The Status of HUMS for Helicopters within the UK Ministry of Defence

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SYNOPSIS

The UK Ministry of Defence (MoD) has been involved with helicopter HUMS since the late 1990's. Beginning with historical events which shaped the rational for the adoption of HUMS by the MoD, this paper aims to convey some of the experience gained during this time and touches on some of challenges faced and lessons learned. It also looks at how HUMS has evolved over time and how the evolution has been influenced and shaped by factors including Regulation of UK Military Aviation, industry service provision and the implementation of disparate HUMS embodied capability across the range of helicopter types currently in service. The question of maximising HUMS exploitation across these disparate fleets through the use of automated data processing and common toolkits is discussed. In a highly specialised niche area of engineering, the importance of knowledge sharing and read across from other sectors such as automotive and rail is covered. Best practice is explored including support structures, responsibility, assurance and empowerment of individuals within their unique roles. The importance of working closely with industry partners to manage obsolescence and functional enhancements to both the airborne and ground support systems is explored as well setting a wide range of strategic exploitation aims. By covering such breadth of material the overall intent off this paper is to provide an indication of the complexity involved in creating and sustaining robust and assured end to end processes which underpin cradle to the grave HUMS support solutions. From defining the initial requirement, through introduction to service, delivery of in-service support and exploiting a HUMS capability to maximum effect through to aircraft out of service is immensely challenging on many levels.

Authors Biographies

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[2] Paul Harding joined the Royal Air Force in 1989 as an Airframes Engineer. His career has seen him serve at RAF Lyneham, RAF Chivenor, RAF Odiham and RAF St Mawgan. Since leaving the RAF and joining the MOD he has instructed in airframes, engines and basic engineering hand skills. He has been the HUMS Desk Officer for Merlin, Puma and Lynx; on promotion he was the HUMS technical lead within the HUMS Project Team. Now in the Lynx Wildcat Project Team he currently has technical and project management responsibility for HUMS on Chinook, Wildcat and Sea King and the HUMS Multi-Platform Ground Station and is responsible for new HUMS capabilities on these aircraft.

Introduction and Background

This paper is focused on the UK MoD experience of implementing, operating and exploiting HUMS on military helicopters in a complex and challenging operating environment, with a range of aircraft types each with their own disparate embodied capability and unique support solutions.

To maximise the exploitation potential of a HUMS system there are many facets and stakeholder requirements to be considered from front line maintenance through to validating manufacturers design assumptions against actual usage spectra.

Within the MoD, a more holistic view is taken where HUMS is a key enabler within a wider Aircraft Health Monitoring programme which includes other complimentary technologies and approaches including Wear Debris Analysis and Non Destructive Testing and Evaluation including visual inspection.

This paper relates to the core UK military helicopter fleets but does **not** include arrangements for Military-Registered Civil-Owned (MRCO) aircraft fleets leased to the MoD under contract for purposes such as initial helicopter flying training. MRCO aircraft are maintained under separate arrangements in accordance with Civil Aviation Authority (CAA) Regulation.

It is also acknowledged that many of the approaches advocated for a large military operator may not be viable or workable in other helicopter operating environments such as those with small fleets or where maintenance is provided under contract. However it is hoped that all readers may achieve some benefit from the MoD sharing its HUMS experience.

History and MoD Adoption of HUMS

There were essentially 2 key events which influenced the initial UK MoD mandate to embody military helicopters with Cockpit Voice/Flight Data Recorders (CVFDR) and Health and Usage Monitoring Systems (HUMS). The second event confirmed the thinking on HUMS adoption and led directly to how we now regulate military aviation and hence how we plan to maximise our HUMS exploitation potential now and in the future.

The first of these events emerged from an increasingly high and intolerable accident rate in the North Sea oil and gas industry. This tragically culminated in a Chinook accident off the Shetland Islands with the loss of 43 passengers and 2 crew. This heralded the birth of HUMS in the UK civil helicopter operations sector, with clear focus on increasing flight safety.

The second of these events involved a Royal Air Force (RAF) Nimrod MR-2, XV230 which suffered an in-flight fire whilst on operations over Afghanistan in September 2006. The aircraft subsequently crashed, sadly with the loss of all 14 crew. This led to an independent review by Charles Haddon-Cave QC into the broader issues surrounding the loss of this aircraft. A number of recommendations emerged from the report including the formation of the Military Aviation Authority (MAA) and the regulation of military aviation.

Another important driver is the UK Secretary of State for Defence's annual statement on Health, Safety and Environmental Protection (HS&EP) where he/she states:

> *"Where Defence has exemptions, derogations or dis-applications from HS&EP legislation, we maintain Departmental arrangements that produce outcomes that are, so far as reasonably practicable, at least as good as those required by UK legislation"*

The pragmatic interpretation of this statement as applied to UK military aviation is “as civil as possible, as military as necessary” which means that we make every effort to follow Civil Aviation Regulation despite having exemption from doing so. Our aim and intention is that flying in military aircraft should be no less safe than flying in civil aircraft, hence the policy to adopt the same HUMS principles as our civil aviation colleagues.

