Deutscher Luft- und Raumfahrtkongress 2016
DocumentID: 420249

Identification and Interpretation of Integrated Vehicle Health Management (IVHM) Generic Architecture and a Case Study

Ali Baghchehsara[1], Tatiana Odinets[2] Jan Robbe[3], Amine Boughalem[4], Jürgen Raps[5], Hendrik Meyer[6]

R&D Engineer, VDev Systems and Services, Flughafendamm 47, 28199 Bremen, Germany
Research Assistant, DLR German Aerospace Center, Air Transportation Systems, Blohmstraße 20, 21079 Hamburg, Germany
Ali.baghchehsara@Vdev.de

Student, Hamburg University of Technology, Am Schwarzenberg-Campus 1, 21073 Hamburg
tatiana.odinets@tuhh.de

Project Leader, VDev Systems and Services, Flughafendamm 47, 28199 Bremen, Germany
Jan.robbe@Vdev.de

Engineer, VDev Systems and Services, Flughafendamm 47, 28199 Bremen, Germany
amine.boughalem@Vdev.de

Professor, Bremen City University of Applied Sciences, Flughafenallee 10, 28199 Bremen, Germany
Juergen.Raps@dlh.de

Researcher, DLR German Aerospace Center, Air Transportation Systems, Blohmstraße 20, 21079 Hamburg, Germany
Hendrik.meyer@dlr.de

Abstract

Upon advancement of health management systems in different forms such as diagnostic on- board maintenance in recently developed aircrafts such as Airbus real time health monitoring or Boeing's Aircraft Health Analysis and Diagnosis, (S. Torhorst et al) the technology trend tracks a prognostic approach.
Meanwhile Integration of a Vehicle Health Management demands a comprehensive perusal to identify and categorize all the key requirements, availability of technologies, functions and elements to ensure the health of the future aircraft, within the context of a feasible approach beside validadablity for the aviation authorities. Nevertheless, each stakeholder has its own requirements, that have to be identified, such as requirements of aviation legislation, data handling. On the other hand, there are drastic roadblocks for the technology feasibility such as data handling. In this paper, the architecture within all the key requirements are defined, analyzed and charted to ease assessing the technology from a technical view on a generic future aircraft architecture plus a clustered within all these parameters to get the best performance and a prognostic methodology is technically studied as a case study on a system failure.

1. INTRODUCTION

One of the most important challenges facing aviation safety today is safeguarding against system/component failures and malfunctions. This is because hardware faults and failures are very difficult to detect, diagnose, and mitigate in-flight with existing technologies. Consequently, when an unexpected failure occur they can lead to catastrophic accidents. Data from the FAA and NTSB are clear: "subsystem, component failures and hazards together contribute 24% to onboard fatalities, and are underlying factors in many of the 26% of the accidents caused by loss-of-control in flight. NTSB accident data covering 7,571 US-registered aircraft from 1980 to 2001, broken down by the accident causes (hardware malfunctions only), show that 52% of the hardware-induced accidents were aircraft system related, 36% were caused by propulsion system components, and the remaining 10% were caused by failures in the airframe. Landing gear caused 36 accidents, turbine/turboprop engines contributed to 33, and flight controls contributed to 10 accidents." (NASA IVHM) [1]

Therefore, health of aircraft is very important and keeping the aircraft healthy is one of the important cost factors. Accordingly, Push To Test system and some other systems were invented [see figure 1] and now this trend pushes the researches to the way forward on IVHM and prognostics. Integrated Vehicle Health Management (IVHM) is a" set of health management (HM) capabilities integrated into a system's design that enable sustainable and safe operation of components and subsystems within vehicle platforms." [2]

Upon development of health management systems in different forms such as diagnostic on- board maintenance in recently developed aircrafts such as Airbus real time health monitoring or Boeing's Aircraft Health Analysis and Diagnosis, (Hölzel et al) the technology trend tracks a prognostic approach. [3] For instance Airbus is developing IVHM systems such as AirThm which is a support service from Airbus based on status of the aircraft systems (which is just accident preventive, not predictive) and is done when there is an alert for failure or error takes place and then they contact the maintenance or the airline to take the proper reaction.

