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Helitune Integrated Vehicle Health Management – Scalable Aircraft Health Monitoring

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Abstract

Whilst there are a few working cases of condition-base maintenance built on Integrated Vehicle Health Management (IVHM), it is still considered an emergent area. Once matured, this technology is set to reduce operating costs and increase availability. Vehicle Health Monitoring (VMH) is a key input to IVHM and is performed using an array of discrete systems for tasks such as rotor track and balance (RTB) and flight data monitoring. The problem and challenge is that whilst these systems provide operators with the functional information to complete a task, they do not easily integrate into IVHM programmes with different stakeholders often requiring functionally different levels of information and detail. This paper discusses the work undertaken by Helitune, Critical Software and the University of Bristol to extend the benefits of IVHM to the mass helicopter market through development of a technology demonstrator being used by industry to obtain representative user feedback in operational environments.

Keywords: Rotor Track and Balance, HUMS, Vibration Monitoring, Data Analytics, Prognostics

Introduction

Vehicle Health Monitoring (VHM) is achieved through a combination of ground support equipment (GSE) carry on systems. These systems enable an array of specific monitoring and maintenance tasks to be conducted by trained technicians and engineers with accompanying software tools providing a means of data analysis, reporting and archiving.

Whilst these tools perform effectively for specific tasks, for example, RTB and Vibration Analysis (VA), the information held within these systems is siloed [1] and cannot easily be combined and exploited within an IVHM system without substantial investment from operators. Although such an IVHM system maybe within the grasp of some very large organisations, there are still issues surrounding the ongoing investments required for enhancement, support and maintain.

This paper focuses on the following key operational and technology barriers facing industry:

1. the overhead of establishing and maintaining in-house IVHM software platforms;
2. the barriers of importing data from many different systems into a single package;
3. displaying data from many systems in a format that meets the needs of stakeholders with different requirements in an efficient and effective format that allows informed decision making at aircraft and fleet level;
4. the ability of smaller aircraft fleet operators to realise equivalent benefits of IVHM as larger operators;
5. to implement modular processing blocks for the analysis of aggregated IVHM data and allow their exploitation in COTS and custom IVHM solutions; and
6. OEMs have specific IVHM systems requiring operators of more than one aircraft manufacture to maintain licencing and training on multiple disjointed platforms.

IVHM-ARRIVE – Opportunity Development

To navigate these barriers, Helitune in collaboration with the University of Bristol and Critical Software and with support from Innovate UK have developed the IVHM-ARRIVE technology demonstrator. The cloud-based IVHM-ARRIVE allows data from many sources to be combined allowing engagement and decision making by operators whom are functionally separate [2]. For the purposes of the technology demonstrator, the scope of IVHM-ARRIVE was limited to the import and display of aggregated RTB and Helicopter Flight Data Monitoring (HFDM) data.

In close partnership with aircraft operators across the UK, the ARRIVE framework layer was developed. ARRIVE is an acronym for the four key layers identified in IVHM data analysis; Assimilate, Relate and Refine, Interrogate, Visualise and Exploit illustrated in Fig. 1.

