A New Engine Monitoring System with Safety Recording for AV-8B

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Abstract—The Naval Air Systems Command (NAVAIR) desires multi-platform information systems that are affordable, minimally intrusive, reliable, and cost effective. The USMC AV-8B is currently planning the installation of a new multipurpose avionic system that simultaneously addresses several aging aircraft issues related to obsolete avionics with a new avionic instrument that provides flight data recording, video recording, health signature data collection and on board analyses and health status alerts. This paper will present an overview of how the technology components form an affordable framework for military and commercial aircraft real time health monitoring without sky high costs for instrumentation and software. The authors will describe the need and requirements for several avionic upgrades for the AV-8B. A concept will be presented that enables the AV-8B program to combine upgrades of the on-board engine monitoring system with upgrades for flight video and data recording. The paper will describe how this combination approach overcomes barriers often encountered by developers of single purpose upgrades; i.e., safety issues, software development, installation and use certification, data analysis centers and life cycle cost. Finally, the authors will present how this avionic system can be the baseline for a general purpose embedded condition based monitoring subsystem and how the approach can reduce CBM system development costs and time. The discussion will include side benefits that reduce weight and life cycle costs. The authors will explain an open architecture with features like user defined real-time data collection, data storage, customized autocoded analyses, and publish/subscribe environment accommodates updates, messages, alerts and data off-load for fleetwide studies.

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1. INTRODUCTION

AV-8B Aircraft

The AV-8B Harrier aircraft is an early 1980s aircraft commonly referred to as a "jump jet" for its short takeoff and vertical landing (STOVL) capability. The AV-8B was derived from the AV-8A (UK GR.1 with GR.3 engine) by adding a larger composite wing and further increasing the engine power. Various avionics upgrades were also added. The AV-8B provides the Marine Corps with a light attack/close air support capability. The AV-8B currently is operated in two configurations, the Harrier II "night attack" and the Harrier II+ "Radar" configuration. Additionally, there are several TAV-8B dual seat trainers operational. The US Marine Corps, the Spanish Navy, and Italian Navy all operate the AV-8B configuration while the UK operates the GR.7 and GR.9 configurations, which have several features in common with the AV-8B. The AV-8B is currently planned to be in operational service through 2022.

Engine Monitoring System

The AV-8B includes an Engine Monitoring System (EMS) to track engine usage, events, and impending engine failure through vibration monitoring. The EMS includes a vibration transducer, charge amplifier, Engine Monitoring Unit (EMU) and supplemental hardware. The original design was by Plessey PLC and is currently a Meggitt Avionics (UK) supported system. The EMU depends heavily on a set of hybrid filters which are now obsolete. Given the usefulness but limited performance of the EMS, an upgrade is required to sustain the AV-8B through its operational life.

2. BACKGROUND

Digital Data Download Flight Information Recorder

The Digital Data Download Flight Information Recorder (D 3 FIR) is a Naval Air Systems Command (NAVAIR) Small Business Innovative Research (SBIR) Phase II FastTrack development for the F/A-18 (PMA-265) and Air Combat Electronics (PMA-209). The D3 FIR extends the Navy standard Crash Survivable Flight Information Recorder (CSFIR) capability to provide an F/A-18 specific implementation for diagnostic and prognostic health management. The D3 FIR is form, fit, and function compliant with the CSFIR and has been demonstrated as such by the F/A-18 Advanced Weapons Laboratory (AWL) at Naval Air Warfare Center, Weapons Division (NAWC-WD), China Lake, CA.

The D3 FIR consists of two primary subassemblies, a Processor/Interface section and a Crash Survivable Memory Unit (CSMU). The Processor/Interface section is bolted on top of the CSMU and the CSMU provides the mounting to the aircraft structure. Figure 1 shows an exterior picture of the D3 FIR. The CSMU is approximately 3.25 inches high and the remainder of the height of the D3 FIR is the Processor/Interface section.

The D3 FIR implements an electrical and software open architecture by utilizing a PCI backplane, Ethernet communications, EIA-422 serial interfaces, MIL-STD-1553B data buses, and an ARINC 653 compatible operating system. However, due to the unique form factor of the existing installation, the D3 FIR is not a physical open architecture.