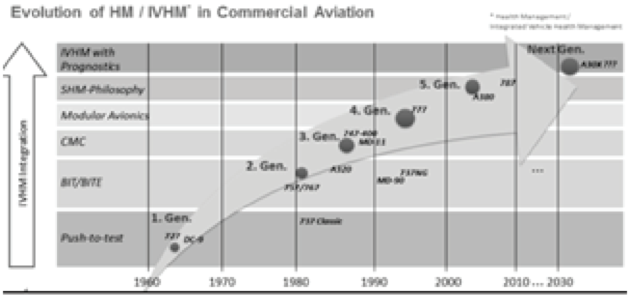


Figure 1. Evaluation of HM in commercial Aircrafts. [2]

In this paper, a simple architecture exhibits elements, components and participants of an integrated health vehicle health monitoring system to ease understanding of the technology. All these parameters to get the best performances. Afterwards technically experimenting system functionalities on a case study for a RAM flap failure has been done. While stakeholders are clustered to ease the understanding of requirements and limitations for such an advancement.

2. METHODOLOGY

The health indication of the whole vehicle relies on health condition and its components, subsystems and systems.

The data needed for determination the health condition of aircraft components, subsystems and systems is gathered by various types of sensors and measurement devices and then It is pre-processed, transmitted and stored for future analyses. Therefore, an architecture is developed using different models and algorithms.

For this huge achievement, it is desired to examine the relationship between different states of operation and estimated remaining useful life.

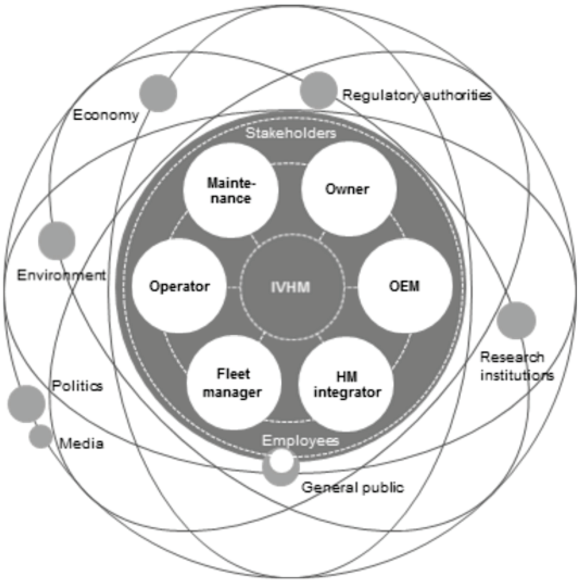
2.1. Aims

The aim of this development and experiment, therefore, is an integrated aircraft health monitoring, optionally with diagnosis and prognosis system to maximize the current and future vehicle's performance. At the same time, it can allow to reduce the maintenance durance and costs [e.g. AOGs], delays and turnout times, and prevent unexpected failures. These are of course high cost related matters, where IVHM can affect substantially while safety, security and reliability are desired to reach higher performances.

Therefore, on the longer term, it can be expected to reduce or even avoid unnecessary maintenance and prevent the unpredicted failures as results of this development. Maintenance would be performed only when and where it is needed at the moment. Scheduled maintenance can be replaced by Planned preventive maintenance (PPM) or Condition Based Maintenance (CBM) upon availability of a complete IVHM system implemented in future aircrafts.

