Expanding Applications, Data Management Technologies and Benefits of HUMS

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Abstract
The primary motivation for installing Health & Usage Monitoring Systems (HUMS) in the early 1990s was the desire to enhance the safety of helicopter operations. Since that time, significant benefits to maintenance and operations have been realised and HUMS is now more widely seen as a worthy investment to new and aging, civil and military platforms of all kinds. HUMS has now been applied to, and will continue to be developed for, wider applications such as fixed wing aircraft and land vehicles. This range of applications, their different environments, cultures and capabilities is demanding that suppliers of HUMS technology develop HUMS data acquisition, processing, data analysis and management components and tools to support multiple applications.

Smiths first developed and supplied HUMS for helicopters and is now using its world leading experience and capabilities to develop HUMS and evolve Integrated Vehicle Health Management (IVHM) and Prognostic Health Management (PHM) systems for a range of vehicle types.

This paper recounts the growth of helicopter HUMS, the evolution of HUMS and IVHM for new applications and the pursuit of further benefits. It then identifies related challenges and outlines ways in which Smiths Aerospace is developing its existing and new diagnostic, prognostic and data management capabilities to ensure that maximum benefits are realised by a wider range of users.

1. ESTABLISHED BENEFITS AND GROWTH OF HELICOPTER HUMS

The introduction of the first HUMS in the early 1990s was driven by the desire, and arguably an ethical obligation, to improve the safety of North Sea helicopter operations. For some time, evidence had suggested that vibration-based drivetrain monitoring could provide early and accurate detection of incipient mechanical defects. First generation HUMS boasted advanced vibration-based drivetrain diagnostics and automatic exceedance monitoring. By the end of the 1990s, the UK Civil Aviation Authority (CAA) claimed that “HUMS…has already reduced fatal accident statistics” and SINTEF [1] concluded that “HUMS was probably the most significant isolated safety improvement of the last decade”. It is arguably the requirement for increased safety that has resulted in the vast majority of HUMS installations to date, where civil operators are increasingly required to meet related regulatory requirements and more military operators are acknowledging a ‘duty of care’.

The implementation of HUMS and many of its matured functions was also driven by the motivation to save costs through maintenance and operational benefits. Many such benefits are now reasonably established and well documented [2], [3]. Whilst the timely and accurate detection of health defects remained a key capability, the emphasis on accurate monitoring and management of aircraft and component usage grew rapidly. It was quickly realised that the efficient combination of these capabilities could significantly enhance fleet management and achieve the broad benefits of increased availability and reliability, reduced downtime and through life costs. For many HUMS operators today a simple, non-exhaustive summary of more specific benefits is likely to include many of the following:

- Improved maintenance planning & targeting
• Reduced dedicated test flights
• Reduced unscheduled maintenance
• Reduced nugatory maintenance, e.g. No Fault Found (NFF)
• Time Between Overhaul (TBO) and inspection period extensions
• Component life extensions
• Reduced logistics (e.g. spares) footprint
• Improved component Mean Time Between Failure (MTBF)
• More efficient aircraft usage
• Improved aircraft and component reliability
• Improved incident investigation

The growth in the awareness of such benefits has resulted in increasing demand for Helicopter HUMS from both civil and military operations internationally. Procurement is being increasingly justified by anticipated through life cost savings afforded by comprehensive HUMS functionality. Indeed, within the last year, Smiths has seen examples of continued growth and diversification in terms of demand for its more comprehensive HUMS: the UK MoD contract for the development and supply of GenHUMS (combined HUMS/CVFDR) for 70 new AgustaWestland Future Lynx Helicopters; the Republic of South Korea contract for the localised development of the Korean Utility Helicopter (KUH) HUMS, leading to 245 production systems; the 100th HUMS order for the new civil AW139.