It is worthy of mention that the Chinook ZD576 accident on the Mull of Kintyre in June 1994, with a loss of 25 passengers and 4 crew did not directly lead to the MoD decision to adopt HUMS, it did however serve as a salutary reminder of the necessity to increase flight safety.

Regulation of UK Military Aviation

Structure and Publications

Before discussing the current status of HUMS for MoD helicopters, best practice and the strategic direction, it is important to understand the regulatory context in which we operate and how that influences our exploitation efforts.

The Military Aviation Authority (MAA) is the Regulatory Authority for UK military aviation. Regulation is delivered by means of regulatory publications (MRP) which are divided into 3 layers namely:

- Overarching documents (policy, glossary and processes)
- Regulatory Articles (RAs) divided into 5 topics (General, Flying, Airworthiness etc.)
- Manuals (various e.g. Air Safety, Airworthiness Processes etc.)

HUMS is addressed in a number of RAs and in the Manual of Airworthiness Processes (MAP-01) - compliance with these regulations is mandatory. Each RA follows a common format:

- Rationale – Sets the context and boundaries.
- Contents – Lists the items of Regulation to be followed.
- Regulation(s) – States what must be done (denoted “ ***Shall*** ”)
- Acceptable Means of Compliance – Outlines how to comply.
- Guidance Material - Provides references to other salient information.

All MAA Regulation is publically available and an overview of the MRP structure is available at Reference1.

RA 4500 - Health and Usage Monitoring [***Reference 2***]

RA 4500 Rationale is defined as:

> *“The term Health and Usage Monitoring (HUM) encompasses a variety of techniques including operational load monitoring, vibration analysis, visual inspections, oil and wear debris analysis. The data obtained through such monitoring is used to preserve and enhance the airworthiness of the platform.”*

RA 4500(1) states:

> *"HUMS shall be included on all new aircraft platforms and retrofitted to existing aircraft fleets where justified by airworthiness and/or cost considerations."*

RA 4500(2) states:

> *"HUMS data shall be exploited to preserve and enhance flight safety and realize maintenance benefits."*

RA 1140 - Military Air System Technical Data Exploitation [***Reference 3***]

RA 1140 Rationale is defined as:

> "*Effective exploitation of operation and maintenance data validates the design and supports the continuing airworthiness of military air systems and is essential to delivering improvements in Military Air Safety. A coherent strategy for the collection, reporting, and analysis of technical data is required for each type of military air system.* "

RA 1140(1) states:

> "*ODHs, supported by CAMOs and assisted by TAAs, shall ensure a coherent Technical Data Exploitation Strategy is in place for each type of military air system in their AoR*."

RA 1140 is a complex piece of regulation where detailed explanation in this paper will offer little benefit to the reader. The Interpretation of this RA for HUMS is that all Aircraft Health Monitoring techniques under the HUMS banner generate technical data and as such must be exploited to support Airworthiness and Air Safety.

MAP-01- Manual of Airworthiness Processes Volume 1 [***Reference 6***]

MAP-01 provides the detailed processes and covers the entire range of aircraft support/maintenance activity. Chapter 11 (Airframes and Engines) relates to HUMS activity as defined in RA 4500 (above) and is broken down into the following chapters.

- Ch 11.2 - HUMS
- Ch 11.3 - Vibration Control
- Ch 11.4 - Wear Debris Monitoring (Including lubricating and hydraulic oils)
- Ch 11.5 - Non Destructive Testing

The MAP01 chapters listed above define the Acceptable Means of Compliance i.e. how to comply with the regulation.

Type Airworthiness Authorities (TAAs) [***Reference 4***]

The TAA is responsible for the Type Airworthiness of an Air System throughout its life from development to disposal. For the purpose of this paper, the TAA is essentially responsible for airworthiness of entire aircraft fleets, not the airworthiness of an individual aircraft. The TAA in the guise of the "Project Team" will also be the principal contact with the aircraft manufacturer for support issues, modifications, enhancements and availability contracts.

The full TAA airworthiness responsibilities are covered in Regulatory Article 1015.

Continuing Airworthiness Management Organisations (CAMOs) [***Reference 5***]

For the purpose of this paper, the CAMO is essentially responsible for airworthiness of individual aircraft under their charge i.e. on their squadrons. This includes controlling maintenance, modifications and repair.

The TAAs and the CAMOs are both HUMS stakeholders since HUMS is a valuable monitoring tool which provides information which is valuable in managing airworthiness.

The full CAMO airworthiness responsibilities are covered in Regulatory Article 1016.