2.2. Requirements

Integrated Vehicle Health Management system meets the needs of an aircraft. It consists of various hardware and software components, operational and maintenance processes that cohesive work together to provide the vehicle perform in the most efficient way. (Rajamani, et al., 2013). The main stakeholders of IVHM could be categorized from requirements perspective in the following manner presented as an atom model:



The figure 2. demonstrates an overall model for Integrated Vehicle Health Management system stakeholders and effecting third parties [7]

As you can see in the figure 2, there are some main stakeholders demonstrating the direct involvement to the IVHM system while there are many other stakeholders with considerably lower impacts on that. Thus, the new capabilities have to be established for providing accurate on-board detection, diagnosis, prognosis, and mitigation of adverse conditions during flight. But nevertheless, these requirements are connected together, meanwhile having interconnections, the following table demonstrates some examples from stakeholder view:

STAKEHOLDERS	REQUIREMENTS
Vehicle owner	Reducing maintenance costs, increasing availability of aircraft in the fleet
Maintainer	Spare parts availability, reducing maintenance costs, optimization of parts inventory, reducing manpower
Original Equipment Manufacturer	Recommendations for the IVHM system
Health Management system integrator	Reducing costs and quantity of contradictory results
Operator	Minimizing the turnaround times and delays, receiving warnings during the flight
Fleet manager	Reducing the delays, optimizing flight schedule

Table 1. Requirements and stakeholder's connection

Of course these stakeholder and requirements are expandable to a much higher detail which is not in the scope of this paper. These requirements can be explained as a model drawn in the figure 3 which demonstrates requirements interconnections from technical side, architecture elements or stakeholders:

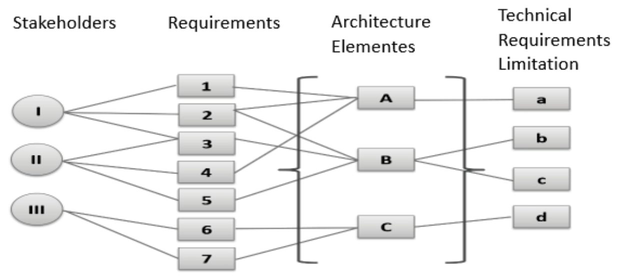


Figure 3. Interconnections between stakeholders, requirements, architecture elements and technical requirements limitations [4]

The stakeholders indeed are just part of the requirements only, but these limitations are linked, for example, the capacity of data processing for simulation purposes on a huge current is a limitation on board especially when the system is onboard of the Aircraft, and this is a linked requirement to the legal authorities in case of having non-deterministic algorithms working on the data. Therefore, these requirements are also considered for such a development.

Airworthiness regulation represent one of the main challenges that IVHM face. EASA established a ruleset "Certification Specification" (CS) for certification and maintenance and repair for aircraft valid throughout the European Union. Certification Maintenance Requirements (CMR) is a periodic task used in a safety analysis for showing compliance with hazardous and catastrophic failure conditions. CMR is established as an operation limitation of the Type Certificate.

Airworthiness Limitations (AL) are items of the certifications process that regulate the process of inspections or maintenance used to determine fatigue and damage tolerance assessment. AL also include a set of periodical tasks [8].

Technical health monitoring requirements are focused on identifying the systems' functionalities, physical characteristics of IVHM system components and the techniques and technologies. In that way, these requirements will be defined during the design process. The IVHM systems components should be of as little weight as possible, so that vehicle is close to its maximum take-off weight, otherwise the fuel consume would increase drastically. (Kerczewski et al., 2009)

It is worth to mention that the above shown list of requirements is not complete. It can change according to actual stakeholders' needs or the priority of some requirements may vary. For example, nowadays there is an urgent need to reduce fuel consumption and COx emissions, stakeholders in this case are environment and organizations like EASA that regulate aviation safety in EU. The weight of IVHM systems may influence fuel consumption of aircraft and this makes this aspect being very important currently.

2.3. Generic Architecture

In this section, a generic IVHM architecture is developed, based on literature research and identification of all technologies and functions in the context of IVHM. The architecture includes various on-board and on-ground elements that enable defects and abnormalities identification, remaining useful life prediction of vehicle components, subsystems and systems, and also support of aircraft condition based maintenance decisions.

