Scenarios Analysis and Development Strategy for Aircraft Integrated Health Management (AIHM)

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***Abstract*—Aircraft Integrated Health Management (AIHM) is one of typical engineering application of the Integrated Vehicle Health Management (IVHM) technology. It is well accepted that business success is the only and ultimate aim of commercial aircraft and right requirements of the stakeholders are key factors, so it is necessary to generate the right targets and scenarios for AIHM in order to clarify the right stakeholders and establish right requirements and establish unambiguous AIHM functions for the commercial aircraft. In this paper, the author provides the scenarios analysis of AIHM for commercial aircraft on the integrator's/OEM's point of view gives a "Centralized-Distributed-Integration–Verification & Optimization" development process according to the System Engineering process through the AIHM life cycles.**

Keywords- AIHM, PHM, aircraft, maintenance, scenario analysis, integration

I. INTRODUCTION

As the IVHM Steering Group of SAE defined, IVHM is "the unified capability of a system of systems to assess current or future state of member system health and integrate that picture of system health within a framework of available resources and operational demand."[1] This definition clearly emphasized IVHM is a result of highly integration: On the one hand, IVHM integrates the member systems' Prognostics and Health Management (PHM) capability, to build the condition monitoring and prognostics capability at the "system of systems" level; on the other hand, IVHM highly integrates system health within available resources and operational demand, to achieve the integrated management capability aircraft health and logistic resources. Meanwhile, this definition also indicated that the IVHM scopes all the components and whole life circle of the vehicle. Large commercial aircraft is an extreme complex vehicle with dedicated systems and enormous components and parts. To develop and implement IVHM for large commercial aircraft shall take fully consideration for the particularity of large commercial aircraft operation environment and logistics support under the premise of satisfying the general characteristics of AIHM, airworthiness and customer expectation. This paper reveals the general targets, scenarios, suggested functions and integration issues for AIHM implementation to realize its engineering application and business value according to the market requirements.

II. TARGETS OF AIHM

The targets of commercial aircraft AIHM capability is to provide unambiguous actionable information to reduce operation and maintenance costs without any adverse impact on existing safety levels. Specifically, from the perspective of the application scenario, targets of commercial aircraft AIHM includes the following aspects:

1) Enhance flight safety by health information: By monitoring the aircraft condition , to detect or even predict possible flight safety risks in a timely manner, and transfer the information to flight cockpit in a proper way so that the crew can make timely and correct response measures.

2) Optimize the process of aircraft operation and maintenance support, and improve operation efficiency: Based on information from aircraft condition monitoring and fault diagnosis and prognosis, deep integration between aircraft health information, ground operation support system and maintenance support resources, the real time aircraft health can be informed. Then the seamless interconnection of activities/elements such as failure detection, condition monitoring, trend prediction, operational decision-making, maintenance task, trouble shooting, spare parts/material supply, training support, etc. will be implemented to achieve the following purpose:

a) Operation decision support, to determine operation schedule according to the aircraft health condition so as to improve the dispatch reliability and minimize the loss of aircraft unplanned stop on ground.

b) Maintenance decision support, to reasonably arrange the maintenance work according to the aircraft health condition, plan the maintenance work and prepare personnel, material before the aircraft landing.

3) Reduce and simplify aircraft maintenance tasks and reduce maintenance costs:

a) Realize automatic and fast fault isolation with fault diagnosis model built with system condition parameters and fleet fault and maintenance historical data, thus greatly improve fault diagnosis efficiency, shorten maintenance time and reduce maintenance cost.

b) Reduce the number of preventive and scheduled maintenance tasks, or to simplify planned maintenance

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work and avoid dis-assembly for inspection purposes alone with condition monitoring and life prediction techniques, thus to greatly reduce the workload of preventive maintenance or inspection.

c) Predict potential problems ahead of time with component life prediction technique, then take effective maintenance measures before major failures occur, so as to reduce the scale and cost of unscheduled maintenance work, and reduce aircraft material consumption and spare pool.