Maximising the Potential HUMS Benefits

Planning for Success

For many years, it has been obvious that HUMS capability across a number of industries has failed to deliver much of the promised potential. In the UK this is true of the land vehicle sector and of the rail industry. Each industry faces the same challenges and failure to deliver and progress has similar causal factors which can often be traced back to incorrect initial assumptions, unrealistic aspirations and an overall lack of understanding of the capability.

The MoD is in a good position to extract the potential which HUMS ownership offers, partly through foresight, careful management and planning but with some good fortune thrown in along the way.

In order to understand the MoD rationale for adopting a HUMS capability and to maximise the potential benefits, it is helpful to take a more fundamental view by considering the 5WH question:

Why, What, When, Where, Who and How.

Although a list of lessons identified (LIs) is included in this paper, when considering each of the 5WH questions, this paper incorporates many of the lessons identified in over 15 years of HUMS operation across a number of HUMS variants. Using the 5WH approach adds context, value and clarity in developing strategic direction and enables the generation of structured achievable exploitation plans.

Why

So why do we have a HUM System fitted to our Military helicopters? Is it because it is mandated or is it because we want to? The answer to this question is actually a combination of both. When MoD was first involved with HUMS in the late 1990s with Chinook and AW101 Merlin it was with a view to enhancing safety but it quickly became clear that adopting HUMS could provide a range of additional benefits including:

- Enhance flight safety
- Sustain airworthiness
- Improve aircraft availability

- Improve through life costs
- Enable more informed fleet management

Fast forward some 15 years and we now adopt HUMS because we are mandated to do so by regulation but the tangible benefits remain extant. Indeed, decisions taken at the beginning of our HUMS interest are likely to pay dividends now. During times of austerity and against a backdrop of reduced aircraft numbers and consistently high operational tempo, we are constantly look to achieve more with our limited and valuable aircraft resource than ever before – innovative use of HUMS exploitation is a valuable tool which will enable us to sustain our aircraft availability and hence our military capability.

What

There are a number of key considerations for this question. The most fundamental is to develop a clear understanding of what you hope to achieve from your HUMS and then articulate it unambiguously in the user requirement definition. This should include specifying the monitoring technology to be implemented and ensuring that it is capable of meeting the stated need. The data handling and analysis capabilities also need to be specified to ensure that they are robust enough to deliver the required performance and enable the extraction of information from data to generate the required knowledge and outcomes.

Identifying the parameters of interest for monitoring and establishing the optimum sampling rates for each of these parameters is a key part of the requirement definition. Involving stakeholders at the outset, initiating technical discussion, challenging assumptions and confirming validity of thinking is likely to pave the way to success.

Other considerations are equally as important such as constraints. Potential data volume is likely to be a topic of interest and therefore availability of IT infrastructure for data management and exploitation. If the infrastructure doesn't yet exist, can it be created and resourced as part of the wider implementation plan? Can constraints relating to the infrastructure be mitigated by reviewing and minimising the monitored parameter list – this will reduce the volume of data being handled and processed and may increase the likelihood of meeting the aspirational output

When

The support envelope for aircraft type incorporates a range of stakeholders which includes industry partners as described later in this paper. Each stakeholder will have their own specific needs and priorities and this will dictate when and how the data is used.

Specific periodicities are mandated within the type specific Aircraft Support Policy Statement. For example, Squadron engineers will usually be required to download individual aircraft data daily in order to assess the serviceability prior to the next sortie. The air station Health and Usage Centre and the Continuing Air Worthiness Organisation will assess the data less regularly to search for emerging fleet wide trends. Vibration and HUMS alerting threshold reviews are conducted periodically (circa biannually). This process either confirms current setting remain valid or enables amendment as necessary

MoD aircraft are deployed worldwide on operational commitments. Consequently the support chain must be agile enough to provide support 24 hours a day, 7 days a week, 365 days of the year.

Annual CVFDR serviceability checks are also performed as mandated by CAA regulation. This provides assurance that the data recorder is functioning correctly, that all channels are recording and that the recoded data is within the tolerances for each defined parameter.

Where

The worldwide aircraft deployment necessitates the ability to operate in harsh and challenging environments. This typically includes maritime operations embarked in Royal Navy Warships or elsewhere in different climatic conditions such as supporting arctic, desert, jungle or tropical operations.

A significant challenge associated with prolonged forward operating is limitation in communications. Clearly each aircraft is a highly valuable asset with regards to achieving operational success and therefore robust procedures for autonomous working are essential. This is achieved by having highly trained and experienced aircraft engineers empowered to make key engineering and maintenance decisions at the front line, equipped with an intuitive and easy to use HUMS Ground Station.

Who

The key to successful HUMS exploitation is creating and utilising multi-disciplinary teams of professionals - Subject Matter Experts in the relevant technology or technical discipline for each aspect.