For maximal best estimation of current and future vehicle performance all information required must be managed by IVHM system. This includes data transfer inside of aircraft, between onboard and ground systems, and ground elements. For example, the data warehouse and some other cubes are selected and were experienced via technical methods to proof the feasibility of the technic solely for prognostics in the next section.

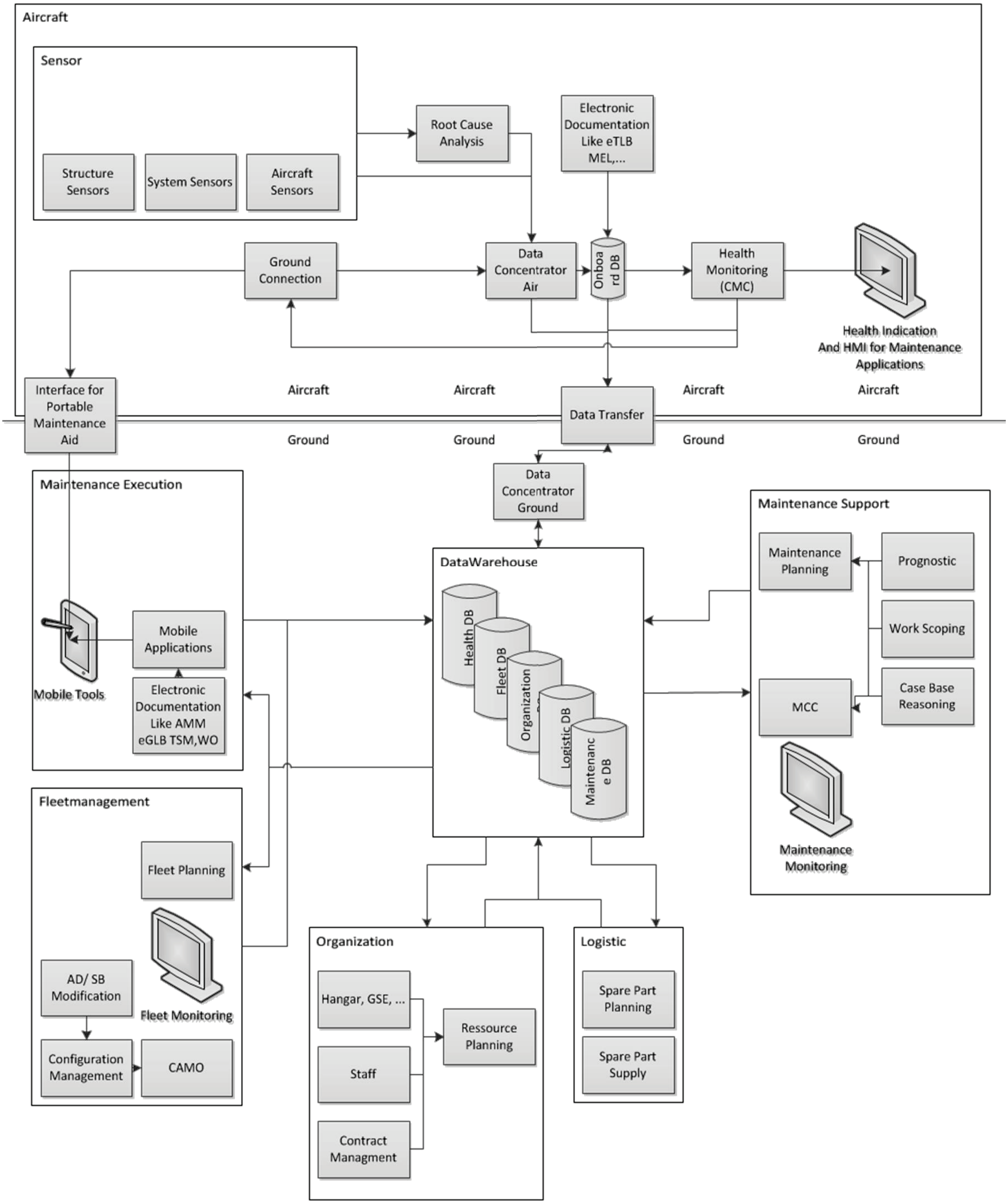


Figure 4. An overall generic IVHM Architecture [4]

Figure 5 illustrates a generic IVHM application and its integration into aircraft support systems. As it is seen, the system is mainly divided by a ground based support and onboard server which they have interfaces to transfer data and messages using different data handling methods. Ground based elements such as logistics and fleet management are performing tasks to firstly avoid and secondly reduce the Aircraft On Ground cases (AOG).

