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A METHOD FOR EVALUATING THE APPLICABILITY OF MAINTENANCE TASKS BASED ON HELICOPTER HEALTH AND USAGE MONITORING SYSTEM

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Abstract

With the widespread use of helicopter health and usage monitoring system (HUMS), the traditional maintenance-support mode has been changed. In order to effectively support the determination of the maintenance-support mode for helicopters considering HUMS, as well as maintenance task decision making, this paper makes use of analytic hierarchy process (AHP), proposes a HUMS-based maintenance task applicability evaluation method.

Key words: Helicopter Health and Usage Monitoring System(HUMS), Maintenance Task, Analytic Hierarchy Process(AHP)

1. Introduction

At present, the new generation of helicopters are equipped with the Helicopter Health and Usage Monitoring System (HUMS) for the condition monitoring of the rotor system, engine, transmission system and the body structure of the helicopter [1]. The traditional maintenance and support mode has also changed, and HUMS-based maintenance tasks have been generated through condition monitoring and life prediction.

However, not all systems are suitable for HUMS-based maintenance. For example, for those products whose failure will cause serious safety and mission impact, only when the technical maturity of HUMS is very high, can it be applied to predictive maintenance, otherwise the maintenance suggestions provided by HUMS can’t be adopted at all. However, for some products whose faults only affect the simple use, the requirements for the maturity of HUMS technology are relatively low. Therefore, a qualitative and quantitative evaluation method is needed to evaluate the applicability of these HUMS-based maintenance tasks.

2. Helicopter Maintenance Strategy Based on HUMS

Because failure must be random, the “HUMS-based maintenance task” mentioned in this paper is a generalized maintenance strategy, that is, the maintenance work based on the diagnosis and prediction function of the HUMS system is not limited to condition-based maintenance or predictive maintenance. It also includes post-fault maintenance, preventive maintenance, etc., which are generated in consideration of the output of the HUMS system. They are difference from the traditional maintenance task without considering the HUMS.

Table 1 – Helicopter maintenance strategy

Category	Passive maintenance	Active maintenance	
	Corrective maintenance	Preventive maintenance	Predictive maintenance

Subcategory	Corrective maintenance	Scheduled maintenance	Condition based maintenance (CBM)	Enhanced condition based maintenance (CBM+)
When	After failure occurrence	Component life based on failure rate	Condition monitoring data collected by sensors	The remaining life predicted base on the actual stress load

Generally speaking, there are two main maintenance strategies: passive maintenance and active maintenance.

There is a close relationship between corrective maintenance task and helicopter's failure, that is, corrective maintenance task is driven by helicopter's failure, which belongs to passive maintenance.

The scheduled maintenance task is related to the scheduled maintenance interval, that is, driven by calendar time or usage time. Time interval is the component life calculated by failure rate. The preventive maintenance task is time driven and belongs to active maintenance.

With the support of HUMS technology, users can monitor the status of key components of helicopter in real time and predict their remaining life. Therefore, there is a third driving method of maintenance task, that is, the maintenance task driven by the status of helicopter. The mastery of remaining life can allow optimal maintenance task planning, which belongs to active maintenance.

If active maintenance is carried out on the helicopter and its components, the life of the helicopter can be extended. Active maintenance, such as the replacement of lubrication and oil filter, or the replacement of failed components, can generally make the helicopter run more efficiently and last longer, which can significantly save costs and improve availability. Although it can't prevent all failures, active maintenance can significantly reduce the number of failures and the downtime of the whole helicopter [2][3].

Of course, in the current technical conditions, fault prediction technology is not completely reliable. The uncertainty factors in fault prediction will affect the accuracy of fault prediction, especially the occurrence time of potential faults, resulting in the execution of wrong maintenance tasks. On the one hand, missing report may occur, which leads to random failure of helicopter in use; On the other hand, false positives may occur, which will lead to unnecessary maintenance tasks and reduce pilots' confidence. At the same time, not all the failure can be predicted. Therefore, the condition-based maintenance task can't completely replace the corrective maintenance task and preventive maintenance task.

To sum up, there are three types of helicopter maintenance tasks based on hums: maintenance tasks driven by helicopter faults, maintenance tasks driven by calendar time or service time, and maintenance tasks driven by current state of helicopter.

3. Failure Mode and Maintenance Demand Analysis Method

The object of maintenance task is the system / component equipped with HUMS. Therefore, it is necessary to analyze and study the failure modes of the typical system with HUMS in the helicopter and the maintenance demand corresponding to these failure modes. A feasible solution is to use FMECA as a guide to list the failure modes, monitoring methods and failure criticality to determine the monitoring content.

The design principle of HUMS requires that the development process be integrated into the whole helicopter's design process. This work can be carried out through a series of helicopter's FMEA to analyze the impact of helicopter's system failure on safety and reliability, as well as the methods of fault detection and isolation. The results of these analysis are the basis of helicopter fault diagnosis and maintenance, combined with cost-effectiveness, so as to determine the most effective method of helicopter maintenance and allocate logistics support resources.