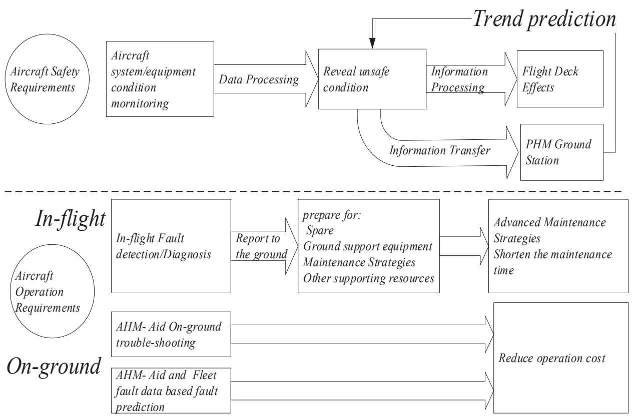

Figure 1. Targets of AIHM

III. SCENARIOS AND STAKEHOLDERS OF AIHM

A. Application Scenarios of AIHM

As stated above, AIHM generates benefits whenever the aircraft is in air or on ground. As depicted in figure 2, how AIHM work during operation can be analysis by the following scenarios:

Scenario 1: Aircraft on the ground - pre-flight - operation control department route planning. The aircraft IAHM system communicates with the airline operation control department. The operation and control department decide flight mission according to the current aircraft health condition.

Scenario 2: Aircraft on the ground - before flight - aircraft inspection. Before the flight, the maintenance crew use onboard health management system to conduct pre-flight inspections of the aircraft, review the latest airborne fault messages, and initiate various IBIT to confirm that the aircraft system condition. At the same time, the maintenance control engineer performs corresponding preparations and predetermines the items of aircraft needs to be paid attention to with historical information and the characteristics of the current mission, as well as the relevant information of other aircraft in the fleet.

Scenario 3: The aircraft is on the ground - before the flight - the flight crew confirms the aircraft condition. When engines start, the onboard health management system provides condition monitoring for the crew and the ground. After the crew boarding, the crew can view the aircraft's health status and health parameters before flight.

Scenario 4: The aircraft is in air - providing aircraft condition monitoring information. After the aircraft is powered on, onboard condition monitoring data collection will be activated immediately, monitoring parameters will be acquired and processed. The condition monitoring parameters acquired by the onboard system and provide reasonable crew display and flight deck effects. During the flight process, the onboard health management system with built-in fault diagnosis capability generates fault messages and processes and stores the data collected from the aircraft at the same time.

Scenario 5: The aircraft is in air - aircraft condition monitoring information and ground communication. Through the air ground data communication, the monitoring parameters, fault message and service information message that need to be implemented and transmitted to the ground are sent to the ground health management system. After obtaining the data from the air, the ground health management system uses its built-in fault diagnosis/prediction model to conduct further fault diagnosis and prediction based on multi-data fusion and form corresponding messages.

Scenario 6: The aircraft is in air-ground repair center to process aircraft condition information. During the flight, the ground maintenance control engineer uses the ground health management system to monitor the aircraft. If a fault was found, the health management system assists the maintenance control engineer to determine whether it is necessary to take measures such as turn back, landing and continuing flight, and timely transmitting important information to the operation control department and the flight engineer at the flight destination/landing site. The corresponding maintenance strategy, preliminary work and maintenance staff preparation can be made.

Scene 7: Aircraft on the ground - after landing / after flight - onboard health management system assist maintenance. After the aircraft landed, the maintenance engineer downloads and retrieves all the condition monitoring parameters, maintenance message data from the onboard health management system through special interfaces and tools. During the maintenance troubleshooting process, the health management system provides full interface support, operational support, information support, and policy support for troubleshooting. In the maintenance process, the onboard health management system also provides a unified data/software loading interface for maintenance personnel. The post-flight health data is used to analysis each system and the results feedback to the maintenance control engineer. The maintenance control engineer reviews the results for maintenance decisions. If the maintenance engineer unresolved the problems, the problem is fed back to the maintenance control engineer. The maintenance control engineer, through consultation with the maintenance expert and data analysis results to make decision.