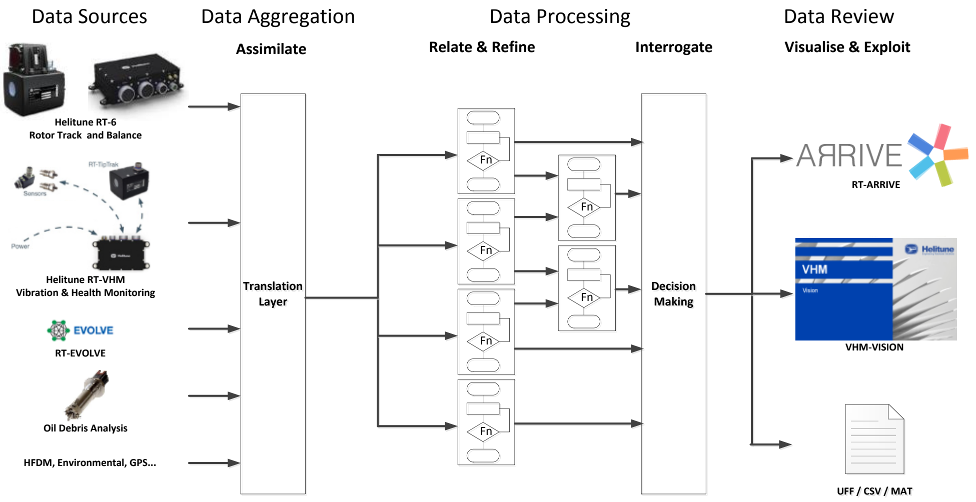


Fig. 1: Process map for Rotorcraft Assimilate, Relate & Refine, Interrogate, Visualise and Exploit (ARRIVE)

Assimilate

Assimilation takes place to aggregate multiple data sources needed for IVHM applications including RTB and HFDM. Aggregated data is then stored within a database structured to allow different data requirements to be queried, for example: component, aircraft or fleet level.

The assimilation layer is built from modular data importers which can manually or automatically import new data into ARRIVE. The modular architecture design was adapted from the existing Helitune RT-Vision ground station products combining the lessons learned in supporting and maintaining modular software designs. The layer can import data from existing Helitune GSE and on-board systems using a proprietary interface in addition to HFDM data using an open JavaScript Object Notation (JSON) format allowing the import of data from other providers.

Establishing robust IT security is a necessity in data transfer irrespective of the deployed environment, this is achieved in the ARRIVE technology demonstrator using Hypertext Transfer Protocol Secure (HTTPS), OAuth2 and integration with Google Plus providing an “out of the box” authentication solution.

Relate and Refine

Data alone has little value in IVHM decision making, without knowing its context. The relate and refine layer achieves this transformation through the binding of information such as the aircraft model, condition and states at time of recording.

The timeless saying ‘garbage in, garbage out’ has never been as important when it comes to large scale data interpretation. As part of ARRIVE, algorithms were developed and integrated based on the work by Maydanchik [3] to identify the presence of erroneous or missing data allowing flagging or exclusion from analysis, thereby ensuring the transparency and integrity of information for which the decisions that are made can be understood and maintained.

Data quality screening is achieved in three steps:

- Data Profiling – the evaluation of data content and data structure allowing the generation of basic statistics, relationships and pattern detection improving the efficiency and effectiveness of data quality screening and further data analysis layers.

- Data verification and validation – the evaluation of the correctness and consistency of the data ensuring that it is fit for purpose.

- Data cleansing – the implementation of prescribed rules upon detection of erroneous or missing data including the removal of data and associated data rows or estimation of missing values.

The level of confidence to which decisions can be made is in part based on the quality of the information being reviewed and importantly understood prior to the decision point. To inform the operator on the quality of data, functions were built into ARRIVE that provide measures of overall quality, completeness and accuracy Eqn. 1, 2 and 3 which is stored alongside the records.

$$\text{Overall Score} = \frac{\text{Count of Relevant Records - Count of Erroneous Records}}{\text{Count of Relevant Records + Count of Missing Records}} \tag{1}$$

$$\text{Completeness Score} = \frac{\text{Count of Relevant Records}}{\text{Count of Relevant Records + Count of Missing Records}} \tag{2}$$

$$\text{Accuracy Score} = \frac{\text{Count of Relevant Records - Count of Erroneous Records}}{\text{Count of Relevant Records}} \tag{3}$$

Interrogate

Once the data has been refined, value is added through the process of interrogation. In ARRIVE, value is added to the data through the application of discrete modular algorithms designed to meet the requirements of specific operators.

Algorithms implemented within the technology demonstrator ranged from simple threshold exceedance detection of vibration data to complex automated threshold level and rate of change setting and exceedance reporting for different operating states.

Smaller fleet operators have in the past struggled to implement and benefit from IVHM solutions due to the cost and limited number of aircraft from which to gain insights. To overcome this barrier, a virtual fleet feature was incorporated into ARRIVE allowing operators to share data anonymously with other users enabling operators to compare data against a crowdsourced virtual fleet. The virtual fleet will allow operators to identify outliers in data with more confidence given that statistics are generated from a much larger data set. Data sharing rules were introduced to ensure anonymity of individual aircraft and operators with data undergoing the same level of refinement to remove outliers. The ARRIVE virtual fleet has currently been implemented for RTB data allowing users to compare the number of flights and final vibration levels obtained with a wider pool of similar aircraft. In the future the ARRIVE virtual fleet functionality will be extended to include HFDM data allowing prognostics and trending functions to be performed by smaller feet operators.

