Research on Construction Method of In-service Aircraft Configuration Data Model

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Abstract. In order to establish the basic data architecture for aircraft in-service configuration management, ensuring efficient implementation of it, the characteristics of configuration change caused by various maintenance and support operation during the service phase of large civil aircraft were analyzed. On this basis, formal classification of in-service aircraft configuration data was carried out. Based on the product structure tree, the architecture of the aircraft configuration data was constructed. The in-service aircraft configuration data schema was defined. By introducing the idea of Skyline query, the configuration change information filtering method was designed and implemented. Finally, method validation was performed by the maintenance and support data of an airline company. The results show that, the automatic extraction of configuration change information is realized effectively, ensuring the full integration of the in-service aircraft configuration data schema and production and maintenance information management, and ensuring the real-time and consistency of in-service aircraft configuration data management.

1. Introduction

Configuration management is the application of system engineering in large-scale complex product engineering change management. For large-scale aircraft used in civil aviation, this complex product has the characteristics of long service life, high maintenance cost, and strict project management in its in-service phase. Engineering changes in the in-service phase of the aircraft are unavoidable. They are uncertain occurrence, involving many parts and components, data fragmentation and hard to manage. However, there is a close relationship between the configuration management of in-service aircraft and the protection of aircraft products, operation safety, and maintenance efficiency. Due to the redundancy and inconsistency of configuration information management, problems such as the insufficiency of guarantee resources such as aviation materials tools and the inaccurate updating of technical publications are often caused, affecting the efficiency of aircraft operation and maintenance, impacting the economic and social benefits of airlines, safeguarding unfavorable conditions, and affecting manufacturers' reputation and evaluation. Therefore, it is imperative to effectively implement in-service aircraft management.
The concept of configuration management was first proposed by the United States Air Force to resolve issues of contractor communication and control. With the rapid development of manufacturing technology, the control of configuration management in the research and development of advanced complex equipment has become increasingly outstanding, and it has quickly been accepted and improved by large manufacturers. In the aviation industry, Boeing Company started the Definition and Control Airplane Configuration/Manufacturing Resource Management (DCAC/MRM) project in 1994 [1]. It officially began operating in the global supply chain in 2001. The essential improvement of the system was to reconfigure and divide the configuration items, and to control the configuration of the product by adding configuration directive files to the original design drawing system and setting the configuration of the specified suppliers [2]. Airbus conducts configuration management of the aircraft's delivery through the "configuration change system". After the aircraft is delivered, it undergoes configuration changes in the form of service bulletins [3]. In the JSF project, Lockheed Martin uses Teamcenter software to build a global collaboration network and uses it as a basis for Product Life-Cycle Management (PLM) to control the configuration of aircraft products.

China started late in the study of aircraft configuration management. Li Qing [4] presented a simplified configuration management method for the use of aircraft, enabling the tracking of aircraft product data management and configuration versions. Ji Jun [5] proposed unit-based civil aviation engine configuration management and modeling method for the process of configuration management based on colored Petri nets to ensure the consistency, completeness and traceability of product data in the collaborative research and designed process of civil aviation engines. Ren Jingquan [6] proposed a mathematical model of data provenance and product’s bill of materials, which significantly reduced the amount of snapshot data stored in the bill of materials version, and solved the problem of version propagation in version management. Ren Weiquan [7] has optimized the design and analysis of the structure of the maintenance bill of materials, which effectively organized and managed massive product maintenance information resources, and reduced the redundancy of information resources organization. In China’s aviation industry, domestic regional jet ARJ21 uses the ECMS system to effectively control and manage aircraft engineering design data, ensuring the consistency, effectiveness, safety, integrity, and traceability of engineering design data [8]. At the very beginning of the establishment of the domestically-made large passenger aircraft C919, the concept of configuration management for the entire model development was established, and a configuration management committee was also set up. With the help of an efficient configuration management platform, the configuration management from configuration marking, configuration control to configuration status accounting and configuration audit was realized.

This article is aimed at the large-scale civil aircraft in service, analyzes the characteristics of in-service aircraft data in the aircraft operation, and establishes the in-service aircraft configuration data model, integrates the model with current aircraft operation and maintenance management, and studies the connotation and correlation of in-service aircraft configuration data. This article defines the in-service aircraft configuration data pattern, and designs the in-service aircraft configuration data filtering method to achieve automatic extraction of information from maintenance information to configuration change information so as to achieve a complete aircraft in-service aircraft configuration data model.