Scenario 8: Aircraft on the ground - safety supervision and accident investigation assistance[2]. Operators and Original Equipment Manufacturer and (OEM) can use the powerful data collection, integration, analysis and processing capabilities of the aircraft integrated health management system to obtain operational condition monitoring data, collect and analyze aircraft condition monitoring/repair historical data, conduct aircraft safety monitoring and accident investigation.

Scenario 9: Aircraft Life Cycle Operations - Customization. Maintenance engineers at airlines and OEM customer service departments can use the customized tools provided by the ground health management system to conduct in-depth customized development of aircraft integrated health management. These developments include but are not limited to:

a) Customized parameters and message information that the aircraft transmits in real time to the ground in the air;

b) Customized fault/diagnostic logic, algorithms or models in the ground health management system by the user or OEM customer service department to optimize the diagnostic/predictive capabilities of the system;

c) Customized data interaction path with the airline's existing information systems such as operation control, maintenance and spares.

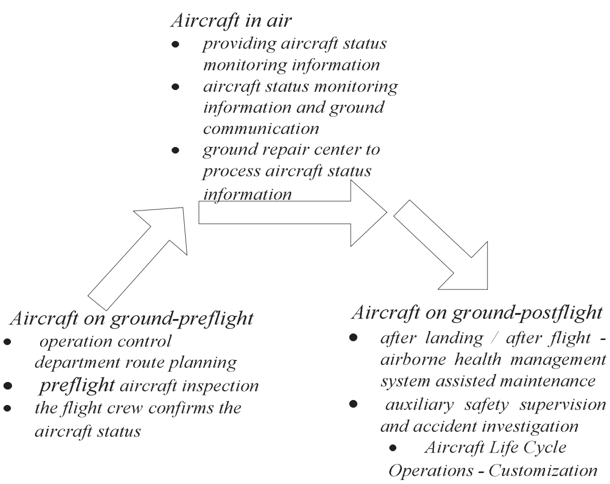

Figure 2. Scenarios of AIHM

B. Stakeholders of AIHM

From the AIHM scenario analysis, typical stakeholders for commercial aircraft AIHM can be sorted out as below:

1) Flight crew
2) Line maintenance personnel
3) Maintenance control engineer
4) Operation and control department
5) Other departments of the operator
6) Maintenance Repair and Overhaul (MRO)

IV. FUNCTIONS AND ELEMENTS OF AIHM

Based on the above scenarios and stakeholders analysis and characteristics of the AIHM system, the basic functions of commercial aircraft AIHM can be implemented through the aircraft and the ground-based support system, figure 3 gives the suggested elements and functions of AIHM:

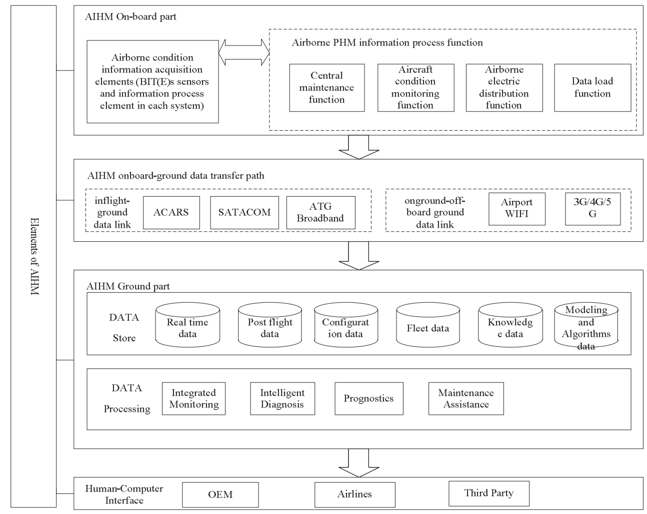

Figure 3. Functions and elements of AIHM

A. AIHM Airborne Part

The AIHM airborne part is consist of two parts: condition information acquisition and signal process elements and airborne information process system.