Engineers - To provide the engineering context and the deep understanding of the aircraft and the monitored components. The engineers will utilise the data for diagnostic purposes and implement the most appropriate maintenance to achieve fault resolution.

Data Scientists – To provide data mining methods, generate algorithms and undertake statistical analyses in order to identify and categorise developing faults and deliver timely bespoke reporting to all key stakeholders.

IT Practitioners - To configure, manage and support all bespoke HUMS support hardware and software including engineer's groundstations (laptops/desktops/tablets etc) data/file/web servers, and network data sharing capability. IT practitioners also provide the first line of defence against cyber-crime by preventing malware infections and in the case of the MoD ensure that all HUMS support assets carry encryption to prevent data compromise.

Project Managers/Project Engineers – To coordinate all procurement and contractual activities and manage all post design service interaction with industry partners. Project engineers are essential in managing obsolescence and the specification/delivery of enhancements to both the airborne systems and the ground support systems.

How

The “How” aspect is key to the delivery of all HUMS exploitation opportunities. In the MoD it is achieved through clearly and carefully defined support processes underpinned by suitable support infrastructure.

As aircraft become more complex there is a need to be more intelligent in undertaking fault diagnosis. However, HUMS analysis is a single tool in the diagnostic process; it will provide some evidence but it still requires empowered, trained and competent engineers to interpret the information and instigate the appropriate corrective maintenance.

1710 Naval Air Squadron (1710 NAS) hosts the Data Centre for all MoD Helicopter HUMS, FDR, vibration and wear debris data. This provides the MoD with a single repository for the exploitation of all helicopter health monitoring data whether that is delivered “in-house” or through data sharing arrangements with industry partners. Data flows into the data centre daily or as mandated within the specific aircraft type Support Policy Statement (see below). All aircraft data is archived and maintained for the life of the aircraft plus 5 years. The data centre is fundamental and is a key enabler for HUMS exploitation.

Formal Data Management Plans for each aircraft type are written as Support Policy Statements (SPS) within the Aircraft Documentation Sets. Each SPS is specific to the HUMS capability embodied within the aircraft type and describes the end to end process of acquiring and analysis HUMS data for that platform. The SPS therefore includes the mandated periodicities for downloading HUMS data, how it is then routed through layers of engineering support stakeholders, the engineering analysis and decision making responsibilities at each stakeholder level, through to the final storage and archiving of the data.

Robust assurance processes are adopted throughout the HUMS support solutions. Where possible an end to end HUMS acquisition and analysis process with qualification testing against a defined and accepted standard is ideal. Qualification using Design Assurance Levels (DAL) levels appropriate to the HUMS embodiment and capability, including all systems which undertake off aircraft data processing and are used in the engineering decision making process is the “gold standard” Using the example of the General Electric Aviation (GE Aviation) GenHUMS system as embodied in UK CH47 Chinook, Sea King and AW159 Wildcat aircraft; the Airborne and Ground Support Systems are all qualified at DAL Level D.

The GenHUMS system provides monitoring down to individual gear and bearing level and is able to identify early onset of component damage. Such damage can be corroborated by the further analysis of samples from the Wear Debris Monitoring programme. Either approach can lead to a gearbox rejection and in such circumstances, MoD works closely with the aircraft manufactures to ensure that component strip reports (full metallurgical inspection) are provided to confirm the diagnosis. Where necessary this could trigger an amendment or enhancement to the monitoring process.

Lessons Identified (LIs)

Having discussed at some length, our perceived best practice for optimizing and enhancing the exploitation of our HUMS capabilities, it is very useful to now reflect on our long experience with HUMS and share some of the lessons identified and explain how these lessons are now influencing our future HUMS exploitation aspirations and our strategic planning to accomplish these aims.

Key Lessons include (not exhaustive):