Figure 1. D3 FIR.

Technical Demonstration Program

The Technical Demonstration Program (TDP) was a technology exploration funded by the UK Ministry of Defense (MOD) to demonstrate a dual vibration transducer configuration that would take advantage of modern engine monitoring technology developed by Meggitt Avionics for various commercial aircraft and to better correlate the results of the EMS vibration monitoring with data from Rolls-Royce engine test cells. NAVAIR PMA-257 (AV-8B Program Office) participated in the TDP program by providing an AV-8B and test facilities at NAWC-WD, China Lake. The overall results of the demonstration program were considered to be very encouraging.

AV-8B needs

The AV-8B Harrier needs are threefold; first, the aircraft is currently undergoing a series of upgrades to address obsolescence issues. The existing EMU is relatively reliable, however many failures involve old hybrid technology that is no longer cost effective to repair.

Second, the AV-8B requires the ability to be brought into compliance with Chief of Naval Operations (CNO) policy directive N88F/9U660308 of 09 NOV 99, which states that, "New production and remanufactured tactical and transport aircraft shall be delivered equipped with a Crash Survivable Flight Information Recorder (CSFIR)..."

Third, the AV-8B program desires to have a growth capability for advanced diagnostic and prognostic health management for the overall weapons system in order to continue to support Fleet operational needs until 2022.

3. Crash Survivable Engine Monitoring Systems

By combining the D3 FIR architecture with the TDP vibration processing to create the Crash Survivable Engine Monitoring System (CSEMS), NAVAIR PMA-257 has identified a uniquely capable upgrade for the AV-8B.

Figure 2. EMU + D3 FIR = CSEMS.

SBIR-Based Program

The D3 FIR was a successful SBIR Phase II program and therefore created a pre-competed status for any Phase III D3 FIR related awards. This allowed a simplified acquisition process with a sole-source award to Management Sciences, Inc. for the CSEMS development. In addition, CSEMS qualified as one of six programs for the SBIR Commercialization Pilot Program (CPP). This resulted in a new SBIR Phase II Accelerated Transition award to support initial CSEMS development while PMA-257 worked to identify funding to complete development and production of the CSEMS program.

The CSEMS Team

Management Sciences, Inc. (MSI) is a small business specializing in Research and Development. As such, MSI has limited hardware development and production capability; certainly not enough to support a program as large as CSEMS. Also, some of the capabilities needed by CSEMS are only available from a limited number of suppliers.

As a result, MSI has assembled a world class team to complete the CSEMS program. As with the D3 FIR development, Honeywell will supply the Crash Survivable Memory Unit (CSMU) which is fully qualified to EUROCAE ED-112 for crash survivability. This CSMU is the same unit used by the D3 FIR. To more fully address the Open Architecture requirements, MSI has teamed with General Electric Fanuc Intelligent Platforms, Embedded Systems (GE Fanuc), to supply open architecture, compact PCI (cPCI) cards, chassis and power supply. The cPCI cards will include a powerPC processor, MIL-STD-1553 interface (4 channel), and special I/O. The Vibration Signal Processor Module (VSPM) will be supplied by Meggitt Avionics in cPCI format. The VSPM includes the data acquisition from the vibration transducer/charge amplifiers and a very low power signal processor to analyze the frequency content of the engine vibrations. The VSPM will execute the vibration processing algorithms based on those proven during the TDP program.

The Government acquisition team includes NAVAIR PMA-257 with support from various field activities including the AV-8B Joint System Support Activity (JSSA) at NAWC-WD, China Lake, the AV-8B Fleet Support Team (FST) at Marine Corps Air Station (MCAS), Cherry Point, NC, plus training, support equipment, and logistics support from various NAVAIR components. PMA-209 (Air Combat Electronics), the original sponsor of the D3 FIR, is providing acquisition and contracting support.

Finally, the CSEMS team will be working with Rolls-Royce Engines, Bristol, UK, to define interfaces and to integrate with the new engine vibration transducers. While Rolls-Royce is not part of the CSEMS team and is operating under a separate PMA-257 contract, close cooperation between the CSEMS program and Roll-Royce will be essential to the successful completion of the CSEMS program.