Stakeholders in the project identified the need to be able to modify and add new algorithms to ARRIVE to allow continuous evolution of IVHM initiatives as well as the capability to exploit the algorithms in other in-house developed software platforms.

To achieve this the ARRIVE algorithms were developed using the Helitune Signal Processing Framework, a set of modular functions that can be assembled to achieve specific processing tasks such as limit exceedance detection, decimation, Fast Fourier Transforms, filtering and interpolation.

To allow the integration of custom algorithms in ARRIVE the airborne Helitune VHM allows the storage of raw time series data, meaning that the raw data used to calculate condition indicators (CI) is retained allowing for new and complex CIs to be calculated after flight data has been collected.

Using the PROSIG DATS software suite, CIs can be developed with the raw data captured by the Helitune VHM, embodied into the signal processing framework and then deployed back into Helitune VHM or ARRIVE as illustrated in Fig. 2.

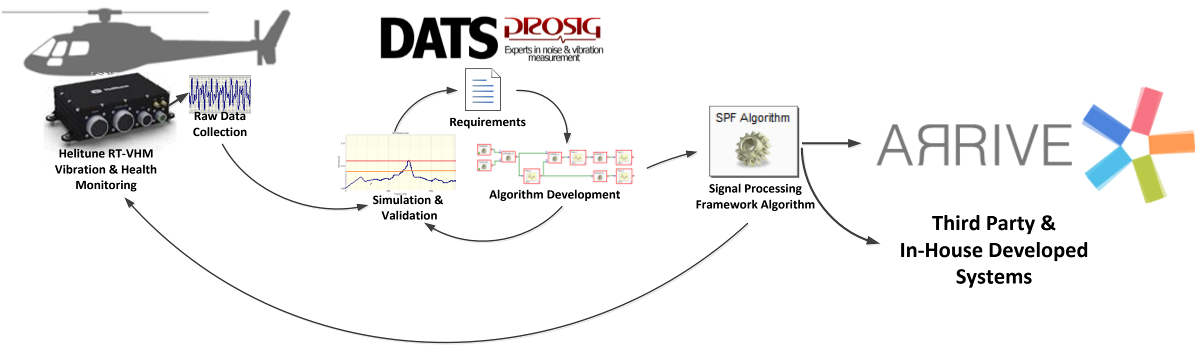


Fig. 2: IVHM-ARRIVE Condition Indicator Development & Deployment

This closed loop algorithm development process allows for new CIs to be deployed in airborne systems well as ground stations, allowing for both real time data monitoring and historic data to be replayed through new CIs enabling comparison and trending against the latest data.

Visualise and Exploit

Following assimilation, relate and refinement and interrogation the data can be finally combined and displayed in an array of formats developed specifically for the target users. The ARRIVE consortium limited the scope of the technology demonstrator only to include displays that help fleet operators determine availability and prioritise maintenance as well as show detailed information on RTB and key HFDM metrics.

The fleet overview display (Fig. 3) was produced to allow fleet operators and maintainers to understand the health and serviceability of each aircraft through a colour coded silhouette of the aircraft referencing its tail number. Specific details of the interrogation and exceptions generating the aircraft health status are accessed by clicking on an aircraft silhouette opening additional pages showing more detailed information.