- In the first instance, understand where you are and establish a clear understanding of where you want to get to, what you want from your system and then support that aspiration with a clear, measurable and achievable strategic plan.
- Ensure that a range of specialist technical training, appropriate to each stakeholder tasks is provided and sustained to accommodate new staff.
- Ensure that robust assurance measures are in place for all HUMS support processes and that all processes are written clearly, unambiguously and using appropriate language which minimises the likelihood of subjective interpretation.
- Having defined the processes, ensure they are incorporated in the Aircraft Documentation Set or Military Regulatory Publications as appropriate and are then subjected to regular review, version control and a robust amendment request process.
- Ensure that all personnel working within the auspices of these processes are regularly audited for compliance with the processes, are authorised to carry out the work and undertake regularly competency assessment.
- Nobody has the monopoly on good ideas. "Look over your neighbour's fence" and share knowledge and experience, embrace and adopt best practice wherever it exists.
- "Every day is a school day." HUMS remains a relatively immature approach and therefore the more you try to use and exploit HUMS the more you will learn. Never stop trying to improve and enhance; the only constraint is imagination.
- To maximise the chance of successful development, engage all stakeholders including industry partners.
- Ensure that you work closely with you equipment vendors and that their strategic aspirations are known and understood. This enables alignment and development with joint or common purposes and can mitigate hardware and software obsolescence and align HUMS enhancements with other aircraft update programmes. The use of robust Risk and Obsolescence Management processes is essential in sustaining current HUMS exploitation capability and successful delivery all future HUMS strategic objectives.
- The creation of a single data centre, with data management processes, data flows and periodicities mandated in the Aircraft Documentation Sets is essential to providing data access, data processing and data reporting services to all stakeholders. This enables the Right Data in the Right Place at the Right Time in the Right Format.
- The likelihood of delivering an efficient, effective end to end HUMS analysis, exploitation and support solution is greatly increased by recognising the importance of using multi-disciplinary professional teams with the appropriate skills for the task e.g. Air Engineers, Data Scientists, IT Systems Administrators or Project Managers and Project Engineers.
- Where disparate ground support systems are in use to harvest HUMS data for different aircraft types, the implementation of a common analysis tool kit may be a better, more cost effective and expedient option for wider HUMS data exploitation than attempting to standardise the groundstation.
- Don't assume that just because you have a HUMS system fitted that you are safe to operate. The data needs to be downloaded, analysed and assessed regularly by trained competent individuals complacency leads to accidents.
- The MoD operates a "Just Culture" and encourages open and honest reporting with regards to air safety. It is acknowledged that professional people will make occasionally make

genuine mistakes but it is essential that they should be able to report these without fear of retribution. The Defence Air Safety Occurrence Report system (DASOR) provides this facility and all DASORs are visible to all members of the military aviation community so that lessons can be learnt by all [***Reference 7***].

Current Status of HUMS for Helicopters in the UK

General Overview

All UK military helicopters now have Cockpit Voice Flight Data Recorders (CVFDR) embodied which provides the Usage Monitoring aspect. With the exception of the current AH64 Apache all other helicopter types include Vibration Health Monitoring. A variety of different vendors systems are embodied within the fleets, largely due to the legacy of how different types were procured and the availability/maturity of HUMS technology at that time.

This inevitably leads to a range of maturity states across aircraft types with respect to HUMS exploitation. Disparate capabilities within the embodied systems generates certain exploitation boundaries and limitations when considering and defining the long term aspirations. Goals which may be easily achievable for some aircraft types may not be achievable for all types.

The MoD's most mature HUMS in terms of both capability and exploitation is the GE Aviation GenHUMS system which was an "after-market" fit to legacy Sea King and Chinook aircraft and a design incorporation into the newly delivered AW159 Wildcat

It is also worthy of mention that UK MoD doesn't constrain itself to the embodied electronic HUMS; we consider other maintenance activities to be a definitive part of Aircraft Health Monitoring, including Visual Inspection, Wear Debris Analysis (WDA) and Non Destructive Inspection (NDI). All UK Military helicopters are supported by established mature WDA and NDI regimes.

Rotor Track and Balance (RTB) is carried out using the embodied HUMS for those aircraft with the GE Aviation GenHUMS system embodied. RTB using HUMS remains an aspiration for other MoD aircraft with trials due imminently for Puma 2.

Gearboxes and drivetrains are monitored using HUMS embodied accelerometers for all aircraft except Apache. However the proposal to procure replacement Apache aircraft from Boeing will align the UK and US models and will therefore include a fully functional HUMS capability.

Integrated Operational Support Programmes (IOS)

IOS support arrangements are in place with all helicopter platform and engine manufacturers. These are often referred to as Availability Contracts as IOS providers are contractually bound to optimise aircraft availability to support front line military operations. In order to achieve outcome, IOS contracts typically offer a range of services including training, servicing and spares.

HUMS exploitation within the confines of an IOS contract can be challenging unless good working relationships are forged with the provider. The challenge here is to gain acceptance and support from the IOS provider that the acquired data is accurate, suitable and authoritative for use in airworthiness decision making. This can be difficult when another vendors HUMS capability is fitted to a legacy aircraft such as Sea King and Chinook. The IOS Gain Share concept, where savings accrued through improvements in support activity are shared between the provider and the MoD is a good vehicle for incentivising this change and adopting novel solutions for the benefit of both parties. It is also useful in enabling the provider to still meet their contractual performance indicators if HUMS analysis leads to a recommendation to reject a component outside the normal maintenance periodicity.

Accident and Incident Investigation

HUMS and FDR data are routinely used in the investigation of incidents, accidents and some engineering diagnostics. As an example, utilising the FDR data has been shown to reduce the time taken to investigate and resolve the cause of Uncommanded Flying Control Movements (UFCM) on Chinook from a number of days to a number of hours thereby reducing nugatory maintenance and increasing aircraft availability.