It is good to mention that IVHM architecture may differ for each of stakeholder. The architecture at the figure 4 is defined without taking into account any of the stakeholders.

It is good to mention that there is a significant difference between civil and military aircraft structural health monitoring concept. In contrast to a commercial aircraft, missions and, thus, loads change extremely. It can require specific sensor networks for different aircraft types.

Signals from sensors are transmitted and stored in the data warehouse for the future analysis. The CMC collects diagnostics messages and reasons out the root causes.

Direct action IVHM functions provide information that is used during the flight. These are safety critical on-board functions, certificated DO-178B Level A or B. Information related to the aircraft health can be sent to the ground via airband radio or satellite for planning and preparing maintenance actions if necessary. Flight crew gets notification warnings and alerts. For unmanned vehicles, this option is not needed.

The data that has no influence on aircraft safety is stored on board and periodically downloaded to centralized ground data base for further analysis and maintenance decisions support.

Handling large amounts of data can require large amounts of processing capability and software components that also enable the real-time data transmission. (Swearingen, et al., 2007) Data exchange should be secure. Each stakeholder should have an access to a very specific subset of all data that requires development of the software enabling this function.

Providing in-flight warnings to the crew is one of the reasons to have an IVHM system for on-board diagnostic functions. IVHM system must provide health estimation for system/control reconfiguration, this need is caused by critical and safety requirements.

One of the important requirements to IVHM system is ability to support aircraft condition based maintenance decisions. (Gorinevsky, et al., 2010) This IVHM function is responsible for a remaining useful life prediction of vehicle components, subsystems and systems. Creating historical data base, trends monitoring can play an important role in this process. Exact RUL prediction enables maintenance, spare parts and resource planning and avoiding of unscheduled maintenance activities and delays caused by them. Thus, this aspect has a significant influence on IVHM economic efficiency [7], [9].

3. CASE STUDY

Bringing such an architecture to reality needs a lot of different technical developments. Nevertheless, it is demanded to plan and develop such an architecture technically and systematically. Thus, in this research a faulty system is almost identified according to a health prognostic model for health state detection of a device in one of the tests that has been done on a RAM Air inlet door [the blue arrows in the figure 5 demonstrates the location of these inlet flaps in aircrafts].

Due to a failure event, some investigations took place on the test data records tapped using ARINC until the latest successful operation via different methodologies on an Airbus A320 pack of Ram Air Inlet Door positioner which failed performing further operations.

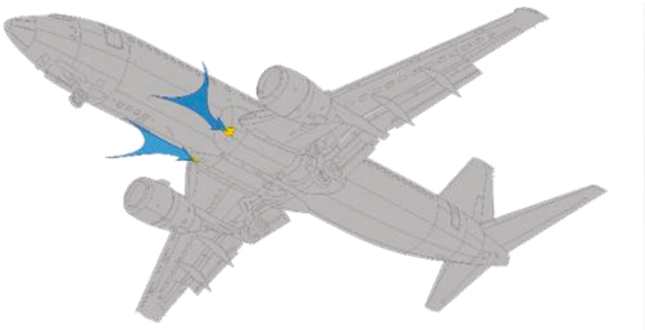


Figure 5. Ram Air Inlet Door positioning on a large aircraft [3]

The systematical development is demonstrated on the Generic Architecture and the Technical side has demonstrated its successful recognition in identification of threads during the ongoing trend during the tests.