1) Airborne Condition Information Acquisition and Signal Process Element

The original condition information of system or component will be captured by BITs/sensors, then processed initially and calculated by the information process elements distributed in each system, and then these processed condition parameters will be transmitted to the airborne PHM information process system via Bus. Some member systems themselves do not have the capability to process their condition information, then their condition information collected by BITs/sensors will transmitted directly to the airborne PHM information processing system.[3]

2) Airborne PHM Information Process System

Airborne PHM Information Process System can be regarded as extended and ungraded traditional Airborne/Central Maintenance System. It has the capability of collecting and storing data from systems and even structure. Airborne PHM Information Process System comprehensively process the information, perform the airborne failure detection, condition monitoring, fault isolation and trend prediction and provides the processing results for FDE or generates the maintenance reports, and the aircraft information query and maintenance interface for maintenance personnel, and deliver the information to the ground station as required.

B. AIHM Ground Part

The ground section system of the commercial aircraft AIHM focus on the following functional applications:

- Integrated monitoring
- Intelligent diagnosis
- Diagnostic methods.

- Prognostics
- Maintenance assistance

The AIHM ground part is a comprehensive software system platform for synthetically collecting, storing and processing aircraft fleet condition monitoring data. Condition monitoring data is obtained by non-destructive testing on ground and other external tests, historical maintenance data. And through the deep integration of these data to enable more advanced troubleshooting, trend forecasting, maintenance decisions, and operational decision support. AIHM integrates and consolidate aircraft health information with the ground operation support system and maintenance support resources, and uses information technology to achieve seamless interconnection of failure detection, condition monitoring, trend forecasting, operation decision-making, maintenance and troubleshooting, and material/spares support, training support and other activities or elements so as to support the commercial aircraft to achieve Enhanced Condition-Based Maintenance (CBM +).[4]

As an information platform, the ground part of AIHM adopts the architectural design discipline, which developed and designed based on cloud computing and big data technology architecture and uses distributed storage and distributed computing technology to provide complete technical service support for various business applications. The platform will be designed as a software tool-set with high security, high compatibility and scalability for different application scenarios and business functions. The platform will support applications in different modes and scenarios such as mobile terminals and PC terminals.

C. *AIHM Data Onboard To Ground Transfer Path*

Commercial aircraft AIHM data onboard to ground transfer path can be realized by two ways. When aircraft is in flight, ACARS, SATACOM, ATG Broadband can be used for data transfer, when aircraft is on the ground, airport WIFI 3G/4G/, even 5G as technology advanced, are option for data transfer depending on the facility and cost consideration of operators.

V. STRATEGY FOR AIHM DEVELOPMENT

The commercial aircraft AIHM is a loose system featured with a "trans-boundary" character, which spatially "Airborne-Ground" and throughout the whole life cycle of aircraft. Among them, the airborne section integrates the on-board condition monitoring, failure detection and fault isolation capability through a series of advanced sensors and the application of self-test function in the aircraft. The ground section realizes the information processing, failure prediction, maintenance and operational decision-making capabilities through the establishment of an advanced information processing system. At the same time, "integrated health management" must also establish an efficient communication path between air and ground information. As a "system", because of the distributed and cross composition of AIHM, it needs to be highly integrated with these distributed elements by function. So that, development of AIHM will be a "Centralized-Distributed-Integration–Verification & Optimization" process, all these developments are suggested to follow the System Engineering Process. Figure 4 gives the IVHM life cycle phases and correlated design strategics[1].