The FUMS™ system, discussed in greater detail later in this paper, provides the ability to replay sorties from FDR data. All FDR parameters are able to be displayed and analysed in a graphical user interface with the addition of an animated reply where the attitude of the aircraft is displayed.

Cockpit voice recordings are not routinely downloaded from the aircraft. However recordings are routinely downloaded and interrogated during incident and accident investigations. The FUMS system is capable of synchronising cockpit voice recordings with the flight data stream which assists investigators in identifying features or events of interest within a sortie.

An additional benefit of our helicopters CVFDR emanates from the broad frequency response of the area microphones. This enables the use of cockpit voice recordings to examine frequencies of interest within all rotating components. Given that we know the rotational frequencies associated with helicopter drive trains including gear mesh frequencies, bearing ball pass frequencies and turbine blade pass frequencies, we are able to determine what the drive train and rotors were doing at the point of interest.

Strategic Planning - Opportunities, Aspirations and Challenges

Flight Data Monitoring

The MoD is currently undertaking a Flight Data Monitoring (FDM) trial on the Chinook and Puma 2 fleets. Otherwise known as Flight Operations Quality Analysis (FOQA), FDM utilises the same usage data from the Flight Data Recorder that our engineering systems use but focussed on how the aircraft has been flown. Through the application of Flight Condition Recognition algorithms (manoeuver recognition) an MoD partner provides regular reports which when any of the pre-defined limits have been exceeded e.g. angle of bank, rate of turn etc. The exceedances currently being monitored emanate from the limits set in the Release to Service document for the aircraft type.

Reports are provided back to senior pilots who are then able to discuss particular aspects of the sortie with the handling pilot with a view to education, improving airmanship and reducing the incidence of the most damaging manoeuvres. By utilising the same data, there is clearly a huge overlap between operators and engineering – understanding how the aircraft has been flown can influence the appropriate required maintenance.

Competence and Certification

As part of the ongoing objective to provide assurance in Aircraft Health Monitoring, it is imperative to ensure that those individuals who make or influence the airworthiness and flight safety decision making process are able to demonstrate that they are suitably qualified and experienced people (SQEP) and are competent to undertake their role. Consideration is being given to achieving certification for HUMS, Vibration and Wear Debris Analysts against recognised standards. This would align analysts in the area of work with their Aircraft Health Monitoring colleagues in the Non Destructive Testing specialisation and provide further evidence of competence. Engineers working in all areas of Aircraft Health Monitoring are already strongly encouraged to undertake professional registration with professional engineering institutes regulated by the UK Engineering Council.

Utilisation of Aviation HUMS Experience to Provide Wider Support

An embryonic opportunity relates to the Royal Navy's new Queen Elizabeth class (QEC) Aircraft Carriers. As all MoD helicopter types will be embarked at some time in QEC, there is some potential to utilise the health monitoring skills, deployed equipment and methods employed by embarked flights to support and maintain the ship. Examples of this include Wear Debris Analysis/Vibration Analysis programmes for the Sampson multi-function radar gearbox and aircraft lifts and automated weapon handling systems.

Alerting Thresholds and False Alarms

Currently the MoD utilises a graduated threshold based alerting mechanism to identify and handle exceedances. Dependent on the capability of the platform this is implemented by calculating and using thresholds from fleet-wide data or by enabling the generation of learned thresholds for each individual aircraft.

Another MoD aspiration is to complement the alerting process by introducing additional data processing to minimise the number of false alerts. The intent is to develop algorithms which enable more informed management of alerts by generating a metric which provides an indication of the probabilistic likelihood of a fault. Successful generation of this capability is likely to enhance aircraft availability and will enable more informed fleet management and usage through the reduction of unscheduled maintenance.

Statement of Operating Intent & Usage and Operational Data Monitoring

The Statement of Operating Intent and Usage (SOIU) is part of the Aircraft Usage Validation Process (AUVP) in support of aircraft Structural Integrity (SI). When substantiating safe life the Design Organisation (manufacturer) make assumptions based upon how the aircraft will be used in service – these are referred to the Design Usage Spectrum (DUS).

The AUVP is a process which compares the actual aircraft in-service usage with the DUS to ensure continued structural airworthiness with the output being the SOIU. [***Reference 9***]

The SOIU review is carried out at regular periodicities, with sortie information e.g. manoeuvres performed, number of take offs and landings etc being traditionally provided manually by aircrew in the form of sortie profile codes. This is a time consuming process prone to human error.