2. EVOLUTION OF HUMS AND IVHM FOR FIXED-WING AIRCRAFT AND LAND VEHICLES

There is now compelling evidence that traditional helicopter HUMS and other evolving prognostic health management (PHM) technologies are being specified, developed and applied for military and civil fixed-wing aircraft and, more recently, land vehicles. In many cases, modern aircraft/vehicle electronics architectures and new and networked logistics systems are also opening the door to integrate health monitoring and management systems with on-board and ground based systems and processes, giving rise to the concept of Integrated Vehicle Health Management (IVHM). As the most obvious example of a new and major military fixed-wing programme, the Joint Strike Fighter (JSF) programme is one of the first to invest in a comprehensive and integrated health management capability. The recognised requirement for maximised mission readiness and availability has led to the specification and development of a powerful Force Life Management (FLM) system. The aircraft itself will be equipped with a combination of traditional and advanced sensors. The ground based FLM system will perform advanced diagnostics and prognostics, individual aircraft and fleetwide life tracking, detailed engineering analysis and integrate with the JSF Autonomic Logistics Information System (ALIS).

The growing appreciation of maintenance and operational benefits through health management has sponsored a number of initiatives to better manage the life of both new and aging legacy fleets of military fast jets and transport aircraft. There are also a number of initiatives to apply intelligent health monitoring to Unmanned Air Vehicles (UAVs) where there is no crew to identify and report faults, take evasive action or help provide input to assist corrective maintenance action.

In the highly competitive world of commercial airlines, where unscheduled downtime carries such explicit costs and huge penalties, airframmers such as Airbus and Boeing now offer performance-based through life maintenance support services and are taking a more proactive approach to health management. Motivations include minimised inventory and logistics costs for the airframer whilst the airline benefits from predictable support costs, optimized aircraft availability and maximized ‘on-wing’ component life. An important enabler is that new airliner designs now include Integrated Modular Avionics (IMA) architectures. These provide a common platform on which multiple applications can be run in parallel and thereby facilitate a truly integrated health management approach and maintenance infrastructure.

Commercial land vehicles and notably, commercial rail vehicles, are increasingly the subject of initiatives to improve safety and reduce their traditionally high operating and maintenance
costs. In the UK, a series of high profile accidents during the latter 1990s, sponsored the introduction and eventual mandatory requirement for fleetwide installations of Operational Train Monitoring Recorders (OTMRs) to monitor how the vehicles were being operated. Today, a number of leasing companies and operators are pioneering the introduction of permanent, and in some cases integrated health management technology, some of which is derived from corresponding initiatives in aerospace.

IVHM is now being focused on military land vehicles. The US Future Combat System (FCS) family of military vehicles variants will include comprehensive health and usage monitoring capability. In the UK, the maturing and major requirement for the Future Rapid Effect System (FRES) and corresponding drive to ensure a modern capability with minimised Whole Life Costs (WLCs) has been the catalyst for an integrated electronics architecture that includes an end-to-end (E2E) HUMS capability. The draft requirement for such an E2E HUMS was captured in DefStan 25-24 [4] which was an important input to the two parallel and competitive Electronics Architecture (EA) Technology Demonstrator Programmes (TDPs) that conclude early this year.

Notably, the evolution of modern on-board integrated electronics architectures such as aircraft Integrated Modular Avionics (IMA) and land vehicle vetronic systems are now assisting the integration of health management capabilities on new aircraft and vehicle designs. Traditionally, on legacy platforms where data is acquired on-board, the data is communicated and stored by dedicated connections and storage media for post-flight/mission analysis by independent ground-based systems. This involves greater weight and complexity on-board whilst data analysis on the ground can be a disparate process. Modern on-board systems, however, provide a modular computing hardware platform and partitioned operating system that hosts all the software for both the mission and utility functions. Most, if not all data is inherently available and multiple applications can be run in parallel. As such, the integrated on-board electronics system provides a common physical and logical maintenance infrastructure that facilitates a truly integrated health management approach.

3. EXPANDING BENEFITS - CONDITION BASED MAINTENANCE AND PERFORMANCE BASED LOGISTICS

Two modern, separate but potentially linked, initiatives that promise to further increase maintenance and operational benefits are Condition Based Maintenance (CBM) and the recent growth in Performance Based Logistics (PBL) contracts.

