Study on the Influence of PHM Technology on Aircraft Maintenance Support Mode

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Abstract—**Maintenance efficiency is the key to modern high-tech warfare. As the basis of condition-based maintenance, PHM(prognostics and health management) technology greatly improves maintenance efficiency by enabling the system with prediction power. To provide theoretical foundation for new equipment maintenance reform, the impact of PHM technology on maintenance support mode was analyzed from the member-level and the regional-level on aspects of maintenance support system, maintenance support resources, maintenance analysis and decision-making process. It is hoped that the results of the proposed study may contribute to the current reform of support modes for aircraft maintenance.**

Keywords-PHM; aircraft; maintenance; support

I. INTRODUCTION

In July 2000, PHM technology was included in the US Department of Defense's "Military Key Technologies" report. Typical applications for PHM include the US SH-60 helicopter usage and monitoring systems (HUMS), aerospace integrated vehicle health management (IVHM), Boeing's air condition health management (AHM) system, aircraft condition monitoring system (ACMS), engine monitoring system (EMS), US Navy's integrated condition assessment system (ICAS) and JSF PHM system. The JSF (joint strike fighter) project of US military was a demonstration of PHM technology as an advanced approach to achieving fundamental changes in maintenance mode and autonomic logistics [1]. It represents changes from traditional sensor-based diagnostics to intelligent system-based predictions [2]. PHM technology includes two folds of meanings: 1) Fault prediction, i.e., predicting the state of a component or system to determine the length of useful lifetime; 2) Health management, that is, to make appropriate maintenance decisions based on diagnosis, prediction information, available resources, and usage requirements [3].

PHM further enhances the ability to monitor health status and build-in test (BIT) of equipment. The transition from condition monitoring to health management is implemented by PHM, which uses fault prediction and health management systems to identify and manage failure occurrences, planned maintenance and decision support to reduce usage and maintenance costs. The focus of aircraft maintenance support has changed from mechanical repair to maintenance decisions based on information acquisition, processing and transmission. Traditional maintenance cannot meet the requirements of equipment support for modern warfare. There is still a gap between what PHM can do and how we actually are able to do it. To fulfill this gap, a detailed and comprehensive analysis of PHM technology's actual influence on various aspects of maintenance is needed.

II. TYPICAL ARCHITECTURE AND FUNCTION OF PHM

A. Architecture Hierarchy

The typical architecture of PHM is divided into three levels: member level, area level and platform level, taking that of the airborne PHM system of the F-35 aircraft as an example. The bottom layer is the sensor or build-in test equipment distributed in the sub-system components of the aircraft. The middle layer is the area reasoner. The top layer is the aircraft platform manager. From the area reasoner, the information is then passed up to a top level Air Vehicle Reasoner where subsystem information is then fused to give knowledge about the health of the entire air vehicle[4-5].The typical structure of the aircraft airborne PHM system is shown in Fig. 1.

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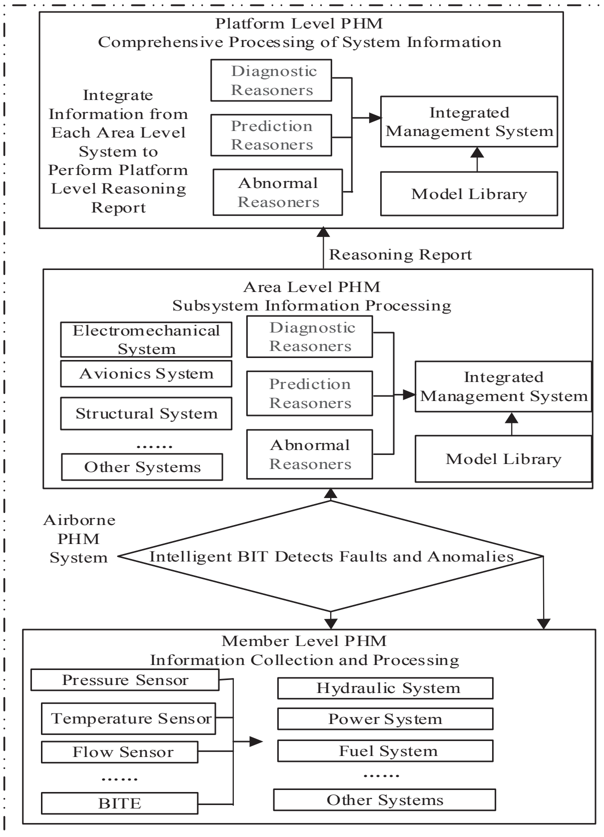