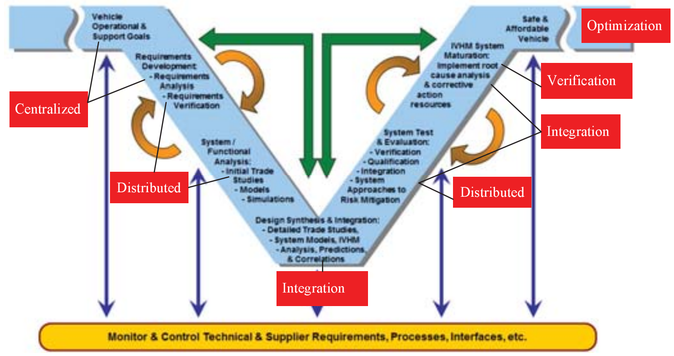

Figure 4. Strategics for AIHM development during life cycle phases

A. *Centralized Definition*

In the pre-development stage, especially in the scheme definition and preliminary design stage, the AIHM must be considered as a whole. The two sections of the airborne and the ground should be coordinated; capture the requirements of AIHM according to the market objectives of the aircraft, the overall design goals, and the safety, testability, maintainability and full-life cycle commercial objectives; determine the overall goals and scheme of AIHM. On the basis of this, perform deep learning of the technical scheme and constraints of AIHM system, coordinate to generate and define the function layout and performance requirements, establish a unified R & D top-level specification, unified interface protocol, design guidelines, economic and technical indicators and ensure R & D work in a unified and coordinated way.

B. *Distributed Design*

The AIHM is a distributed "system" ,its on-board section includes avionics software and hardware systems for information integrated processing， signal acquisition devices and signal processing units distributed within each system (or even structure), various airborne equipment and ground support equipment that used for Air-Ground data exchange as well as a vast ground information system. This series of work needs to be carefully broken down into the specific responsible departments and units, the onboard system design department / supplier engineers, structural engineers, customer service engineers, information technology (IT) engineers, etc., independently and collaboratively with each other to complete the design of each unit. In a United-Distributed process, there are significant requirements need to be decomposed and co-ordinated, as well as the capture and validation of new constraints and derived requirements that require to be fully converted aircraft safety, operationalbility, testability and maintainability to the specific design requirements of the avionics and the member system, deeply coordinated with the architecture and performance requirements of system equipment / structure.

C. *Integration*

The AIHM's integration work is broadly divided into three major aspects: the integration of the AIHM system itself, the integration of the AIHM with the aircraft, and the integration of the AIHM with the aircraft operation support system.

1) Integration of health management function from onboard systems

Integration of AIHM system itself includes two aspects: hardware and software interface integration and condition information integration.

a) Hardware and software interface integration, hardware and software interface relying mainly on the avionics and the member systems and air-ground data communications designed to ensure that the monitoring signals of airborne components at all level levels are able to achieve process and deliver function as predetermined requirements.

b) The integration of condition information, the purpose of which is to realize the full integration of the test monitoring information at different units and different product levels, and realize the mapping between signals and faults through a series of diagnosis/prognosis models. While the integration of information requires a dedicated specialty that can coordinate the all aircraft design specialties, to take responsibility for the development and optimization of related models. The aircraft IVHM capability itself is the result of comprehensive integration of the PHM of each member system. The commercial aircraft is suggested to use the ISO13374 framework to conduct AIHM system integration. ISO13374 regulates information interface and process between standardized condition monitoring and diagnosis processing, which can solve the problem of information transfer from any underlying unit to the upper system in the development of PHM system, and provides a standard guide for realizing this capability integration[5]. This framework includes the layout of the sensor, the design of the information processing unit, and the diagnostic / prognostic model development, so that each sub-unit of the PHM design exist as a higher-level PHM sub-modules, step by step up, ultimately, the aircraft-level integration will be completed.

2) Integration of the aircraft level AIHM function with Aircraft

The AIHM is part of the aircraft and due to the large number of its constituent units that are distributed and integrated into the aircraft's system / structure, the integration problem between these units and its sustenance must be addressed; in addition, the onboard PHM Information processing system itself is also part of avionics system, which must be involved in the work of the avionics system integration.