There is an increasing desire to use established HUMS and evolving IVHM technology to transition from the traditional maintenance approach to one that includes CBM. On HUMS-equipped helicopters in particular, a number of military operators have already granted servicing period extensions for specific drivetrain components. However, for civil operations, the change to CBM requires the award of HUMS ‘maintenance credits’ in accordance with Advisory Circular AC 29-2C MG-15 [5], whereby assurance is obtained that the HUMS will reliably detect any failure modes that are currently controlled through scheduled maintenance and can initiate timely maintenance intervention. Due to the challenging certification processes, HUMS civil in-service experience demonstrates the award of very few maintenance credits.

Recent FAA sponsored research by Smiths and the Sikorsky Aircraft Corporation suggests, however, that there are good CBM candidates, particularly where there are a limited number of potential failure modes and in-service evidence that HUMS monitoring systems can reliably detect such failure modes [6]. In these cases, CBM benefits are likely to include extension or even elimination of time-based inspection and servicing periods resulting in reduced maintenance man-hours and aircraft downtime. The credit-potential of HUMS will almost certainly increase as more in-service experience is gained. However, whilst the mature HUMS diagnostic technologies provide the original basis for a CBM approach, evidence suggests that it is likely that the combination of these with evolving intelligent decision support technologies will
accelerate the CBM credit validation process for civil applications and ultimately contribute to the implementation of CBM across a range of both civil and military applications.

A number of parallel initiatives are underway to accelerate the inclusion of CBM for military aircraft. One of these is the development and publication of open standards for IVHM systems, led by the publishing of the Open Systems Architecture for Condition Based Maintenance (OSA-CBM) standard on new aircraft and vehicle designs. OSA-CBM defines a common structure that enables multiple companies to work together to produce the software components for an optimised IVHM system where all the data is available to the operator in a single location and format. The standard was developed under a NAVAIR Dual Use Science and Technology (DUS&T) programme in 2002 and is now being used on a range of IVHM initiatives and programmes, some of which are described later in this paper.

Recent years have seen a rapid growth in PBL and Power-By-the-Hour (PBH) contracts where the original equipment supplier (OEM) or an approved service organisation takes on the support of the equipment (engines, transmission, or entire aircraft) and guarantees levels of availability of aircraft systems, spare parts and maintenance. Such contracts offer benefits to both the OEM/service provider and operator. The operator is provided with a single cost-effective support solution with predictable support costs, optimised aircraft despatch reliability and high-quality maintenance. The OEM/service provider can minimize inventory and logistics costs and allow operators to focus on keeping parts “on wing” longer. It is likely that the predictive health monitoring capability that supports a CBM approach will play an increasingly significant role in such contracts.

4. CHALLENGES FOR TOMORROW’S HUMS/IVHM SUPPLIERS

The rapid expansion of health management applications and range of users is forcing suppliers to both adapt existing technologies and develop new approaches to meet the requirements of different environments, operating and maintenance cultures and operator skill levels.

Suppliers of HUMS and IVHM technologies are now challenged, more than ever, to provide generic, flexible, expandable and cost-effective capabilities that can simultaneously provide through life benefits to a wider range of applications and users. Whilst the adage ‘the right information to the right place at the right time’ still holds, specific challenges include:

- Effective and efficient use of simple and traditional, new and advanced sensing and measurement techniques and technologies.
- On-board acquisition, processing and analysis applications that can be implemented either as part of a standalone system or embedded into a vehicle’s existing integrated electronics architecture.
- More efficient data transfer.
- Automatic and intelligent data integrity validation.
- User-configurable systems and tools that do not require software skills.
- Open, expandable and interoperable systems that can interface to and integrate with 3rd party diagnostic, prognostic and logistics systems.
- Remote access to information including autonomous vehicle monitoring and analysis.
- More concise presentation of advanced diagnostic, prognostic and life management information.
- Intelligent decision support tools can enhance anomaly detection capabilities, diagnostics and prognostics and support a CBM approach.
• More efficient and creative use of existing data to help meet the weight, space, environmental constraints of a specific application.
• Capability and flexibility to provide benefits from early stages of implementation.