Figure 1. The architecture of the PHM system

B. Member Level PHM System

The member level PHM system can perform data fusion through acquired data and information, and realize subsystem/component abnormality detection, status monitoring alarm output, and enhanced fault diagnosis [6]. The bottom layer of the member-level PHM are separate units consisting of sensors and BITE. These separate units send the status information parameters of the detected object to the member level PHM system manager for signal and data processing. For example, for hydraulic systems, temperature sensors, vibration sensors, pressure sensors and flow sensors are required to monitor the operating status of the hydraulic pump. The temperature sensors are used to monitor the temperature and temperature change rate. If the temperature rises sharply in a short time, it often represents abnormal wear inside the hydraulic pump. Vibration sensors and intelligent algorithms can also diagnose the vibration information of the shell caused by abnormal wear. The pressure and flow sensors monitor the output pressure and flow of the hydraulic pump. When there is a leak or a slowly changing fault inside the hydraulic pump, its performance is degraded and the outlet pressure and flow rate are reduced.

C. Area Level PHM System

Depending on the complexity of the equipment and the requirements of object monitoring, the same equipment can be divided into multiple area PHM systems. For aircraft systems, it can be divided into typical area PHM systems such as electromechanical system, avionics system, engine system and aircraft structures system.For example, sensor data and information from different member-level systems, such as environmental control systems, landing gear, fuel systems, air-conditioning systems, oxygen systems, hydraulic systems, etc., are first sent to the regional-level PHM system of the electromechanical system for pre-processing. Then, the feature signal is extracted and sent to the model library for data fusion of the feature layer, and the operation status of the device is determined and predicted to obtain a more reliable health status of the subsystem. If there is a fault, the fault is confirmed and isolated to the line replaceable unit.

D. Platform Level PHM System

The platform level PHM confirms and isolates the fault by correlating the fault information of all systems, and finally forms the health assessment report of the whole aircraft and the knowledge information for the pilot, and transmits it to the ground PHM and the autonomous logistics information system (ALIS). Maintenance personnel can use ALIS based on health assessment report to adjust usage plans, implement technical state management, update aircraft status records, generate maintenance work items, and analyze the health of the entire fleet.

III. Influence of PHM Technology on Advanced Aircraft Maintenance Support Mode

The purpose of designing a PHM system for an aircraft is not to eliminate the faults, but to predict them when the faults will occur or activate a simple maintenance item in the event of an unexpected fault. The benefits of adopting PHM technology are to help reduce or eliminate the need for test equipment, tools and other diagnostic equipment, and to delay the maintenance of certain unimportant areas to the appropriate time, thereby reducing the need to deploy spare parts on the field during wartime.

According to the hierarchical architecture of the airborne PHM system, the corresponding level of PHM system also shows different capabilities. The member level PHM has the on-board intelligent BIT diagnosis, alarm and auxiliary ground comprehensive diagnostic capability; the area level PHM shows that some systems have predictive and health management capabilities; the platform level PHM has the whole machine PHM and ground PHM platform, with complete machine prediction, health management and maintenance analysis and planning capabilities.

A. Typical Maintenance Support Activity Process Based on PHM

In the routine maintenance inspection and pre-flight inspection on the ground, the airborne PHM can be used to complete the aircraft health assessment report to ALIS, which will arrange the maintenance plan based on the assessment results. If a system has an abnormal alarm event, it will be isolated by the regional PHM. If it cannot be isolated to a single LRU, it will be re-detected by the ground test equipment. If the fault is false or faulty, the maintenance activity will be arranged according to the result. A typical maintenance support activity process based on PHM is shown in the Fig. 2.

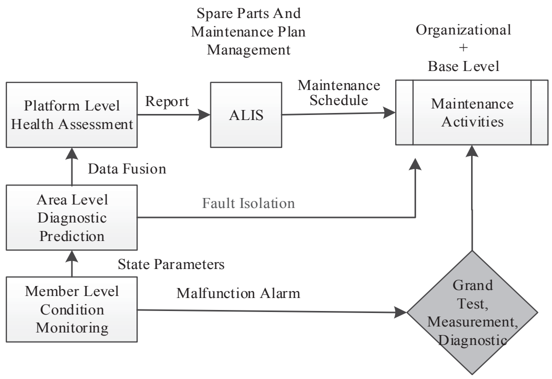

Figure2. Typical maintenance support activity process based on PHM

Considering the current development level of PHM technology and the specific conditions of the selected system, this paper mainly selects the typical objects of the aircraft member level PHM and area level PHM. Assuming that the aircraft has member level PHM systems and area level PHM systems, what impact will it have on the maintenance process, maintenance support system, maintenance support resources, etc., the impact of PHM technology on the maintenance support model will be studied.