These trends are indicating the threads and will be filled in a risk matrix according to detection of the state based on condition and health status according to Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes (CS 25.1309).

The philosophy of this calculations is simple to first understand “where are we now” (Figure 6) and second how much more time do we have to fail.

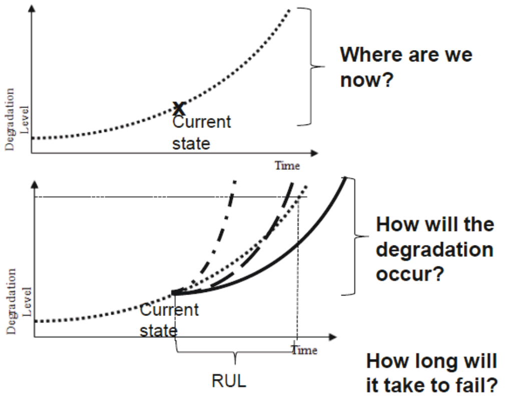


Figure 6. State detection phase and estimations. [15]

Therefore, we need:

1) a RUL (Remaining Useful Life) estimation either physically based to detail physics on component degradation, in cases where we have formulas known.

2) data driven based simulation such as the Monte Carlo simulation where we have the sample data analyzed from the failure progression.

In order to maintain a scientific process on data, we need to explore this data, and make a clean data set from the raw data collected. After that we can run these data through models and algorithms and visualize the result and then make a decision for prognostic. This path must be evaluated with reality in order to ensure a safe circle.

State detection and ruling is the first method used in combination with calculations for the failure prediction within degradation and estimate an accuracy within some time frames, in the same way explained. Therefore, next step is to minimize the errors via regression. After completion of this circle, the IVHM algorithms and models are supposed to be identified and evaluated.

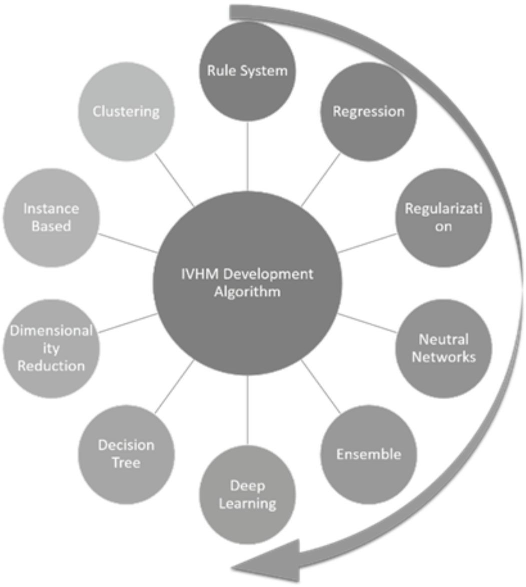


Figure 7. Completion method (Development outlook)

This simulation has used monte Carlo methods for failure prediction per data and showed that different tests have different behaviors according to the health state.

4. RESULTS /CONCLUSION

These data were handled and cleared using a measurement systems tapping the data from the aircraft via ARINC on ATA 31st chapter. The data was evaluated on 20 runs upon different algorithms. However, the final method used Monte Carlo simulation based on two different theories of variance and uncertainty.

Monte Carlo as known, is a repeated random sampling to obtain numerical results. The essential idea is using the randomness to solve problems. However, if we implement probability distribution and variance in uncertainty. The result is expectable. By contrast, Monte Carlo sample from a probability distribution for each variable to produce hundred outcomes is not useful for such a case. Therefore, the related theory is simple for Relative Uncertainties [15]:

$(A \pm \varepsilon A) \times (B \pm \varepsilon B) = (A \times B) \pm (\varepsilon A + \varepsilon B)$

Continues variance is also calculated according to this formula:

$$\mathrm{Var}(X) = \sigma^2 = \int (x-\mu)^2 \, f(x)\, dx = \int x^2 \, f(x)\, dx - \mu^2$$