5. SMITHS ACTIVITIES

Smiths has developed and continues to develop systems, techniques and technologies and support programmes and initiatives that bring benefits to a wider range of applications and users.

The following sections illustrate examples of Smiths systems, tools, research and demonstrations and development and production programmes that directly address many of the challenges associated with expanding applications and benefits.

5.1 Fleet & Usage Management System (FUMS™)

Since the early 1990s, Smiths has worked closely with the MoD to evolve the Fleet & Usage Management System (FUMS™) [7], [8]. FUMS™ provides a single, modular software framework that can host a wealth of built-in decision support tools and will interface to 3rd party applications and systems, as illustrated in Figure 2.

![Figure 2: FUMS™](image)

FUMS™ also allows users to build their preferred applications without software rewriting, as shown in Figure 3.

As such, FUMS™ has been configured and utilised by military users to manage structural, engine and avionics usage for a wide range of rotary-wing and fixed-wing aircraft fleets.

5.1.1 Diagnostic/Prognostic Tools

The user is able to access and exploit a comprehensive built-in toolset but also plug-in third-party tools and algorithms. Equally, the FUMS™ graphical and analysis capabilities facilitate display and process data from external sources. The built-in toolset includes signal-processing, statistical and mathematical analysis tools, a range of AI-based diagnostic, prognostic, life management and decision support tools and a suite of proprietary specialised tools such as flight recreation, flight envelope exceedance and automatic trending. The FUMS™ tools address many of the challenges previously listed and can be applied to a wide range of platforms and applications. By way of example, the Usage Indices, data integrity validation and ‘virtual sensor’ specialised tools are summarised below.

• ‘Usage Indices’

The Smiths FUMS™ Usage Indices (UIs) provide concise summaries of recorded flight data and, at the same time, indicate the impact of usage on component condition and life. Developed and implemented to support Operational Loads Monitoring (OLM) and Structural Prognostics Health Management (SPHM) on UK military aircraft, UIs have been demonstrated to accurately compute the fatigue of engine and structural components. UIs can also summarise sensor data, strain...
data, vibration data and other data derived from measured flight data to provide further prognostic information to evaluate the condition/life of additional aircraft subsystems including electronic equipment. ULs provide a high data compression ratio without loss of significant aircraft condition/life information and this enables the on-board system to carry the history of the aircraft. Storing the aircraft history in a concise UI format provides operational, management and safety benefits. For example, as improved damage computation methods or new knowledge from fatigue tests emerge, retro computations can be readily performed for each individual aircraft without the need for large amounts of historical flight data. By simple data mining techniques, prognostic relationships can be derived to link aircraft usage patterns to equipment failures and unscheduled maintenance.

- **Data Integrity Corruption and Correction**

  Smiths has developed a generic algorithm for automatically detecting and correcting short periods of corruption, noise filtering and lost signal reconstruction in monitored data. The algorithm has been developed using recorded flight data from a range of aircraft types and has been supplied for automatic data correction on the F-35 JSF programme.

- **‘Virtual Sensors’**

  Using flight data information, the FUMSTM model-based network is able to generate parametric ‘virtual sensors’ that synthesise information and avoid the installation and penalties of ‘real’ permanent on-vehicle sensors that may otherwise impose weight, space and reliability issues. Once trained, FUMSTM can synthesise strains, structural loads and stresses, fatigue, rotor torque, aircraft All-up-weight (AUW), Centre of Gravity (CG), aero-engine metal temperatures, thermal transient stresses, Low Cycle Fatigue (LCF), High Cycle Fatigue (HCF), creep and crack growth. Virtual sensors offer an affordable, non-intrusive increase in aircraft sensing technologies without increasing aircraft weight. Smiths are currently developing virtual sensors for the F-35 JSF where data from the JSF SPHM system will be used to monitor the health of the critical components and perform Individual Aircraft Tracking (IAT) of the JSF fleet.

