Research on Modeling of Aircraft-Level High-lift System Architecture Based on SysML

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Abstract. The aircraft-level high-lift system architecture of civil aircraft includes functional architecture, logical architecture and physical architecture. The system architecture describes the hierarchical relationship, cross-linking relationship and information interaction between the function, logic and physics of the system. This article is based on the SysML modeling language, using the MagicDraw modeling tool to transform the traditional design work based on experience and documents into model-based architecture design work, using the association and traceability of the model to ensure the integrity of the information in the design process. This article establishes the design relationship between its functional, logical and physical layers of the high-lift system to verify the efficiency of this modeling method.

1. Introduction

With the increasing scale and complexity of civil aircraft systems, many design problems will arise in the process of aircraft architecture design. Traditional document-based system engineering will generate a large number of different documents. These documents contain various parameters of the system and it is becoming more and more difficult to describe the entire design process through documents, which leads to incomplete, inaccurate and ambiguous representation of information. It is also difficult to find and trace the location of information in a large number of documents. The completeness, consistency and traceability of design information are of great significance to system design.

This paper proposes a design method of civil aircraft high-lift system architecture based on model-based systems engineering. Its modeling language is based on SysML language, and its modeling tool uses MagicDraw software to convert traditional design work based on experience and documents into the architecture design process of the model, including the functional architecture, logical architecture and physical architecture modeling of the high-lift system. The system parameters are expressed graphically through the model to ensure the integrity, consistency and traceability of the design information of the aircraft during the design process. This method can be promoted and applied to any civil aircraft system architecture design.
2. Model-based system engineering

The definition of model-based systems engineering was given in 2007 by the International Council on Systems Engineering (INCOSE) in the "Systems Engineering Vision 2020": Model-based systems engineering (MBSE) refers to the standardized application of models that fully support system requirements, design, analysis, verification, and validation activities during the entire life cycle of system conceptual design, system development and later[1-2].

From the definition of model-based system engineering, it can be seen that its core idea emphasizes the use of models to express the design process of the system. It uses visualization and graphical system modeling language to describe the various levels of the system, and then builds an integrated, specific and visualized system architecture model layer by layer, which improves the accuracy, comprehensiveness, consistency and traceability of system description.

At present, model-based system engineering methods have been gradually developed in various fields at home and abroad. Foreign organizations including NASA, Boeing, the U.S. Department of Defense, Lockheed Martin, IBM, etc, have actively used MBSE, and have achieved a lot of progress and results[3-7]. Some domestic scholars have also begun to study the MBSE theory and modeling methods. For example, Liu Yusheng et al. studied the method of using models to drive complex product design modeling[8], and Li Qing studied the application of model-based systems engineering to aircraft Technology development[9], Ge Limin and others applied model-based system engineering methods in the avionics system design process[10].

The system modeling language is developed from the standard language UML in the software engineering field[11]. As a new system modeling language in the field of systems engineering, SysML integrates the advantages of object-oriented and process-oriented visual design languages, and it is a standard system modeling language popularized in the field of systems engineering[12].

3. Introduction to the method in this article

Model-based architecture modeling describes the boundaries and interfaces between high-lift system components in graphical form, including the definition and description of each component of the system. According to the requirements of the aircraft design, it is necessary to establish the breakdown structure of the functional blocks, clarify the composition and interfaces between the functions, define the interactive content between the functional blocks, and form the functional architecture Block Definition Diagram (BDD) and Internal Block Diagram (IBD).

The functional architecture of high-lift system is the vertical hierarchical relationship formed after the functions are decomposed, and the logical relationship among several sub-functions in each horizontal hierarchy.

The logical architecture of high-lift system describes functional groupings, adopts specific logical components to undertake functional architectures, reflecting the connection relationships and data interface relationships between logical components. It also describes the definition of the logical scheme of the system, including logical non-redundant architecture and logical redundant architecture, forming a logical architecture BDD and IBD, and establishing the mapping relationship between functional architecture and logical architecture (without redundancy), logical architecture (without redundancy) and logical architecture (with redundancy).

The physical architecture of high-lift system describes the hierarchical relationship, cross-linking relationship and signal/material interaction among devices from the product level. It provides a hierarchical organization of software/hardware components and their related interfaces and gives the BDD and IBD of the physical architecture. It then maps the relationship between the logical architecture (with redundancy) and the physical architecture, establishing the design scheme of the aircraft system. The relationship between the functional architecture, logical architecture and physical architecture of its system architecture is shown in Figure 1:
Figure 1. Aircraft-level system architecture design process

4. System architecture definition and modeling
Based on the SysML modeling language and the MagicDraw modeling tool, the traditional experience and document-based design work is transformed into a model-based architecture design process, and the association and traceability of the model are used to establish a unified coordination among the functional, logical and physical levels design relationship and improve design efficiency.

