTOR: P. Coleman, S. Nelson, J. Maram, A. Norman; Rockwell International, Rocketdyne Division

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: This paper discusses current trends in the automation of visual inspections for reusable rocket engine systems. The application of automated inspection methods for between-flight maintenance and manufacturing is discussed. In addition, the application of vision processing to images acquired by current methods of visual inspection is examined.

DOC. NUMBER: 77

TITLE: Rocket Engine Diagnostics Using Neural Networks

AUTHOR: B. Whitehead, E. Kiech, M. Ali; Center for Advanced Space Propulsion, University of Tennessee Space Institute

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: Two problems in applying neural networks to fault detection and identification are (1) the complexity of the sensor data to fault mapping to be modeled by the neural network, which implies difficult and lengthy training procedures; and (2) the lack of sufficient training data to adequately represent the very large number of different types of faults which might occur. Methods are derived and tested in an architecture which addresses these two problems. First, the sensor data to fault mapping is decomposed into three simpler mappings which perform sensor data compression, hypothesis generation, and sensor fusion. Event training is performed for each mapping separately. Secondly, the neural network which performs sensor fusion is structured to detect new unknown faults for which training examples were not presented during training. These methods were tested on a task of fault detection and identification in the SSME. Results indicate that the decomposed neural network architecture can be trained efficiently, can identify faults for which it has been trained, and can detect the occurrence of faults for which it has not been trained.

DOC. NUMBER: 78

TITLE: Role of Microstructural Sensors for Space Propulsion Health Monitoring

AUTHOR: H.T. Henderson, W. Hsieh; Department of Electrical and Computer Engineering, University of Cincinnati

PUBLISHER: AIAA

DATE: July 1989

DOC. TYPE: Conference Paper

ABSTRACT: The University of Cincinnati was assigned one of the new NASA research centers through a national competition held last year. The area of research here is health and condition monitoring for space propulsion.

This area of research is composed of five major subsets: materials modeling; algorithms and control; structural dynamics; flow and propulsion; and sensors.

It is the purpose of this paper to broadly describe the sensors thrust, with an example or two, in order to provide a perspective of the direction and possibilities of this effort. Most specifically, a microflowsensor will be described to illustrate the power of "micromachining" for creation of miniature, smart, affordable, and reliable sensors which might be placed in locations where parameter monitoring has been previously impossible.

The microsensors and semiconductor microstructures group is now working primarily with mechanical structures at the mil (thousandths of an inch) level, but with our optical and electron beam facilities and our new nanostructures lab, we are set for dimensional progress over the coming decade.

DOC. NUMBER: 79

TITLE: Selection of Monitoring Techniques for a Liquid Propellant Rocket Engine

AUTHOR: E.P. Jurado, J.B. Shade, M.A. Weise; Pratt & Whitney

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: Methodology for selecting a liquid propellant rocket engine condition monitoring system has been developed as part of the rocket engine condition monitoring system program under contract from the United States Air Force. This paper describes the development and use of procedures which evaluate gas generator rocket engine failure modes and associated costs to select monitoring techniques for fault detection and the prevention of fault propagation. An expert system computer program has been developed to select an optimum health monitoring system based on potential life cycle savings. This methodology determines the effects of incorporating an engine monitoring system on costs associated with catastrophic future, mission scrub, launch delay, scheduled and unscheduled maintenance action, ground support equipment, engine shutdown, sensor false-flag, algorithm development, and development and production of monitoring techniques. The health monitoring system identified by these methods establishes the required sensors, algorithms, ground support equipment, and signal processors along with the failure modes and engine parameters that become monitored with their selection. Implementing this methodology will result in improvements in both mission success reliability and system life cycle cost.