B. Analysis of the Impact of Member Level PHM on Maintenance Support Mode

The member level PHM has state monitoring and intelligent BIT alarm capabilities. For example, the aircraft electromechanical PHM system is a comprehensive system for centralized monitoring and display of distributed monitoring. The system uses technologies such as electronic technology, sensing technology and fault diagnosis. The system has faults detection, alarm, and diagnostic capabilities. The following is an example of the monitoring and maintenance activities of the engine fire alarm subsystem to analyze the impact of the member-level PHM on the maintenance support mode. The alarm and maintenance activities of the fire alarm system are shown in Fig. 3.

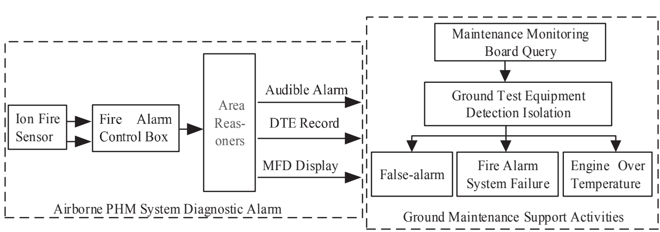

Figure3. The alarm and maintenance activities of the fire alarm system

The impact of member level PHM on aircraft maintenance support mode is mainly reflected in:

1) Maintenance support system. Responsible for monitoring and diagnosis of aircraft airborne equipment, and reducing the field maintenance workloads. For example, the fire alarm system only checks when there is a fault alarm. A large number of preventive maintenance work has been reduced compared to the second generation aircraft. However, the periodical maintenance and repair work of the condition monitoring equipment in the member level system has been increased. Because BITE and the sensor itself also have faults, especially false alarms, this increases the difficulty of fault diagnosis. The aircraft can only isolate the faults to the LRU, and need to reduce the intermediate level maintenance. The two-level maintenance can basically be realized. There are many types of information data in the comprehensive diagnosis system, and the data information is used by multiple departments. Therefore, it is necessary to solve the data separation and comprehensive management mechanism, such as establishing a specialized information data management department, etc.

2) Maintenance support resources. The reduction of field maintenance workload directly affects the configuration and scale of support personnel. At the same time, the application of new technologies is bound to involve the integration of maintenance professionals, and there is a higher level of demand for maintenance personnel. The general diagnostic and test equipment reduce the need for number of dedicated test equipment, and need to increase the information diagnostic equipment such as the on-board monitoring information download equipment.

3) Maintenance analysis and decision-making. The various diagnostic elements of the system provide sufficient data support for maintenance decisions. Maintenance management personnel make the maintenance decision more scientific and reasonable through comprehensive evaluation of information.

C. Analysis of the Impact of Area Level PHM on Maintenance Support Mode

Aircraft avionics systems, engine power systems, electromechanical systems and structural systems have area level PHM systems. Area level PHM system have the capabilities of predictive and health management. The regional PHM system can monitor the status of regional systems such as aircraft avionics system, and predict the remaining life based on the actual state of these systems, and then plan maintenance support. In addition, the whole equipment has realized the made condition monitoring and evaluation smarter. The engine health management system (EHM) maintenance support activity implementation process is used as an example to analyze the impact of regional-level PHM on the maintenance support model. The EHM maintenance support model implementation process is shown in Fig. 4.

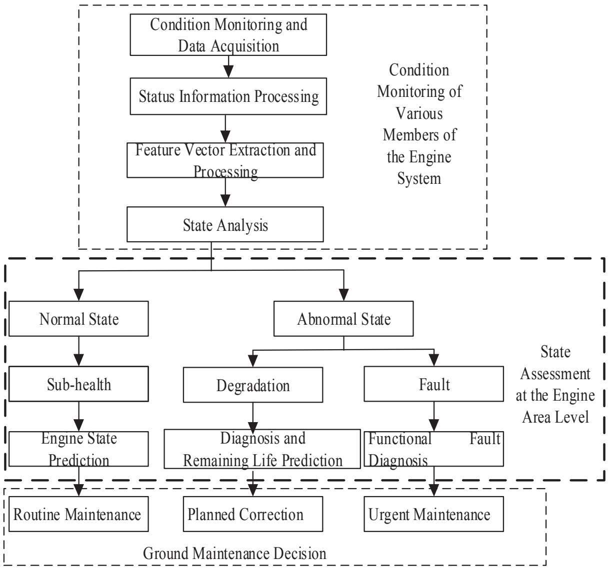

Figure4. The process of EHM maintenance support model

The engine maintenance support model implementation based PHM includes four steps maintenance activity.