5.1.2 **FUMSTM Applications**

FUMSTM has been configured and applied to the analysis of data from a wide range of military helicopters such as Chinook, Lynx and Apache helicopters, fixed-wing aircraft including JSF, Eurofighter, F16, Tornado and Harrier and aero-engines including the RB199 and Pegasus. Applications of FUMSTM capabilities and tools include the following:

- Selected as the JSF Force Life Management (FLM) system. The FLM system will perform advanced diagnostics and prognostics, individual aircraft and fleetwide life tracking, detailed engineering analysis and integrate with the JSF Autonomic Logistics Information System (ALIS).
- Analysis of flight data downloaded from Tornado, Typhoon, Apache, Chinook, Lynx, F16 and Hercules.
- Support of life management programmes for the Harrier engine fleet by analysing MoD logistics data.
- Analysis of UK MoD fast jet aero-engine vibration data acquired via test-beds by ground-based Vibration Monitoring Equipment (VME).
- Validation of structural, engine and avionics usage and characteristics against design data.
- Review and management of the usage of UK MoD Chinooks and Apache helicopters.
- Management of MoD GenHUMS Condition Indicators (CIs).
- Validation of the serviceability of on-board sensors and provision of ready access to flight information to assist first line maintenance.
- Support of the qualification process for the Merlin HUMS on-board system.
- Investigation of rare helicopter faults such as Uncommanded Flight Control Movements (UFCMs).
- Fusion of oil wear debris and flight data to produce enhanced diagnostics, prognostics and decision-making.
5.2 Intelligent Decision Support Tools

AI-based Intelligent decision support tools, such as those within FUMS™ are being used to improve the effectiveness of existing and new health monitoring systems. There is particular focus on the requirement to improve the detection of anomalous trends in health monitoring data to assist the transition to achieve CBM. This is motivated by a number of factors associated with the validation of monitoring data:

- Existing potential for false alarms.
- Expertise required to understand the significance of trends of multiple condition indicators and determine the corresponding maintenance action.
- Difficulty in gaining experience to interpret multiple trends associated with rare faults.

Under the Probabilistic Diagnostics & Prognostic System (ProDaPS), a DUS&T programme, jointly funded by the US Air Force Research Laboratory (AFRL) and Smiths Aerospace, Smiths has developed Artificial Intelligence (AI)-based technologies in data mining, anomaly detection, information fusion, reasoning and decision support for multiple on-board and ground-based applications [9]. These technologies have been applied to helicopter HUMS data, US Air Force engine performance data and airline Flight Operation & Quality Assurance (FOQA) data.

The core tools developed under ProDaPS include a state-of-the-art data mining tool incorporating a suite of learning algorithms. Using the ProDaPS probabilistic cluster algorithm, this has been further developed to produce a unique anomaly detection capability. ProDaPS also includes a probabilistic reasoning and decision support tool based on Baysian networks. Probabilistic networks offer significant advantages for in-field applications as they can model uncertainty, can accommodate missing or conflicting data and can be updated with in-service experience.

Following early work funded by the UK CAA [10], Smiths has worked with Bristow Helicopters Limited (BHL) on a further CAA-sponsored programme [11], to apply these AI-based anomaly detection techniques to the analysis of HUMS Vibration Health Monitoring (VHM) in both an off-line and an in-service environment. Most AI-based approaches assume that the training data set used to train and construct the model comprises exclusively normal, (i.e. healthy) data. However, HUMS VHM data presents additional challenges as ‘normal’ data will vary from one gearbox to another and, due to limited feedback from gearbox overhauls, it may not be known whether all the components included in the training set are truly healthy. The modelling approach must therefore assume that any training data set will contain some anomalous data and Smiths has developed enhancements to its anomaly detection process, including trend extraction pre-processing algorithms and a two-stage data modelling process, that overcomes such additional challenges. The anomaly detection system was successfully demonstrated on BHL’s database of historical AS332L HUMS data. It was shown that this process clearly detected the important test case of a cracked main gearbox (MGB) bevel pinion that was missed by the currently installed HUMS. As part of the live trial, BHL used this intelligent decision support system via the Smiths web-based infrastructure (described later in this paper) on a daily basis to monitor their North Sea AS332L fleet.