2. In-service aircraft configuration data model
The basis of configuration management is the management of configuration information content and the control of configuration change information. Through the analysis of the services that cause configuration changes during the operation and maintenance of the aircraft, and based on the frequency of information changes and the characteristics of related services, the in-service aircraft configuration data is divided, and the design and production management is integrated into the in-service aircraft configuration data pattern to establish in-service aircraft configuration data model.

2.1 In-service aircraft configuration data division
During the use and maintenance of the aircraft, maintenance and repair services such as regular maintenance, troubleshooting, repairs, technical changes, overhaul, etc., often lead to alterations and changes in the configuration of aircraft in service. And the definition and management of in-service aircraft configuration items should be based on the product structure tree, associate the relevant maintenance support with the configuration item node, and integrate the configuration management with the aircraft operation and management to construct a basic in-service aircraft configuration data system, as shown in Figure 1.

Fig.1 In-service aircraft configuration data system

The static basic data refers to the basic characteristics of the aircraft that are related to the aircraft configuration and changes in frequency during the life cycle. During the use and maintenance of the aircraft, the configuration status of each aircraft is often different. Therefore, for the in-service aircraft configuration, it is required to face the stand-alone management. In order to realize the concept of aircraft full life-cycle configuration management, the management of in-service aircraft configuration data continues the basic structure of in-service aircraft configuration management provided by the product structure tree in the research phase and based on the content and granularity of in-service aircraft configuration changes, the product structure tree is adjusted.

The dynamic configuration data refers to the information contained in the connotation of the aircraft configuration and the dynamic information covered in the change process. The dynamic configuration data is changed more frequently during the lifecycle of the aircraft and its version needs to be tracked. Dynamic configuration data includes module and configuration items and support data. Modules and configuration items are the bridges that connect in-service aircraft configuration management and aircraft operation management. Configuration changes caused by maintenance support services can be extracted through the configuration information change filter, and the configuration items are related to the corresponding positions of the product structure. Therefore the lifecycle configuration management system is integrated with the operational management of the in-service aircraft. Supporting data is the basis for safeguarding the operation and maintenance of the aircraft, and is updated synchronously as the configuration changes.

2.2 In-service aircraft configuration data pattern

By defining each type of in-service aircraft configuration data, the correlation between them is established, and combining the current aircraft operation and management data pattern, the in-service aircraft configuration data pattern is established, as shown in Figure 2.
The in-service aircraft configuration data pattern focuses on the stand-alone product structure. For each aircraft in the airline fleet, it stores its entire machine type information in a unified manner, stores its configuration information separately in the form of product structure, and records all configuration change information through the stand-alone configuration tracking data sheet. Airworthiness directives, service bulletins, major repairs, troubleshooting, and scheduled inspections and maintenance are necessary maintenance support activities in the operation and maintenance of aircraft. Such information will be continuously recorded to ensure the normal operation and management of airlines. The maintenance support information that causes the configuration change will be filtered out and stored in the adding list, retrofitting list, and repair list according to the category, and the corresponding stand-alone product structure information will be updated based on this.

3. Data filtering method for configuration change extraction

3.1 Data filtering process design

The airline's massive operation and maintenance data includes information on in-service aircraft configuration changes. It requires screening and filtering to extract changes to the in-service aircraft configuration information, so as to achieve complete records and continuous tracking of in-service aircraft configuration information.
The in-service aircraft configuration data filtering process is shown in Figure 3. The airworthiness directives and service bulletins are issued by the quality department to the production department, and the production process is carried out according to the production arrangements. The overhaul of the parts is performed by the contractor, and the troubleshooting and scheduled maintenance and inspection are carried out in the corresponding production processes. The configuration change process is synchronized with it. When a production task completes the corresponding information storage in the database, the in-service aircraft configuration data filtering process is triggered. According to the type of maintenance support, the maintenance information is stored in the corresponding temporary sheet. According to the configuration change rules, it is determined whether the current maintenance support information has undergone a configuration change. And the configuration change level is evaluated according to the degree of its configuration change. For the level of attention information, according to its aircraft number or the involved part number, the corresponding information item can be found in the stand-alone product structure sheet, and the original information item will be backed up to the stand-alone configuration tracking sheet, and then the new configuration information will be updated. And after the version number is upgraded, it is stored in the stand-alone product structure sheet so as to complete the filtering of the in-service aircraft configuration data.

![Fig.3  In-service configuration data filtering process](image)

3.2 Data filtering method based on improved Skyline query

Skyline query, as a typical multi-objective optimization problem, looks for interesting points from the data sets, which are not dominated by other points. The Skyline query will return a subset of the dataset. The points in this subset cannot be dominated by any other point in the dataset. The point that satisfies this condition is called the Skyline point (SP). In order to filter the in-service aircraft configuration data, the Skyline method will be improved to compare the maintenance support information with the configuration change rule as a benchmark, and the change in the configuration of the maintenance support information in the temporary sheet which will be greater than the requirement of the rule, is filtered and extracted; objects whose degrees of configuration changes do not meet the requirements of the rules will not be saved as configuration information.