DOC. NUMBER: 80

TITLE: Validation Requirements for a Rocket Engine Control and Monitoring System

AUTHOR: A.M. Norman, Jr., J. Maram, A. Weiss; Rockwell International, Rocketdyne Division

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: This paper discusses the requirements for a validation system for rocket engine CMS and why one is needed in the near term. There is an implicit assumption that although failures (perhaps multiple failures) are a probabilistic outcome, the consequence of failure must be a well-known deterministic function, mainly for political reasons. The proposed solution is an engine simulation program sufficiently sophisticated to model the failure modes of interest.

A.3 TECHNOLOGY

DOC. NUMBER: 81

TITLE: Analysis of Airframe/Engine Interactions - An Integrated Control Perspective

AUTHOR: D.K. Schmidt, J.D. Schierman; Arizona State University
S. Garg; Sverdrup Technology Inc.

PUBLISHER: AIAA

DATE: July, 1990

DOC. TYPE: Conference Paper

ABSTRACT: Techniques for the analysis of the dynamic interactions between airframe/engine dynamical systems are presented. Critical coupling terms are developed that determine the significance of these interactions with regard to the closed loop stability and performance of the feedback systems. A conceptual model is first used to indicate the potential sources of the coupling, how the coupling manifests itself, and how the magnitudes of these critical coupling terms are used to quantify the effects of the airframe/engine interactions. A case study is also presented involving an unstable airframe with thrust vectoring for attitude control. It is shown for this system with classical, decentralized control laws that there is little airframe/engine interaction, and the stability and performance with these control laws is not effected. Implications of parameter uncertainty in the coupling dynamics are also discussed, and effects of these parameter variations are demonstrated to be small for this vehicle configuration.

DOC. NUMBER: 82

TITLE: Engines and Artificial Intelligence

AUTHOR: Len Buckwalter

PUBLISHER: Avionics

DATE: February 1986

DOC. TYPE: Magazine Article

ABSTRACT: GEN-X is a software package that enables experts, possessing just a basic familiarity with computers, to devise their own systems by inputting their knowledge and experience for troubleshooting. The first application of this software was computerizing the troubleshooting of locomotives in railroad service shops. Other early applications include maintaining the pitch control of the F-15 flight control system and diagnosing gas turbine faults.

DOC. NUMBER: 83

TITLE: Propulsion System-Flight Control Integration-Flight Evaluation and Technology Transition

AUTHOR: F.W. Burcham, G.B. Gilyard, L.P. Myers; NASA Ames Research Center, Dryden Flight Research Facility

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: Integration of propulsion and flight control systems and their optimization offers significant performance improvements. The NASA Ames Research Center, Dryden Flight Research Facility has, over the years, conducted research programs which have developed new propulsion and flight control integration concepts, implemented designs on high-performance airplanes, demonstrated these designs in flight, and measured the performance improvements. These programs, first on the YF-12 airplane, and later on the F-15, have demonstrated increased thrust; reduced fuel consumption; increased engine life; and improved airplane performance, with improvements in the 5- to 10-percent range achieved with integration and with no changes to hardware. The design, software and hardware developments, and testing requirements have been shown to be practical. This technology has been transferred to the user community through reports, symposia, and industry cooperative programs, and is appearing on operational and advanced airplanes. The flight evaluation and demonstration have been shown to be key in maturing the technology and hastening its transition into production.

DOC. NUMBER: 84

TITLE: Oil Debris Monitoring

AUTHOR: H.M. Belman; Tedeco Division, Aeroquip Corporation

PUBLISHER: Avionics

DATE: February 1986

DOC. TYPE: Magazine Article

ABSTRACT: Failure of mechanical systems such as transmissions is usually preceded by an increase in the number and size of particles in the lubricating oil. Four types of sensors for detecting these particles are discussed in this article. With a collector sensor, a magnet is withdrawn for inspection periodically. The second type of sensor, an electric detector, resembles a spark plug. A particle shorts the detector and in fact the sensor can detect one particle. The third type of sensor, a pulsed electric detector, is similar to the second sensor, but small particles are periodically blown away by a current pulse. The sensor can count small particles, but the sensor fails with a big particle. The final sensor is a quantitative debris monitor (QDM), which magnetically counts and sizes particles. This sensor provides the best results, but with the most cost.