Technically, FMEA is a system analysis method used to evaluate risk and reliability. Generally, starting from low-level hardware (component FMEA / FMECA) or system function (function FMEA / FMECA), determine the basic failure mode that has a direct impact on these components or system functions, and then determine the impact of failure on the current system level and the whole helicopter. Generally, the failure rate of relevant failure will be considered.

Taking aeroengine as an example, the typical faults of aeroengine mainly include: stability fault, gas path fault, vibration fault, wear fault, flameout fault, bearing fault, structural fatigue and control system fault [4].

4. Factors Influencing the Applicability of HUMS-based Maintenance Tasks

4.1 Demand Dimension

4.1.1 Safety

The important reason why the helicopter is equipped with HUMS is the demand to ensure flight safety. Generally, criticality analysis is carried out from the two dimensions of hazard severity and hazard possibility. The classification and definition of qualitative hazard severity are shown in the table below. The definition of each kind of mishap should be made clear when dividing the severity of specific helicopter.

Table 2 – Hazard Severity Level

Level	Definition
I	Death of personnel, complete damage or scrapping of helicopter, serious irreversible environmental damage
II	Serious personal injury (or serious occupational disease), serious helicopter damage, serious but reversible environmental damage
III	Slight injury to personnel (including slight occupational disease), slight damage to helicopter or environment
IV	Personnel injury, helicopter or environmental damage less than category III

On the other hand, the hazard possibility should also be considered. The classification of qualitative hazard possibility is shown in the table below.

Table 3 – Hazard Possibility Level

Level	For the component itself	For the whole helicopter
A	It may happen frequently	It happens continuously.
B	It may happen several times	It happens all the time.
C	It may happen occasionally	It happened several times.
D	Rarely, but probably	Rarely, but there is reason to believe that it may happen.
E	It rarely happens, but it can be considered that it will not happen	It rarely happens, and there is reason to believe that it is almost impossible.

From the two aspects of hazard severity and hazard possibility, the qualitative risk priority number can be used to comprehensively evaluate the risk level of hazard.

Table 4 – Example of Risk Priority Number

Hazard possibility	Hazard severity			
	I	II	III	IV
A	1	3	7	13
B	2	5	9	16
C	4	6	11	18
D	8	10	14	19
E	12	15	17	20

Furthermore, the qualitative evaluation of the demand degree of each hazard to the HUMS system is given.

Table 5 – Demand Degree to the HUMS

Risk priority number	Demand degree

1~5	Strong need
6~9	Really need
10~17	Need
18~20	Less need

4.1.2 Task Oriented

From the perspective of task, the failure of some structural parts occurs in its internal, although its importance level is not high, but it is not easy to find, inconvenient disassembly and maintenance work is cumbersome. It is time-consuming and unnecessary to carry out the repair and traditional scheduled maintenance. Therefore, hums is required to bring great convenience to the use of aircrew, reduce the frequency of scheduled maintenance and corrective maintenance, optimize inventory management and resource allocation, and bring convenience to the ground crew, so as to ultimately reduce delay and improve efficiency.

From the perspective of diagnosis and maintenance, because the hums system can realize fault detection, diagnosis and prediction, thus avoiding unnecessary time-consuming and labor-consuming detection and maintenance tasks in the process of fault occurrence or maintenance. Therefore, based on the idea of "avoiding cost", the task factors of typical helicopter system maintenance task based on hums are considered as follows

$$Task\ Value = C_1 + C_2 + C_3 \tag{1}$$

Where, *C1*: the cost saved by reducing the corrective maintenance; *C2*: the cost saved by reducing unnecessary or changing the interval of preventive maintenance; *C3*: detection and isolation cost saved during maintenance.

According to the specific helicopter measurable data, qualitative or quantitative methods are used to evaluate it. The quantitative method is mainly calculated by collecting the saved costs (such as the economic cost in RMB / or the time cost in hours). The qualitative method is mainly scored by experts, such as 1-10 points, where 1 point represents little task value and 10 points represents great task value.

4.2 Capability Dimension

In the field of condition monitoring & Diagnostics (CM&D), ISO 13374 gives the data processing and information flow of CM&D system. ISO 13374 sets up six function blocks. The first three modules are used to collect state data, and the last three modules are used to give decision suggestions. At present, in terms of theoretical research and engineering practice of hums in China, the design principles of ISO 13374 and the underlying principles of open system architecture (OSA) are incorporated into hums system to form a general functional reference model of hums system.

HUMS is mainly composed of Data Acquisition (DA), Data Manipulation (DM), State Detection (SD), Health Assessment (HA), Prognostics Assessment (PA), Advisory Generation (AG) and interface.