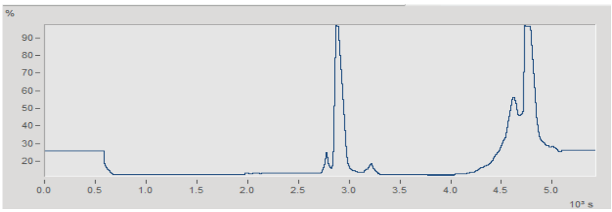


Figure 8. Normal Profile

Now looking at profiles of the operations, the normal operation of this motor data is shown in figure 8. There are two huge peaks in 2.9k and 4.9k seconds. By contrasts in the malfunction profile [figure 9] a huge amount of delivered data are not identical and not healthy. But how to detect such a point, before occurrence.

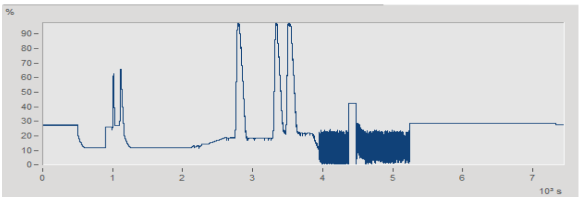


Figure 9. Malfunction Profile

After processing and analyzed these data using the monte Carlo uncertainty simulation, we can see the detection root and trend of failure here:

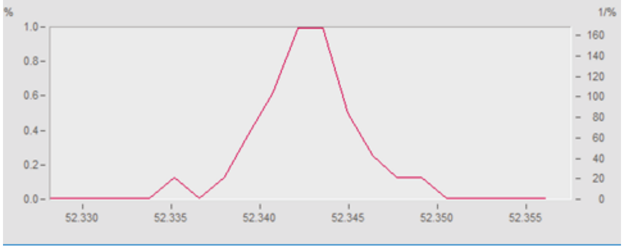


Figure. 10

In the figure 10 you can see how clear the curve is while the motor is completely healthy and everything is operating very well. Besides that, figure 11 also shows some states of difference in about 25 percent changes in the same time interval which is substantial and well might be indicating of a failure.

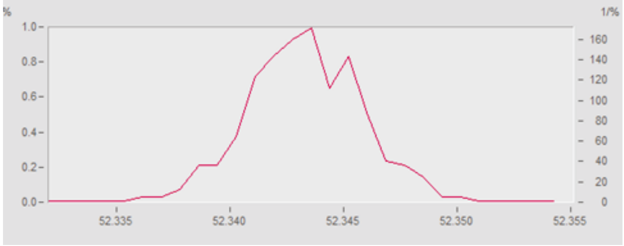


Figure.11

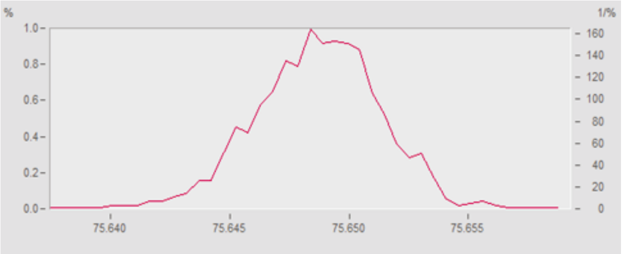


Figure. 12

In figure 12, the average data range is shifted from 50 to 70, while in figure 13, this shift is reaching almost 96 which is the data analyzed from the failure event, plus having a sharp edge on the side.