Work is underway to automate the SOIU review process for our AW159 Wildcat fleet using the usage data acquired by the on-board HUMS. This will be achieved by defining a set of Flight Condition Recognition (FCR) algorithms which match the manoeuvres defined in the DUS and processing the acquired data using the FCR algorithms to calculate the proportion of time spent in the various regimes. Any significant variance may trigger a Scheduled Maintenance Review (SMR)

A similar approach is being taken for undertaking an Operational Loads and Usage Validation (OLUV) exercise for the MoD Puma 2 fleet in the guise of Operational Data Recording (ODR). This allows the comparison of actual loads, normally monitored by use of instrumented aircraft, against the DUS. Instrumenting an aircraft is very costly and time consuming and therefore processing the usage data from the flight data recorder against the FCR algorithms provides MoD with considerable cost savings and reduces the impact on aircraft availability. [***Reference 10***]

Strategic Delivery – Common Analysis Capability

1710 Naval Air Squadron (1710 NAS) provides science and engineering support to a range of stakeholders for each aircraft type with potentially unique requirements. Stakeholders include front line squadrons, Type Airworthiness Authorities (TAAs) and Continuing Airworthiness Management Organisations (CAMOs). This presents a considerable challenge to deliver robust, assured and coherent services.

Like many organisations, the MoD faces the “Big Data” challenge with respect to HUMS however our challenge is on a more modest scale than most. There is a clear requirement to undertake wider trending and data analysis to accurately identify instances of early onset damage within monitored components. With substantial volumes of disparate data being generated by large aircraft fleets and insufficient resource to undertake manual data analysis, an automated data processing capability is the key to success.

The MoD solution to this challenge is to implement a single analysis tool kit, common across all aircraft types, to provide a framework for automated data processing, utilising a scalable library of bespoke algorithms which can be written within the analysis tool kit or incorporated as a plug-in. This enables us to provide an immensely powerful analysis and diagnostic capability which meets the needs of the full range of stakeholders. Those stakeholders who possess specialist data analysis and diagnostic skills will be provided with full access to the tool kit to generate their own algorithms and reports. Those without such skills will be provided with technical reports as mandated or when requested, generated by 1710 NAS.

The toolkit adopted to deliver this capability is the General Electric Aviation (GE) Fleet and Usage Management Software (FUMS™). This was chosen as it complements the GE Aviation Generic HUMS (GenHUMS) embodied in the MoD’s Chinook, Sea King and Wildcat fleets and the GE EVADR based HUMS embodied in the UK Apache fleet. This decision to use FUMS for the single analysis toolkit was further endorsed by a long and successful history of FUMS usage.

FUMS provides a comprehensive suite of advanced analysis tools which include data fusion, diagnostic, prognostic and decision support capabilities. At this time, developing enhanced diagnostic capability is the priority and the data fusion capability is regarded as a being a key enabler to the success of this goal. For example, the ability to fuse HUMS vibration data with component Wear Debris data, supported by aircraft maintenance data and indeed Failure Modes Effects and Criticality analysis (FMECA) data should provide an intimate understanding of the mechanical condition of monitored components.

A further example of FUMS potential may provide the ability to implement Advanced Anomaly Detection (AAD) methods as adopted by some operators in the UK civil sector. The UK CAA paper 2011/01 [***Reference 8***] provides useful background information as MoD use of AAD remains under consideration at the current time is therefore beyond the scope of this paper.

Maximising the exploitation of our HUMS capabilities opportunities by harnessing FUMS potential is very much at the centre of our strategic thinking, planning and ability to deliver. It is clear that embracing the opportunities presented by FUMS as common tool will provide the ability to develop and deliver robust, assured and evidentially sound methods of sustaining airworthiness, flight safety and aircraft availability.

Adoption of FUMS is not without its significant challenge. In particular, a new data management structure needed to be developed to make FUMS truly multiuser as FUMS had historically been a single user standalone capability, normally resident on an engineer's laptop. Increased processing power was required to support the amount of automated analyses and a networked delivery method was required to provide functional access via MoD desktop computers.

The resultant model delivers an end to end process; aircraft data flows into a "dropbox[1]" location where it is automatically detected on arrival and processed into a common format (essentially parameters and values understood by engineers) prior to storage in a central repository. The original data is also stored, unprocessed, as an archive in the repository to provide a robust audit trail if required. Reports are then generated by further common format data processing using any of the available algorithms for delivery to the stakeholder. Current focus is on the generation of static reports but the intention is to deliver dynamic reporting in the near future. Finally, stakeholder interaction is currently delivered through the provision of FUMS instances (full FUMS functionality) via VMWare virtual machines, however the likelihood is that a switch to delivery as a Virtual Appliance[2] will streamline delivery to stakeholders and reduce IT support management burden.

Working closely with Dell Computers and virtualisation experts, a scalable hardware infrastructure was specified and delivered, optimised to deliver large data storage and virtual desktop provision with accelerated graphics processing. This is currently undergoing testing for the new multiuser automated Chinook and Apache version of FUMS. Business cases are currently being developed to implement FUMS versions the other MoD helicopter fleets.