DOC. NUMBER: 85

TITLE: Vibration Monitoring

AUTHOR: J. Higgins, Charles Witt; Endevco Corporation

PUBLISHER: Avionics

DATE: February 1986

DOC. TYPE: Magazine Article

ABSTRACT: Vibration monitoring of a turbine engine is a problem, since a turbine engine produces mechanical vibration amplitudes at virtually all frequencies in the audio range. A vibration monitoring system must discriminate between engine vibration at frequencies of interest and vibration at other frequencies. The monitoring problem is compounded by the fact that vibration frequencies from a turbine engine are not constant; as power increases or decreases, rotating elements correspondingly change speed. Simple vibration monitoring systems, therefore, are often designed to accept any signals within the operational speed of the engine. An efficient system accepts signals from engine tachometers which then control the center frequency of the bandpass tracking filters. A filter which can track frequencies of interest does not need to be very wide in frequency and is very effective in rejecting unwanted vibration signals.

DOC. NUMBER: 86

TITLE: The Application of an Expert Maintenance and Diagnostic Tool to Aircraft Engines

AUTHOR: Dr. R.L. De Hoff, L. Miller, J. Frenster; Systems Control Technology, Inc.

PUBLISHER: AIAA

DATE: July 1990

DOC. TYPE: Conference Paper

ABSTRACT: Next generation aircraft and engines will have the capability to detect, isolate, and accommodate failures in components and subsystems while in flight. To completely realize the full benefits of weapon system integrated diagnostics, intelligent systems must be developed to assist maintenance personnel in servicing the aircraft efficiently and correctly while on the ground.

This paper describes experiences gained in developing and fielding expert maintenance and diagnostics systems for modern aircraft engines. Specifically, SCT's expert maintenance tool (XMAN) has been developed for several USAF and USMC engines. The architecture and functionality of XMAN are discussed and its applicability to future engines is presented. Lessons learned are derived which address issues of knowledge acquisition, maintenance training, and insertion into the logistics support infrastructure.

DOC. NUMBER: 87

TITLE: EPAMS - Engine Performance Assurance Monitoring System

AUTHOR: Howell Instruments, Inc.

PUBLISHER: Howell Instruments, Inc.

DATE: September 1988

DOC. TYPE: Product Brochure

ABSTRACT: The microprocessor-based H598 EPAMS monitors engine parameters constantly during all flight operations while calculating theoretical engine parameters for flight conditions as a basis of comparison to actual performance and performs real-time analysis of engine operation.

EPAMS provides the following engine documentary data: engine usage, mission profiles, parts-life tracking, and an automatic history of all limit exceedances. EPAMS will record the number of engine starts, time at maximum power, time above selected levels of performance for up to 22 different values, total engine time, and engine cycles. EPAMS will also detect engine misuse or abuse through its data logging ability.

DOC. NUMBER: 88

TITLE: On Condition Engine Monitoring

AUTHOR: G. Tonnison; Basingstoke Division, Smiths Industries

PUBLISHER: Avionics

DATE: February 1986

DOC. TYPE: Magazine Article

ABSTRACT: Currently, aircraft engines are scheduled for overhaul rather than having maintenance performed on-condition. On-condition maintenance requires that equipment be removed for overhaul when specified deterioration is identified. Engine monitoring could reduce the risk of on-condition maintenance to acceptable levels. Systems exist for aircraft engine monitoring as well as for rotary-wing aircraft. A typical monitoring system provides facilities in six broad groups: life usage and exceedance; performance-data recording; incident recording; vibration analysis; BITE; and external communications. From these facilities, several analyses are available: low cycle fatigue, thermal fatigue; creep; time/temperature; time speed; gas path analysis; and oil debris monitoring.