This capability enables the operator to obtain a global picture of gearbox component behaviour that clearly identifies abnormal trends, degree of abnormality and provides a means of independently checking gearbox state following a related HUMS alert. Such enhancements to the decision making process reduces the operator’s workload in managing HUMS, particularly where the operator may have to simultaneously manage a number of different HUMS. With broader application, it is anticipated that such decision support technologies will accelerate the civil CBM credit validation process but also ultimately contribute to the implementation of CBM across a range of both civil and military applications.

5.3 Integrated Vehicle Health Management Research Programmes

Smiths has teamed with a number of aerospace OEMs and other companies to research the integration of established and new aircraft monitoring functions to achieve extended and
improved maintenance operational and safety benefits [12]. Existing aircraft systems generally have a set of standalone computers, a disjointed set of data sources and are therefore limited in their capability to perform integrated data collection and monitoring. The evolution of IVHM systems offers a solution by integrating all the condition monitoring, health assessment and prognostics into an on-board open modular architecture and then supporting the operator with intelligent decision support tools such as those previously described.

A number of enabling technologies provide a sound basis for IVHM. One of these is the evolution of modern IMA architectures that provide a common physical and logical maintenance infrastructure, such as the Smiths Core Computing Systems (CCS) and Modular Processing Systems (MPS) - selected for the Boeing 787, C-130 AMP and Northrop Grumman X-47 UAV. Another enabling technology is the development and publication of open standards for IVHM systems. These include the Open Systems Architecture for Condition Based Maintenance (OSA-CBM) standard that defines a common structure and optimised IVHM system where all the data is available to the operator in a single location and format. Further enabling technologies include the range of intelligent decision support tools, such as those developed by Smiths Aerospace. Two examples of Smiths partnered IVHM research programmes that exploit such technologies are summarised below.

5.3.1 AEPHM

The ‘Advanced Electrical power Prognostics Health Management’ (AEPHM) programme was an AFRL sponsored DUS&T initiative with Boeing Phantom Works and Smiths Aerospace in respective prime and subcontractor roles [13].

The programme was motivated by the growing trend towards increased use of flight-critical electrical components such as actuators, pumps, valves and fans and the safety, maintenance and operational benefits achievable by providing early and accurate fault and failure prediction. The programme included seeded fault and accelerated wear tests of electrical components and the monitoring of electrical loads via a Smiths Power Distribution Unit (PDU) to characterise fault modes and develop corresponding diagnostic and prognostic models for AI-based causal network ‘reasoning’ techniques. Using these techniques, it was demonstrated that the actuator, fuel pump and electrical arc faults could be automatically detected, measured, trended and alerted from the electrical load data alone within the Smiths PDU. Hence, using the existing electrical system data as a part of a ‘virtual sensor’ can dispense with the need to add additional dedicated sensors.

The AEPHM programme also demonstrated that causal networks used to fuse data for AI-based reasoning can be established and enhanced with the use of design data prior to in-field practical experience. Failure Mode and Effect Analysis (FMEA) design data is traditionally used in the design of new systems to identify possible component failure modes, failure rates, effects on sub-components and criticality. As such, a FMEA effectively captures diagnostic information and is readily mapped onto a causal network to construct a diagnostic reasoning engine. As in-field experience is acquired, the causal network can be updated to include updated probability distributions. This enhances the data fusion process and hence the diagnostic and prognostic capability.

5.3.2 TATEM

‘Techniques and Technologies for New Maintenance Concepts’ (TATEM) is a four-year, €40 million project co-funded by the European Commission under its ‘Framework 6’ research programme. The aim of the project is to show how new integrated health management technologies and techniques can improve aircraft availability and reliability and reduce maintenance related costs for commercial airlines by 20% within 10 years and 50% within 20 years. The project, led by Smiths, involves 56 partners including airframers, airlines, suppliers and research organisations from Europe, Israel and Australia.

The project required understanding current maintenance management processes including limited levels of health monitoring, the impact of unscheduled maintenance, human factors and how integrated on-board/off-board health monitoring,
diagnostics and prognostics could provide a range of benefits including CBM.