For aircraft systems, the key thing is the use of advanced BITs and sensors. In the process of system-level PHM development, it is necessary to optimize the layout of the BIT and the sensor while optimizing the architecture of the system. The selection and layout of the BIT and the sensor are integrated into the system scheme for trade-offs, so as to achieve best match between condition signal acquisition element and the unit under test, and enables optimal condition monitoring with fewest sensors and system resource costs.

Structure PHM technology development is an important direction of commercial aircraft PHM in the future, which is also shall be taken into consideration in the development of commercial aircraft IVHM. Under the framework of ISO13374, the AIHM system provides an open AIHM platform. Therefore, the structure PHM also needs to meet the standards of OSA-CBM and provide the AIHM system with a compliant structure condition monitoring parameter signal, and the corresponding structure fault diagnosis / prognosis models, the structure PHM can be incorporated into the aircraft level AIHM. However, due to the particularity of the structure PHM technology and the condition signal extraction unit arranged on the structure, the structure design and integration shall be performed by the structure engineers, to provide accurate and reliable monitoring signals. The AIHM system for the commercial aircraft will reserves sufficient signal bandwidth and interfaces for the structural PHM in order to meet the structural PHM's development requirements in range and scale.

The integration of airborne PHM information processing system, airborne PHM information communication and AIHM air-ground data link belongs to the aircraft avionics system integration. Airborne PHM information processing system major in on-board maintenance system, some may also involve the avionics core system, indication and recording system and cockpit integration issues. In addition, the integration of AIHM air-ground data link mainly involves communication system. The architecture and integration of avionics systems play a leading role in this part of the work. The requirements of AIHM need to be linked to on-board maintenance system, indication and recording system, communication system and avionics core systems. AIHM engineers are directly involved in the scheme trade-offs of these systems.

3) Integration between AIHM and Aircraft Operation Support System

For better realize the value of commercial aircraft AIHM throughout the aircraft life cycle, it is necessary to consider the how to establish deeply integration between the AIHM and the aircraft operations support system. In the development of the AIHM ground information system, the data interface and integration issues with the various application systems of the OEM, operators, authority and other MROs shall be fully considered and proactively planned when the development start, also the AIHM ground information system architecture and scheme design shall make a comprehensive arrangement, optimal solution for the interfaces and integration issues.

D. *Verification & Optimization*

During the development of AIHM, thorough verification methods shall be employed to ensure that the design of the aircraft at all levels of AIHM meet the expected design requirements. On the one hand, it is necessary to fully verify the rationality of the signal point layout, continually optimize the layout to achieve the maximum monitoring coverage with the fewest sensors, and secondly, for the underlying element of the unit/ equipment/ components, it is necessary to fully verify the validity of the monitored parameters, and the compatible matching between the means of detection and monitoring and system functional requirements; the third aspect, interfaces and information channels scattered at all levels of the whole aircraft and the hardware and software systems of onboard health management shall be fully verified to ensure that the monitoring signals can be transferred and processed accurately and timely and the models can operate as expected. Fourthly, all the diagnostic prognostic models must be fully verified to ensure that they can realize effective fault detection, diagnosis and prognosis according to the collected signals. Finally, as a large-scale "air-ground" system, comprehensive cross tests must be completed to ensure the exchange of information between air-ground to meet the expected target and the functions and performance of ground system meet the expected application goals.

VI. CONCLUSION

This paper research the development and implementation of AIHM for large commercial aircraft on the aircraft integrator's/OEM's point of view. Important aspects of AIHM, includes targets, application scenarios are dedicated described the right targets and scenarios.after above question answered, suggested function and elements of AIHM are given. During System Engineering of AIHM development, a "Centralized-Distributed-Integration–Verification & Optimization" process is given and co-related consideration is presented for successful implement of AIHM.

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