Combined with the application conditions and constraints of each technology, the technical feasibility is analyzed. Based on the development and current situation of technology, the maturity of technology is analyzed. According to NASA's technology readiness level (TRL) classification rules, "technical feasibility" and "technology maturity" level descriptions can be determined respectively [5].

5. A Method for Evaluating the Applicability of HUMS-Based Maintenance Tasks

As mentioned above, the applicability of a system to maintenance tasks based on hums depends on its requirements for hums and the capability level of hums. For example, the urgent need plus better capability determines that the system has a strong applicability to maintenance tasks based on hums.This chapter mainly studies the maintenance task applicability evaluation method of typical system based on hums. According to the different requirements and characteristics of typical system, the weight of each factor is analyzed from two dimensions of requirements and capabilities. The applicability level of hums application and deployment is obtained by comprehensively weighing the influencing factors, and the specific applicability evaluation method is proposed.

The general idea of applicability evaluation method is: select a typical system, according to the main failure mode of the system, measure according to the demand dimension (safety, task) and ability dimension (technical feasibility, technical maturity), calculate the applicability relationship between the failure mode and HUMS-based maintenance task. In this paper, AHP is used to determine the weight of each influencing factor.

Firstly, the hierarchical structure model is established.

(1) The "Target" is "maintenance tasks based on hums";

(2) The "Criteria" includes "Safety", "Task oriented ", "Technical feasibility" and "Technical maturity";

(3) The "Sub-criteria" is divided into four parts:

- The "Hazard severity" and " Hazard possibility" under the "Safety";
- The "Diagnosis level" and "Maintenance level" under the "Task oriented";
- The "Da (Data Acquisition)," DM (Data Manipulation), "SD (State Detection)," HA (Health Assessment), "PA (Prognostics Assessment)," AG (Advisory Generation) "under the" technical feasibility ";
- And the "DA", "DM", "SD", "HA", "PA" and "AG" under the "technology maturity";

(4) The “Scheme" includes "Failure mode 1 ","Failure mode 2 "..."Failure mode N".

Table 6 – Hierarchical Structure Model to Evaluating the Applicability of HUMS-based Maintenance Tasks

Target	Maintenance tasks based on HUMS															
Criteria	Safety		Task oriented		Technical feasibility						Technology maturity					
Sub-criteria	Hazard severity	Hazard pPossibility	Diagnosis level	Maintenance level	DA	DM	SD	HA	PA	AG	DA	DM	SD	HA	PA	AG
Scheme	Failure mode 1		Failure mode 2		Failure mode 3				······				Failure mode N			

Secondly, invite experts to fill in the questionnaire to compare the factors in the evaluation index. Here, the index scale method is 9-scale method, and the results are summarized by the principle of minority subordinate to majority. The result of comparison is established as a judgment matrix. It includes three levels of judgment matrix: 1 criteria layer for target layer, 4 sub criteria layers for criteria layer, and 16 scheme layers for sub criteria layer. The connotation of these judgment matrices are the weights of the lower layer factors to the upper layer factors.

Then, the AHP based mathematical method can be used to calculate the total ranking weight of each level element to the target layer, that is, the weight under the criterion can be synthesized from bottom to top. The final total matrix is the weight of each scheme for the total goal, that is, for the selected typical system, the applicability evaluation of each failure mode for the maintenance task based on hums.

6. Conclusions

This paper mainly studies the applicability evaluation method of maintenance tasks based on HUMS in typical systems. First of all, this paper discusses the helicopter maintenance strategy based on HUMS, and analyzes the connotation of different maintenance tasks. Secondly, the failure mode and maintenance demand analysis method of typical helicopters systems are described. Moreover, from the two aspects of demand dimension and capability dimension, the influence factors of HUMS-based maintenance task applicability of helicopter typical system are analyzed. Finally, the suitability of a system for HUMS-based maintenance tasks depends on its demand for HUMS and the level of HUMS capabilities. In this paper, AHP method is used to determine the weight of each influencing factor.

In the process of practical application of applicability evaluation method, it should be noted that the composition and maintainability of different components in the same system are quite different. In order to meet the needs of applicability analysis of different components, for typical systems, expert scoring concepts can be divided into two categories. One is for safety, and the influence factors of safety and technology maturity of key components are more important. On the other hand, for the equipment / system that is not important but inconvenient to disassemble and repair and has a lot of maintenance work, the weight of task factors and technical feasibility factors is heavier.

Abbreviations

HUMS	Health and Usage Monitoring System
AHP	Analytic Hierarchy Process
CBM	Condition Based Maintenance
CM&D	Condition Monitoring & Diagnostics
OSA	Open System Architecture
TRL	Technology Readiness Level
DA	Data Acquisition
DM	Data Manipulation
SD	State Detection
HA	Health Assessment
PA	Prognostics Assessment
AG	Advisory Generation

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