Smiths Aerospace health management research focused on how AI-based data mining and reasoning could support improved diagnostics and prognostics techniques for complex critical components such as electrical power and actuation systems by fusing performance and health parameters. The results, which have made use of real data scenarios, suggest the potential to provide enhanced maintenance benefits in terms of reduced unscheduled maintenance and downtime, improved maintenance scheduling, optimised maintenance intervals, reduced maintenance activity and spares holding and an increased information-to-data ratio.

IVHM: Changing Maintenance

![Figure 4: Example of TATEM Objective](image)

For example, Figure 4 shows how, for a next generation commercial airline, early detection, diagnosis and warning of degrading components allows the ground maintenance crew to prepare and reduce the time required for a turn-around. If, with an IVHM approach, a fault can be detected earlier still and more accurately, the need to perform maintenance during turn-around might be eliminated and scheduled for conventional hangar-based maintenance periods.

5.4 Integrated Ground System Support

Smiths has developed a range of generic capabilities that support current HUMS operators toward an integrated IVHM capability. These include networked and remote ground system products and services that can be applied to any aircraft or vehicle operation. Two examples are illustrated below:

5.4.1 Web-based Support Services

Smiths has developed a comprehensive web-based support capability to assist its HUMS operators in managing and achieving maximum benefit by fully exploiting the information available from HUMS data. The service involves Smiths managing the exchange and flow of data and information between the operator, Smiths and the manufacturer. As far as possible, the transfer of data and information is an automated process. Figure 5 illustrates the flow of HUMS data and information.

![Figure 5: Web-Based Services](image)

Operators’ HUMS data is automatically transmitted, via the internet, to the data warehouse on Smiths file servers where the data is processed via Smiths proprietary data-exploitation decision support toolset that convert processed HUMS data into advanced information. In turn, the operator’s operations, maintenance, logistics and flight line departments (and the manufacturer as arranged) together with Smiths in-house and infield support engineers are able to access this advanced information. However operators require only a local ‘browser’ capability rather than full HUMS ground station capabilities. Smiths manages the HUMS data and its effective exploitation via the stages of download, storage, distribution, interpretation and advice. In accordance with its in-house capability, the operator is able to select the level of service and analysis/interpretation required. Where operators choose to manage their data, Smiths provides assistance with diagnostic and prognostic interpretation as required.
An example of a related support service is the provision of the Smiths fault database. Smiths arguably holds the largest HUMS fault database worldwide, containing a large number of fault trends and condition indicator exceedances. As part of its support service to operators, and with supported operator’s permission, all fault data is ‘sanitised’ to remove all operators’ identities and aircraft tail numbers and made freely available to all Smiths HUMS operators. As a consequence, a Smiths HUMS operator is able to obtain powerful assistance when interpreting apparent fault data by accessing the Smiths Support Website to view and compare his data with the database of real fault trends from corresponding aircraft and components from many operations around the world. The website incorporates a sophisticated search facility so that the user can examine more general or very specific data as required. Web-based services that fully exploit information to maximise operational and maintenance benefits provide a firm basis for CBM maintenance approaches and for enhanced PBL support.

5.4.2 Intelligent Data Card

The Smiths Intelligent Data Card (IDC) has been developed to support deployed aircraft and vehicles that do not have access to a dedicated support infrastructure or HUMS ground station and its corresponding data analysis capability. The IDC is a laptop compatible PCMCIA card that hosts the conventional HUMS advanced diagnostics and prognostics analysis tools. The IDC can be simply plugged in to a laptop that itself requires a browser and a PCMCIA slot. When inserted, the IDC enables the review of critical HUMS data, recommended adjustments (such as helicopter RTB) and HUMS system built-in test status.