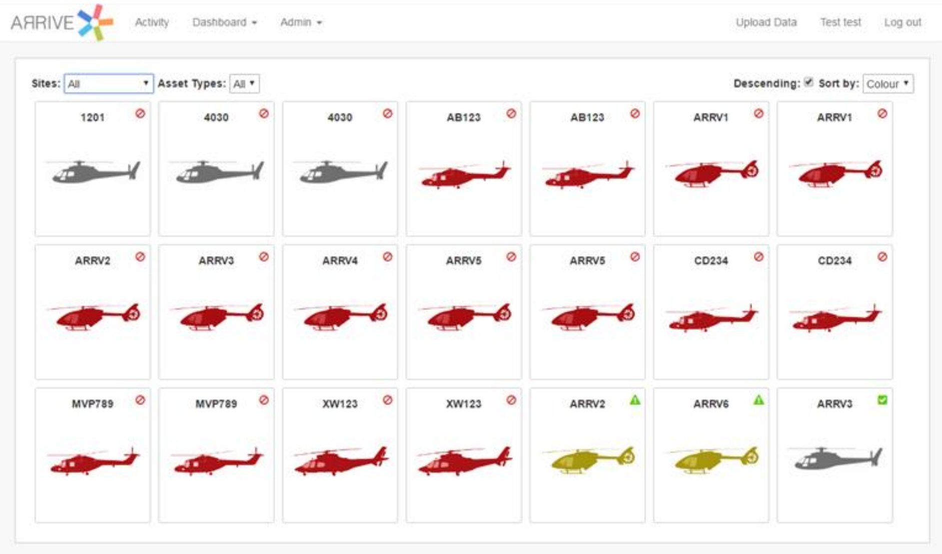


Fig. 3: IVHM-ARRIVE Fleet Overview

A successful RTB involves skilled engineers and pilots performing an array of flights, data collections and adjustments to bring an aircraft's vibration levels and track into operational limits. To allow the overall health of an aircraft's RTB to be understood and communicated without having to review and understand the measurements from multiple components an 'RTB Index' display (Fig. 4) was developed and integrated into ARRIVE.

The RTB Index is a dimensionless aggregation of RTB measurements and operational limits. A value of 5 or greater indicates that an operational limit in one or more flight conditions has been exceeded, the closer the value is to 5 the closer RTB measurements are to exceeding operational limits. The RTB Index allows for an overall indication of RTB improvements from flight to flight to be trended increasing the likelihood of detecting an incorrect RTB adjustment or the presence of a non-adjustable fault.

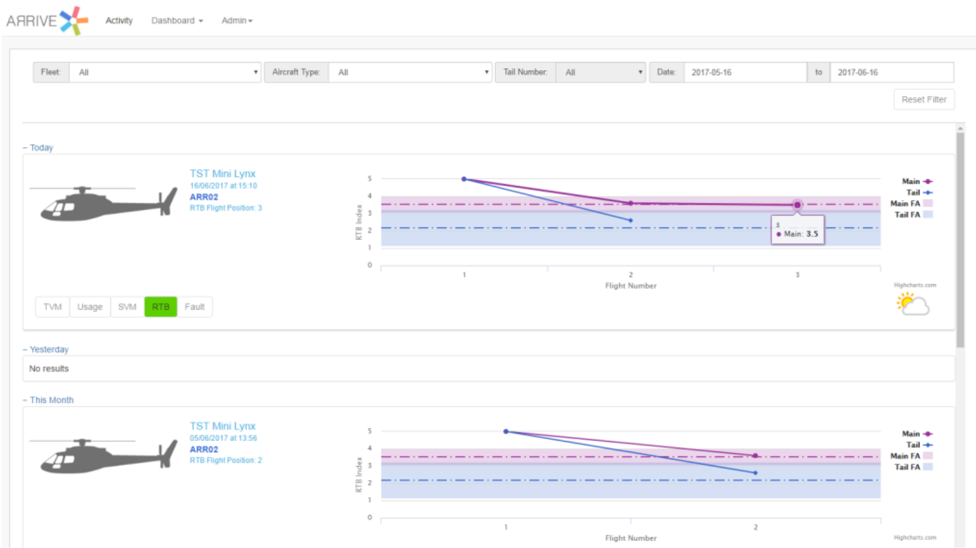


Fig. 4: IVHM-ARRIVE RTB Index Display

A specific display was generated for technicians performing RTB (Fig. 5) indicating the status of key components through simple colour coding and showing more detailed information on measurement conditions, trim tab and balance configurations. Using Helitune's Minimum Flight Routine (MFR) algorithm which has been proven to reduce RTB flights by 50% on the Royal Air Force (RAF) Puma helicopter [4], ARRIVE displays RTB adjustments after every data import reducing the need to conduct specific flights for RTB data collection.