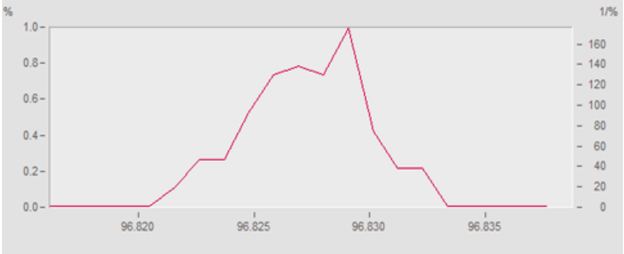


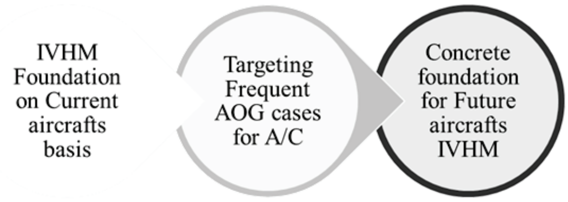
Figure. 13

These substantial shifts during the trend of the test completely was visible in the processed clean data during 4-day period. For a better understanding a normal operation is shown in the figure 8, and the failed system operation profile completely can be seen on figure 13.

Therefore, these graphs (8-13) are in a timely manner and this indicates a prediction for the failure.

5. VISION

IVHM is a very complicated topic and development of such topics are very dependent to the plan and vision. the future development steps are planned to gain roots and systems and failures completely identified and establish a foundation from current aircrafts. Secondly targeting frequent AOG cases on different Aircrafts to make a concrete basis for future developments, and then use this foundation for establishing a new basis for operation and maintenance of future aircrafts.



6. REFERENCES

[1]. NASA Integrated vehicle health management: final technical report, Robert W. Mah, Ph.D. N.p., 2016. Web. 11 Nov. 2009.

[2]. Rajamani, R., Saxena, A., Kramer, F., Augustin, M., Schroeder, J. B., Goebel, K., .. Lin, W. (2013). Developing IVHM Requirements for Aerospace Systems. SAE International.

[3]. Identification and Evaluation of the Potentials of Prognostics and Health Management in Future Civil Aircraft (n.d.): n. pag. Web

[4]. Torhorst, S. (2014). Identification and evaluation of the potentials of Prognostics and Health Management in future civil aircraft. München. Lehrstuhl für Luftfahrtsystem TU München.

[5]. Image retrieved in 09.2016 from: http://www.avsoft.com/scrm/courses/B734-C16/AircraftGeneral/AircraftGeneral-29.jpg

[6]. Meyer, H. (2016). Development of a generic Integrated Vehicle Health Architecture, DLR LY

[7]. Odinets, T. (2016). IVHM Generic Architecture. Hamburg. TUHH.

[8]. Civil Aviation Safety Authority. (20. August 2013). Civil Aviation Safety Authority (CASA). Von AWB 00-022 Issue 1 - Certification Maintenance Requirement and Airworthiness Limitations Terminology Explained: https://www.casa.gov.au/files/awb-00-022-issue-1-certification-maintenance-requirement-and-airworthiness-limitations

[9]. Gorinevsky, D., Smotrich, A., Mah, R., Srivastava, A., Keller, K., & Felke, T. (2010). Open Architecture for Integrated Vehicle Health Management. AIAA Infotech@Aerospace. Atlanta, Georgia: AIAA.

[10].Kerczewski, R. (2009). Off-Board Communications for Vehicle Health Management. Bangkok, Thailand: ICAO.

[11].Rajamani, R., Saxena, A., Kramer, F., Augustin, M., Schroeder, J. B., Goebel, K., . . . Lin, W. (2013). Developing IVHM Requirements for Aerospace Systems. SAE International.

[12].S. Torhorst, N. B. (kein Datum). Identification and evaluation of the potentials of Prognostics and Health Management in future civil aircraft.

[13].Swearingen, K., Majkowski, W., Bruggeman, B., Gilbertson, D., Dunsdon, J., & Sykes, B. (2007). An Open System Architecture for Condition Based Maintenance Overview. 2007 IEEE Aerospace Conference. Big Sky, MT: IEEE.

[14].Fundamentals of Prognostics 10 April 2013 Newbury, UK Dr. Fatih Camci

[15]. Baghchehsara, A., Development of Integrated Vehicle Health Management System for Aircraft With a focus on Architecture, Technology and Operation, DLR IB-328-2016-15