5.5 FRES Technology Demonstrator Programme (TDP)

This year sees the conclusion of the Team ISIS (Integrated Scalable Independent Solution) FRES EA TDP. As part of Team ISIS, Smiths was responsible for producing trade studies on the benefits, technical effectiveness, diagnostics and prognostics of an E2E HUMS. Smiths was also responsible for demonstrations of specific elements of an example E2E land-vehicle HUMS. Whilst it is anticipated that production FRES HUMS will be part of an integrated modular avionics architecture, for the purpose of the TDP demonstration, the on-board system was based on existing commercial-off-the-shelf (COTS) hardware and software. The demonstrations included a mobile trial on a General Dynamics’ Advanced Hybrid Electric Drive (AHED) combat vehicle and a Systems Integration Laboratory (SIL) demonstration.

During the mobile trial, Smiths demonstrated the successful acquisition of on-vehicle HUMS data from both dedicated sensors and the vehicle EA databus followed by wireless transfer of a Situation Report (SITREP) from the vehicle to the off-vehicle HUMS Base Station some distance away via high-bandwidth WiFi communications and UK Army Bowman digital radio. The use of a ruggedised laptop to collect and display HUMS data remotely from the vehicle was also demonstrated.

As part of the SIL demonstration, Smiths demonstrated the response of the HUMS system
to a genuine fault (an engine inlet filter breach caused by high levels of sand ingestion detected by new technology electrostatic sensors).

Following accurate fault diagnosis, the diagnostic information was transferred through the information management chain from the vehicle to the Information Management System (IMS) and the Joint Asset Management System Engineering Solution (JAMES). The demonstration also included the generation of a Casualty Report (CASREP) and automated vehicle availability status, showing how HUMS data may be used to provide operational decision support.

As part of the FRES TDP, Smiths demonstrated two leading-edge capabilities that represent respective ends of the FRES E2E HUMS. At one end was an electrostatic-based filter integrity sensor. This was derived from a similar Smiths COTS electrostatic sensor previously used to monitor UK Warrior vehicles and which exploits the same technology used to perform aero-engine gas path debris monitoring on the JSF aircraft. The electrostatic sensor successfully detected the ingestion of the sand particles and alerted the filter’s compromised integrity. At the other end of the E2E HUMS and in collaboration with Lockheed Martin, Smiths demonstrated the integration of HUMS with the operationally fielded JAMES logistics system with successful two-way communication. It was clearly shown that health status and ultimately fault information generated by the HUMS on-board system was readily available to the JAMES and that the JAMES was able to communicate an alarm-acknowledgement back to the on-board HUMS.

Both mobile and SIL demonstrations illustrated the capability of integrated HUMS and IVHM technologies, in conjunction with operationally fielded communications and IMS, to reduce whole life costs through improved maintenance but also the huge operational and force multiplying benefits available to a fleet of fighting vehicles. These include improved collective situational awareness, through the accurate and timely health and consumable status reporting; improved mission effectiveness, planning and probability of mission success through accurate fault and failure prognosis.

6. CONCLUSIONS

The safety, maintenance and operational benefits promised by comprehensive helicopter HUMS are generally being realised. This HUMS technology is mature and is the basis for continued growth based on justifiable through life cost benefits. The application of comprehensive HUMS and fleet management technologies to fixed-wing aircraft and land vehicle is evolving. Indeed, the advent of integrated modular electronics architectures and networked logistics systems supports the integration of health monitoring and management with on-board and ground based systems and the concept of Integrated Vehicle Health Management (IVHM).

The prospect of transitioning traditional maintenance to include a condition-based maintenance approach is attracting considerable interest and would appear to have positive implication for modern performance based logistics contracts. Whilst the existing, mature HUMS diagnostic capabilities provide the original basis for including a CBM approach, evidence suggests the combination of these with evolving intelligent decision support technologies, such as those being developed by Smiths Aerospace will accelerate the implementation of CBM across a range of both civil and military applications.

Suppliers of HUMS and IVHM technologies are now challenged, more than ever, to provide generic, flexible, expandable and cost-effective capabilities that can simultaneously provide through life benefits to a wider range of applications and users with different environments, operating and maintenance cultures and operator skill levels. With a principal focus on enhancing the quality of information to achieve a “right information, right place, right time” approach, Smiths has developed and continues to develop flexible and affordable systems, tools and techniques to support programmes and initiatives that bring increasing benefits to a wider range of applications and users.
7. REFERENCES