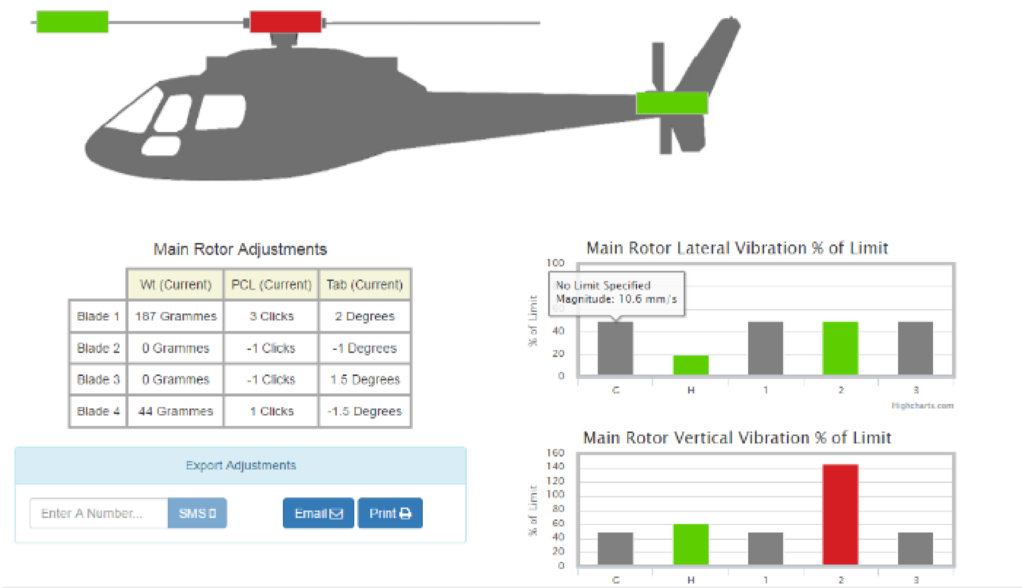


Fig. 5: IVHM-ARRIVE RTB Display

To show at a high level RTB and HFDM information, an Activity Feed display was generated (Fig. 6) summarising the status of component level fault screening algorithms for Transmission Vibration Monitoring (TVM) and Structural Vibration, Usage, RTB and custom fault detection. The display allows the user to review the history of all flights completed along with an overall summary of the latest flight. Filters were introduced to enable screening of an individual or fleet of aircraft to help identify patterns and anomalies.

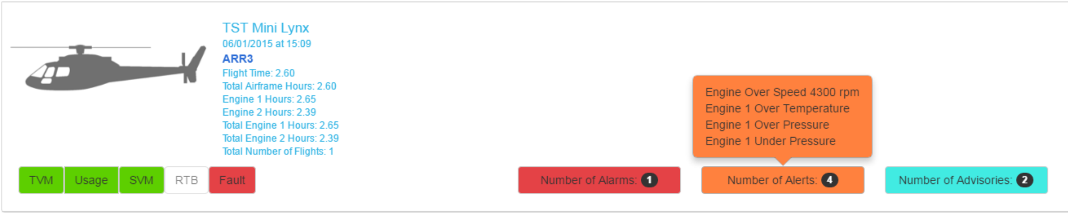
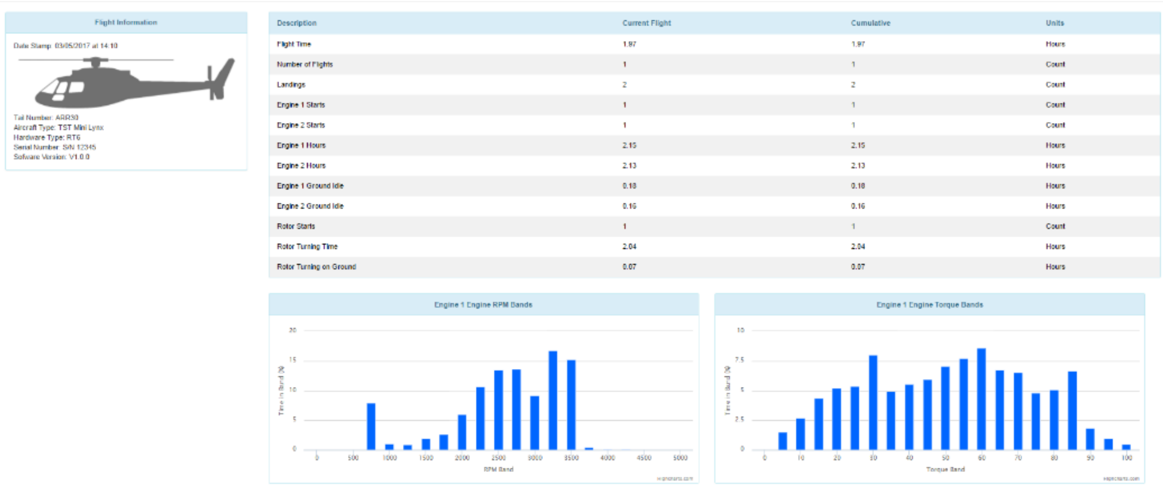