4. CSEMS ARCHITECTURE

The CSEMS is based on open architecture cPCI modules with PCI Mezzanine Carrier (PMC) modules added where appropriate.

The Processor

The main processor is a Commercial-off-the-Shelf (COTS) 1 GHz powerPC. This module includes two Gigabit Ethernet connections and two RS-232 serial ports. One of the serial ports will be used as a console port during development and testing while the other will be a spare. One of the Gigabit Ethernet connections will provide a connection to Ground Support Equipment (GSE) for data offload and program loading.

VSPM

The VSPM supports vibration data acquisition and analysis. The CSEMS will implement a single-engine, dual-channel vibration analysis, however the VSPM is capable of dual-channel vibration analysis on two engines so that application of the CSEMS to a dual engine application is relatively straightforward.

MIL-STD-1553

The AV-8B, depending upon the aircraft configuration, has two (2) or three (3) MIL-STD-1553B dual standby redundant data buses. The CSEMS will utilize a 4 channel COTS 1553 card which will operate as a Remote Terminal (RT) on bus #2 with an emulation of the existing EMU interface. In addition, the other buses will be routed to the CSEMS and will monitor these buses (including bus #2) for avionics parameters to be recorded or utilized in advanced engine monitoring algorithms. Data access over all buses is controlled by a separately loadable table that is auto-generated from the MIL-STD-1553 ICD for the aircraft.

The MIL-STD-1553 bus #2 will also support a program load capability via the Navy standard Memory Loader/Verifier (MLV).

The Rolls Royce F402 engine utilizes dual Digital Engine Control Units (DECUs) with DEF STAN 00-18 Part 3 serial interfaces. Part 3 utilizes MIL-STD-1553 interface hardware and waveforms to provide a single source/multiple sink capability. The fourth MIL-STD-1553 channel on the COTS 1553 card will be modified to interface with these two DECU interfaces.

Unique I/O

A PMC will be used to host special I/O required for the CSEMS integration on the AV-8B. This card will be custom designed for the CSEMS but will utilize standard circuit designs already proven in other applications. These signals include discrete inputs/outputs and TIA-422/485 serial interfaces to the Engine Performance Indicator (EPI) in the aircraft cockpit.

Software

The CSEMS will re-use the D3 FIR software to the extent practical. The ARINC 653 compatible operating system (OS) will be replaced by a COTS microkernel based OS (QNX Nutrino). Another change will be the replacement of the CSFIR emulation software with EMU emulation.

The D3 FIR and the CSFIR make extensive use of a "rules" engine to operate on the incoming data. Rules can be simple logic expressions used to detect events or can be applied inferences that result in a probabilistic representation of a condition. Probabilistic logic can be represented in neural nets, Bayesian Classifiers, Naïve Bayesian Networks, Dynamic Bayesian Networks, Hierarchical Hidden Markov Models, Sequential Hidden Markov Models, etc. Normal practice when using such capabilities is to collect data on board the vehicle and offload it for extensive ground processing. This approach results in considerable and substantive delays between collection of the data and having the assessment results of the condition of the on-board equipment. MSI has developed highly efficient algorithms that approximate the answers with sufficient accuracy (2-3 places of precision in lieu of 10+ places of precision for the ground processing system) to make appropriate decisions on equipment maintenance.

Table Driven Recording

MSI's latest Rules Engine provides the ability to create simple parameter tables that define the data to be recorded within any specific data file. Should the user desire to change the parameters to be recorded, a simple edit of the corresponding parameter table will accomplish the change instead of waiting two or more years for a software program change as required by most equipment.

Ground Support Software

Most recorders utilize unique software in the Ground Support Equipment (GSE) to access and download the data files that were recorded. With the Navy Marine Corps Internet (NMCI) standardization of computers and software, the qualification of such GSE software can take a considerable amount of time and effort.