DOC. NUMBER: 89

TITLE: Helicopter Operators Forecast Steady Growth into Mid-1990s

AUTHOR: N.C. Kernstock

PUBLISHER: Aviation Week & Space Technology

DATE: February 1990

DOC. TYPE: Magazine Article

ABSTRACT: The global civil helicopter industry has experienced a rebound, although business has not yet returned to the high levels seen in the late 1970s. Four operators typify those who are achieving success by controlling the growth of existing business and their entry into new markets, as well as exploiting profitable niches. While these companies' operations encompass a wide variety of helicopter missions, three major markets are responsible for most of the growth: the oil industry, police and public service, and medical flight service.

DOC. NUMBER: 90

TITLE: TRENDKEY

AUTHOR: Keystone Helicopter Corporation

PUBLISHER: Keystone Helicopter Corporation

DATE: 1987

DOC. TYPE: Product Brochure

ABSTRACT: TRENDKEY is a self-contained panel-mounted system that provides operators with a real-time display of aircraft performance during all flight operations. TRENDKEY can also be interfaced with other avionics and systems to monitor, analyze, and display fuel, air data, and navigational information.

APPENDIX B
HEALTH AND USAGE MONITORING SYSTEMS SUMMARY

SYSTEM	MFG	Helicopter H / FW Fixed Wing	Type A/C	M/D Monitoring Diagnostic Type	Airborne / Ground	AI/ Expert (Y/N)	FAA Approved (Y/N)	MATURITY			REMARKS
								Concept	Dev	Opera-tional	
1. EPAMS	Howell Inst.	H/FW	Various	M	A	N	Y			✓	Usage and exceedance monitoring, optional vibration monitor
2. H/PESA	Honeywell	H	Various	M/D	A	Y	N	✓			Emergency advisory system
3. HELIX	Sikorsky	H	TBD	M/D	A	Y	N		✓		Diagnoses engine failures
4. IFIP	Sikorsky	H	TBD	M/D	G	Y	N		✓		Follow-on to Helix, maintenance oriented
5. AIMS/HUMS	Plessey/BHL	H	TBD	M/D	A	N	N		✓		Joint effort for CAA requirements
6. PAR	Teledyne	H/FW	Various	M/D	A	N	Y			✓	Power assurance checks, exceedance and usage monitoring
7. ROTABS	Vibro-Meter	H	---	M/D	A/G	–	N			✓	Rotor track and balance, maintenance instructions
8. COMPASS	RR/SD-Scicon	FW	---	M/D	G	N	N			✓	In use with Lufthansa, British Airways and TWA
9. XMAN	SCT	FW	Various	M/D	G	Y	N			✓	PC-based maintenance/diagnostic tool, military engines
10. AAM/DA	Bell	H/FW	---	M/D	---	–	N	✓			Maintenance and diagnostic design criteria for future military avionics
11. ETADS	Bell	---	---	M/D	---	–	N		✓		Engineering development tool
12. IMETS	Bell	H/FW	TBD	D	G	N	N	✓			R&D, PC-based maintenance/training
13. VSLED	Bell	H	V22	M/D	A	N	N		✓		Vibration, structural, life, and engine monitoring for V-22 Osprey
14. LH ID	Bell	H	LH	D	A	N	N		✓		Integrated diagnostics for LH helicopter
15. GIMADS	GD/Bell	H/FW	Various	M/D	G	TBD	N	✓			Integrated diagnostics program aimed at developing mil-standards for USAF
16. TRENDKEY	Keystone Heli	H	Various	M	A	N	Y			✓	Measures exceedance & fuel mgmt., systems monitor, air data computer, lower cost market
17. TMS	Safe Flight Instruments	FW	Various	N	A	N	N			✓	Thrust management system
18. EMSC	Ametek Douglas	FW	F-16	M/D	A	N	N			✓	Exceedance monitoring and fault isolation
19. CADS	Gadzala	H	---	D	G	Y	N	✓			Lcdr Gadzala, Naval Post Graduate School
20. EDS	McDonnell Douglas	H	AH-64A	M/D	A/G	–	N		✓		Structural monitoring, operational loads data