[1] The "dropbox" is an area of shared data storage, with a simple web interface which provides users with a 2 way transfer capability to share HUMS and other aircraft data by uploading or downloading.

[2] In a virtualised application hosting environment a Virtual Appliance is a "traditional" software application designed to be installed and run on a local machine but is accessed across a network via an HTML5 compliant Web Browser.

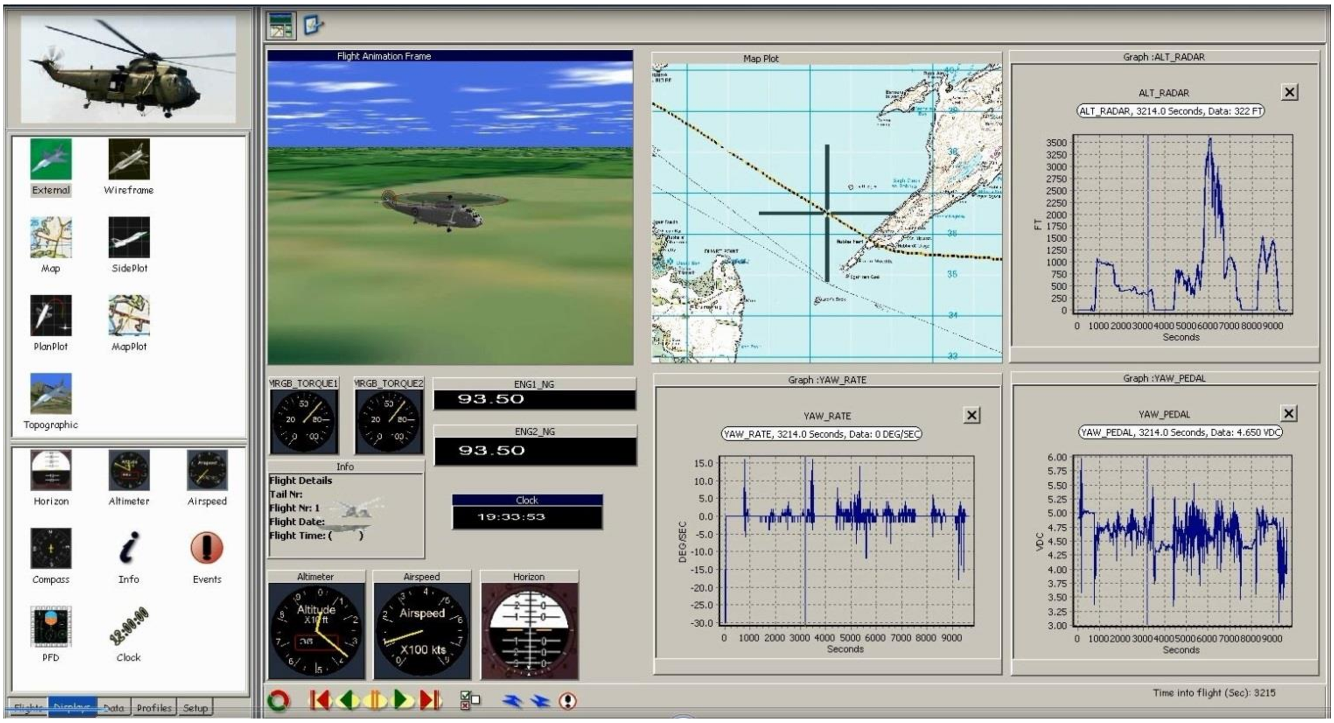

Figure 1 – FUMS Screen Capture

Conclusion and Summary

The MoD has a HUMS capability on all aircraft. However the disparate embodied HUMS systems necessitate a number of complex support arrangements. Some aircraft types have limitations which determine the extent of their HUMS exploitation plans and strategic aspirations. This is not necessarily a problem as despite any limitations all MoD aircraft types have significant exploitation opportunities.

Regulation of military aviation provides a valuable framework within which to work. Regulation requires robust assured processes to be implemented and undertaken by SQEP and competent people.

The creation of a Data centre and common data management plans provides MoD with the right data, in the right place, at the right time and in the right format for all HUMS aircraft types.

Many lessons have been identified over many years of HUMS operation and these have been utilised in a positive manner to drive improvements.

Obsolescence of both airborne and ground support systems is understood and is being managed proactively. Funding is available for HUMS exploitation and progression.

The need for automated data analysis is recognised. A plan is in progress to implement a common toolkit for the development and implementation of bespoke algorithms and dynamic reporting delivery.

Future strategic exploitation plans are maturing. Stakeholder needs are articulated, understood and reviewed as necessary and are included in the plans.

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