To overcome this issue, CSEMS will host a small web server utilizing standard web protocols (HTTP, FTP, etc.). The GSE can now be any standard computer with a web browser capability to access CSEMS over the Ethernet interface. Standard web pages allow the GSE operator to access the stored data, upload new software, reconfigure the support files and databases (Rules, MIL-STD-1553 data tables, etc.) and access Built-In-Test (BIT) results and other maintenance data. A special access capability is available to field engineers to access key parameters to monitor and assess operational parameters. The only required special GSE to access this capability is an Ethernet cable from the standard computer to a circular MIL connector in the aircraft wheel-well.

5. STATUS AND CONCLUSIONS

Status

The CSEMS has completed an initial program definition phase and is just completing a program planning phase. The program definition effort included the development of a top level System Performance Specification (SPS) and a detailed Interface Control Document (ICD). This phase also established the overall CSEMS architecture approach.

The Program Planning effort allowed MSI and each of the subcontractors to develop the necessary program plans and processes to be used during the CSEMS development. These plans and processes were coordinated across the total program to yield consistent practices for the delivery of the CSEMS hardware. This effort is nearing completion with the development of an Integrated Master Schedule for the program.

A System Requirements Review (SRR) has been successfully completed and Preliminary Design Review (PDR) is scheduled for Summer 2008. Flight and ground testing is due to be complete by early 2010 with production and Fleet installs to follow shortly thereafter.

Conclusions

MSI, as a small R&D company, has the ability for the rapid development of complex software capabilities. But to deliver production software for an operational weapons system, MSI has needed to improve many internal capabilities. The establishment of full time Configuration Management and Quality Program capabilities has been completed. Additional capabilities will necessarily be added as the program progresses.

The requirement for a small business to manage a program with the complexity of CSEMS is not unreasonable, but when the program includes three major subcontractors, as well as several smaller specialty companies, then the program management aspects become challenging. This is especially true when one of the companies is international (Meggitt Avionics in the UK) and International Traffic in Arms Regulations (ITARS) applies.

Working with several government activities adds some complexity, however the various Naval activities have been very cooperative and easy to work with. A minor complication is that the program has activities across 8 time zones so coordination can be challenging.

The CSEMS program funding has been a source of unexpected complexity. Funding has come from a combination of SBIR funding, with its attendant limitations on subcontracting of funds, and an Indefinite Delivery, Indefinite Quantity (ID/IQ) Phase III contract. This results in several "colors" of money with different restrictions and having to work with multiple contract offices.

To control risk on the CSEMS program, funding was initially planned in smaller blocks with completion of program gates to access additional blocks of funding. This could have worked if the contracting process had been more responsive. However, contracting personnel were required to give priority to Middle East warfighter needs which resulted in substantial contracting delays. This issue created inconsistent funding levels and uncertainties in program timing. Subsequently, the program funding increments have been consolidated in a simpler format to reduce contracting workload and make program timing easier.

The CSEMS program has many of the standard technical risks including power and weight, but the CSEMS development team is committed to delivering a highly capable system to support the AV-8B Harrier program through its operational life.

BIOGRAPHY

***Francis E. Peter** is the Manager for Systems and Programs for MSI. Mr. Peter currently manages the development of Safety Recording and Engine Monitoring systems for military aircraft. He has 16 years experience as a Navy civil servant and 21 years in the defense industry specializing in electronic warfare and Systems Engineering of data bus and common avionics/electronics systems. He has extensive experience in the analysis and development of system level requirements and specifications. Mr. Peter is an expert in system development processes and systems integration. He has a BSEE from Ohio Northern University. Mr. Peter was the 2006/07 President of the Enchantment Chapter of the International Council on Systems Engineering.*

***Gena Bulleri** is the Avionic Systems Project Engineer for NAVAIR PMA-257, AV-8B Harrier II. She has 20 years experience as a Navy civil servant, including 10 years on the AV-8B program. In addition to the CSEMS upgrade, she is the lead engineer responsible for several avionics obsolescence upgrades for the AV-8B. As a member of the AV-8B Mission Systems Team, she was responsible for several major capability block upgrades, including the ACAT II Open Systems Core Avionics Requirement (OSCAR). Ms. Bulleri has a BS in Computer Science and an MS in Information Systems from Drexel University, Philadelphia, PA.*