Fig. 6: IVHM-ARRIVE Activity Feed

For a detailed visualisation of HFDM information, tabular and graphical displays (Fig. 7) were generated showing metric and statistics including flight time, no. of engine starts, time in flight conditions and torque bands.



Description	Current Flight	Cumulative	Units
Flight Time	1.97	1.97	Hours
Number of Flights	1	1	Count
Landings	2	2	Count
Engine 1 Starts	1	1	Count
Engine 2 Starts	1	1	Count
Engine 1 Hours	2.15	2.15	Hours
Engine 2 Hours	2.13	2.13	Hours
Engine 1 Ground Idle	0.18	0.18	Hours
Engine 2 Ground Idle	0.16	0.16	Hours
Rotor Starts	1	1	Count
Rotor Turning Time	2.04	2.04	Hours
Rotor Turning on Ground	0.07	0.07	Hours

Fig. 7: IVHM-ARRIVE HFDM Display

The cloud-based architecture of the IVHM-ARRIVE technology demonstrator means that displays showing a variety of raw and post processed information can be generated and deployed efficiently and at lower cost to the end user in comparison to stand alone software installed on local machines. Future development will include the refinement of existing displays and the generation of new displays tailored to project key information for targeted operators.

Conclusion

This paper has introduced the building blocks of IVHM-ARRIVE a technology demonstrator developed with the aerospace industry forming a foundation for the opening of siloes for VHM data facilitating exploitation. The IVHM-ARRIVE technologies demonstrate support and maintenance efficiency improvements for multiple aircraft platforms through data assimilation, refinement, interrogation and visualisation.

The IVHM-ARRIVE architecture provides a foundation from which the industry can build on opening the benefits of IVHM to smaller aircraft operators through the modular design allowing display of data from multiple aircraft manufactures displayed in formats that meet the needs of fleet management, maintenance, logistic and supplier operators.

The project has integrated the concept of virtual fleets allowing smaller operators to perform comparisons, outlier detection and prognostics with anonymised data of similar aircraft owned by other operators strengthening the confidence of decision making.

The project has realised and implemented several processing algorithms that can be integrated with other organisations IVHM or custom data mining platforms.

IVHM-ARRIVE technology demonstrator currently sits at technology readiness level 5/6. Development towards a commercially viable product that can be used by helicopter operators around the world is currently ongoing in close collaboration with industry.

Following the successful development in of its third generation Rotortuner 6 RTB and VA GSE system (entering service in 2014), Helitune has continued to invest heavily in this technology platform where the Rotortuner 6 core data acquisition unit is at the heart of its onboard VHM system. The fully certified system has several unique features including continuous multichannel data acquisition, processing and storage for high frequency vibration sensors as well as flight data parameters.

Current commercial projects include collaborations with Castle Air, MD Helicopters and ZFL. A recent project with a UK operator and maintainer has seen applications development for the Leonardo A-109 helicopter which Helitune has been able to test its latest technology developments for anomaly detection in collaboration with the University of Bristol.

As Helitune continue the development of the on-board HUMS RT-VHM systems, core capabilities identified during the IVHM-ARRIVE project will developed including custom reporting and display features and integration into third party VMH, maintenance and logistics software suites.

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