1) Condition monitoring, including data collection and analysis. The engine online monitoring system is used to collect engine state data and fuel, oil and vibration information in real time, process input data and output digital filtered signals, spectrum and eigenvalue data, compare the output data with known operating characteristic thresholds, and analyze output status indication.

2) Status evaluation, including assessment and prediction. Evaluate engine health status, determine possible failure modes and trends with a certain degree of confidence; evaluate the condition of each component of the engine, predict future status based on the current state of the engine, and estimate the remaining life of the engine for a given operational plan.

3) Maintenance decision. Provide maintenance or replacement recommendations, maintenance procedures, during implementation, and spare parts distribution options.

4) Maintenance implementation. Maintenance are carried out according to the decision-making, and maintenance decisions are modified in due course according to actual conditions during the implementation process. Routine maintenance activity includes cleaning the intake of the engine, lubricating the fan blades, and maintaining the ignition system.

The impact of regional PHM on maintenance support mode mainly includes:

5) Maintenance support system. The prediction and health management capabilities of key systems have greatly simplified the maintenance process of some aircraft systems, reduced the requirements for field maintenance support, and required maintenance systems to be re-adjusted at all levels. A two-level maintenance support system is required to meet high-efficiency fault diagnosis and prediction, and it is necessary to increase the number of integrated monitoring personnel in the flight support squadron.[9] Predigesting system from level three to two level maintenance could save maintenance cost, and improve readiness. Key system prediction and health management capabilities and condition monitoring technology change the maintenance content of each level. For example, the prediction of some systems can greatly reduce or eliminate the regular maintenance of the field. At the same time, combined with the status monitoring of the whole aircraft, fault diagnosis is more intelligent. The workload of field maintenance is greatly reduced, and more is to replace the modules, scheduling maintenance resources, etc.

6) Maintenance support resources. The comprehensive optimization level of aircraft maintenance support resources is higher. In particular, some systems already have PHM capability. Through life prediction and system health management, the demand for maintenance personnel (technical level, training, etc.) and spare parts can be predicted in advance, and maintenance resources are guaranteed. The deployment and planning have won sufficient time and greatly reduced the scale of maintenance support. After implementing PHM in complex equipment, it is necessary to add the necessary status online monitoring components, such as sensors, signal acquisition circuits, shielded cables, remote transmission equipment, etc. The operational status of these components directly affects the PHM status assessment and prediction results. Therefore, the maintenance and repair of such components must be included in the maintenance system through reasonable and rigorous task division. The ground maintenance process also needs to increase the corresponding resources.

7) Maintenance analysis and decision-making. At this level, the impact on maintenance decisions is mainly reflected in the systems with PHM. On these systems, PHM detects faults and isolates in time during flight, transmits them to the ground maintenance and support information system through the air-ground data link. It is used to guide the ground maintenance support management agency to prepare for the protection in advance. After the flight, the ground maintenance personnel comprehensively make various maintenance decisions to determine the repair timing and maintenance depth of the faulty system. In addition, some systems have implemented condition monitoring, fault prediction, life prediction, and planning maintenance support based on forecast information. Therefore, new maintenance modes are gradually applied to aircraft maintenance support, such as condition-based maintenance.

IV. CONCLUSION

PHM technology can greatly enhance the fault diagnosis capability, simplify the maintenance process, reduce the field maintenance support requirements, the number of ground test equipment and maintenance support personnel, and the inventory rate of spare parts and maintenance support costs. By effectively predicting the future condition, operational effectiveness and remaining life of the equipment, a more optimal maintenance system can be established. The research of PHM technology is of great significance to give full play to the operational effectiveness of aircraft and to improve the maintenance support capability of modern equipment.

In the future, it is advised that more quantitative analysis studies should be carried out on the impact of PHM technology on maintenance support resources and corresponding maintenance decision making.

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