4.1. Functional architecture definition and modeling
The high-lift system architecture is established based on the aircraft's top-level design requirements and goals. First, using the BDD and Block elements based on the SysML language to define functional components and establishing the decomposition structure of the functional blocks. Taking the high-lift system "load bearing function" as an example. The BDD is shown in Figure 2, which expresses the decomposition and composition relationship of the function.

Figure 2. BDD with load bearing function

The port type of the functional block is clarified. Proxy Ports are used to distinguish between input and output, and is divided into signal port, material port and energy port according to the type of transmission interaction item. The definitions of three types of ports are shown in Figure 3.
Figure 3. Definition of function block port of high lift system

The content of the interaction between functional blocks in the functional architecture can also be defined. There are three types of interaction items: signal, matter, and energy. Examples of interactive item definitions are shown in Figure 4.

Figure 4. Definition of functional architecture interaction items

Based on the defined functional components and interactive items, it is possible to establish the connection relationship between the functional components, and to clarify the content of the interactive items transmitted between the functional components thus forming the functional architecture IBD. Figure 5 shows an example of the functional IBD of the high-lift system.

Figure 5. IBD of high lift system function

4.2. Definition and Modeling of Logical Architecture

In the design process of the logical architecture, in accordance with the design requirements of the functional architecture, combined with the mature design of the existing system logical architecture, the logical architecture design is carried out to clarify the interaction between the logical components, including signals, matter and energy, to form the without redundancy logical architecture. Then, based on the logic architecture without redundancy, considering the design characteristics, safety and performance requirements of similar models, it is possible to design redundant components and redundant control logic to form a logic architecture with redundancy.

The output of logical architecture design mainly includes logical architecture, logical architecture interface control diagram (ICD) and logical architecture description documents. The logical architecture includes the BDD of high-lift system logical components, logical component port
This method is consistent with the functional architecture design method. Based on the defined logical components and interactive items, the connection relationship among the logical components can be established and the content of the interactive items transmitted between the logical components can be clarified to form a logical architecture IBD. The IBDs of the logical architecture components of the high-lift system are shown in Figures 6 and 7, including the logic without redundancy and the logic with redundancy.

According to the logical architecture, the distribution relationship from function to logic component can be established, and the distribution relationship from logic without redundancy to logic with redundancy is formed to form an allocation table. As shown in Figure 8 and Figure 9, the mapping table from function to logic without redundancy and from logic without redundancy to logic with redundancy is given.
4.3. Physical architecture definition and modeling

The physical architecture is connected to the logical architecture. After completing the logic with redundancy architecture design, the corresponding logical components should be implemented at the product level, that is, the process of physical architecture definition, and the relationship between devices should be defined from the perspective of product implementation and interface form.

In the process of physical architecture design, the definition of physical components is based on logical architecture and logical grouping. Logical groups can be named according to the importance of logic, the complexity of logical associations, the degree of logical coupling, etc, that is, the definition of physical components. Figure 10 shows an example of a BDD of some physical components of a high-lift system.
The port type of the physical component is clarified. Proxy Ports are used to distinguish between input and output. According to the type of transmission interaction item, it is divided into signal port, material port and energy port. As shown in Figure 11, three types of port definitions are given.

The content of the interactions between physical components in the physical architecture can then be defined, including three types of interaction items: signal, matter, and energy. Figure 12 provides some examples of interactive item definitions.

Based on the defined physical components and interactive items, the connection relationship between the physical components can be established and the content of the interactive items transmitted between the physical components can be clarified to form the physical architecture IBD. As shown in Figure 13, a high-lift system physical architecture IBD is given to form a high-lift system architecture scheme.
5. In conclusion
Aiming at the characteristics of civil aircraft development, the aircraft-level system architecture modeling method based on SysML language during the development of civil aircraft is introduced. The boundary and interface between system components are described in the form of models from functional architecture, logical architecture and physical architecture. This includes the hierarchical relationships, cross-linking relationships, and data/energy interactions between the architectures. Based on the SysML modeling language, using the MagicDraw modeling tool, the functional, logical and physical architecture of the high-lift system are established, using the graphical association and traceability of the model, realizing a unified collaborative design relationship between functional, logical and physical architecture, improving the design efficiency of the civil aircraft research and development process, and it is of great significance to the design of civil aircraft systems.

Figure 13. High-lift system physical architecture

Based on the physical architecture, an allocation relationship from logical to physical components can be established to form an allocation table. The allocation table of high-lift logical components to physical components is shown in Figure 14.

Figure 14. Allocation table of high-lift logical components to physical components
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