Assume that the quantized rule of the in-service aircraft configuration change is an \(m\)-dimensional tuple \(R\); Object \(P\) belongs to the \(n\)-dimensional maintenance support information collection \(S\),
whose each dimensional attribute is \( \{r_1, r_2, \cdots, r_m\} \) and \( \{p_1, p_2, \cdots, p_n\} \) respectively; extract attribute in object \( P \) that corresponds to quantized rule \( R \), and Generate object \( P' \) whose dimensional attributes are \( \{p_1', p_2', \cdots, p_n'\} \).

If for \( \forall i (1 \leq i \leq m) \), \( p_i' \geq r_i \), and \( \exists j (1 \leq j \leq m) \) and \( p_j' > r_j \) all are established, then \( P \) supports \( R \), written as \( P \supseteq R \).

If \( \exists i (1 \leq i \leq m) \) and \( p_i' \geq r_i \), then \( P \) incompletely supports \( R \), written as \( P \subseteq R \).

Selecting all objects sets that follow the incompletely support of quantized rule \( R \) from collection \( S \) will then accomplish the filtering of in-service aircraft configuration data.

Algorithm 1 In-service aircraft configuration data filtering method

Input: \( m \)-Dimensional In-service Aircraft Configuration Quantized Rule \( R \), \( n \)-Dimensional Maintenance Support Information Set \( S \)

Output: In-service Aircraft Configuration Change Data Set \( S' \)

Algorithm Description
1) int flag[] = new int [n]; // Initialize tag array
2) for(int i = 0; i < n; i++)
3)   flag[i] = n;
4) for(int i = 0; i < m; i++)
5)   for(int j = 0; j < n; j++)
6)     if(R[i].getAttribute().equals(R[j].getAttribute()))
7)       flag[j]=i; // The attribute corresponding to \( R \) in tag \( S \)
8)   for(int k = 0; k < S.size(); k++)
9)     con_G++; // The query does not completely dominate the object of \( R \)
10)    int pos=flag.indexOf(i);
11)   if(R[i]>=S[j][pos]) // Incomplete governance decision algorithm
12)      con_G++;;
13) if(con_G>=1)
14)   S'.add(S[k]); // The target object is stored to \( S' \).
15) return S'; // Return query results

In the algorithm description, the incomplete dominance decision algorithm differs depending on the forms of the maintenance support information data.

3.3 Example verification
To verify the data filtering method based on the improved Skyline query, the FAA airworthiness directive managed by an airline is selected as an example, as shown in Figure 4.
In-service aircraft configuration management software stores airworthiness directives, including the serial number, source, number, version number, revision number, title, ATA chapter number, effective date, release date, issue reason, applicable aircraft type, and applicable engine types, names of related department, references to airworthiness directives or service bulletins, annex etc. By matching the data items of the algorithm tags with the rules, the software output intermediate results are shown in Figure 5.

The in-service aircraft configuration management software according to the algorithm labels of Figure 5, filters out extraneous attributes and simplifies the sample, and Figure 6 shows the labeled attributes after extracting.

In the example, the airworthiness directive is stored as a text form, and the incomplete dominance decision algorithm combined with the semantic meaning analyses LDA model method. The first airworthiness directive is calculated by an incomplete dominance decision algorithm, and the final output of in-service aircraft configuration data information is shown in Figure 7. The first airworthiness directive is the retrofitting of the thrust-reverser inner walls on the engine. It belongs to the in-service aircraft configuration change category and complies with the in-service aircraft configuration change rule. Through the analysis of the specific information of the first airworthiness directive, the involved nodes in the product structure tree of the corresponding aircraft in the fleet are identified, the basic configuration information is changed, the version number is updated, and the cause of the configuration change is recorded, which achieve the tracking of configuration changes.
4. Conclusion

By combining the product structure tree with the maintenance and support business of civil aircraft in service, the architecture of aircraft in-service configuration data is established, and the data model of aircraft in-service configuration is designed. Through the improvement of Skyline query, a data filtering method based on it is proposed. Finally, the software verification shows that the in-service configuration data architecture ensures the hierarchical docking of maintenance support business management and aircraft in-service configuration management. The data filtering method realizes the extraction of configuration information from maintenance support information. And the in-service configuration data model guarantees completeness, consistency and traceability of data management.

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