Application of Model-Based System Engineering Method in Civil Aircraft Communication System Design

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Abstract. Model-based system engineering theory is a new breakthrough in aircraft development methodology, which can solve the problems of aviation system development, high integration, difficult management and high risks. This paper introduces the basic theory of MBSE, and applies MBSE method in the design of communication system to realize audio communication function. Starting from the needs of stakeholders, perform analysis and define system use cases. According to different scenarios, define the function requirements activity flow and determine the functional model. Then map the functional architecture to the physical layer, carry out scheme trade-off analysis, architecture design and generate physical architecture diagram to ensure that the final solution meets the needs of stakeholders. Through model evolution and iteration, product design is realized. Modeling can provide all parties with a universal and unambiguous design information exchange platform, and at the same time facilitate the realization of system virtual integration and improve the existing design process.

1. Introduction
Civil aircraft is a typical complex product system, with strong interdisciplinary, high system integration, high technical difficulty, large investment, high safety and reliability requirements, and high development risks and management difficulties. The interoperability of system functions has evolved from independence to interaction based on shared resources, the interface definition has developed to highly integrated and tightly coupled, the integration work has developed from simple functions to more complex functions, and the system interconnection has changed from discrete to highly networked. Traditional system engineering is based on document management. For example, user needs and design schemes are often iteratively modified in the system design process. It is difficult to ensure the consistency of product data and the traceability of data. Traditional system engineering is based on document management, such as the user's requirements, design scheme in the system design process often appear iterative modification, which is difficult to ensure the consistency of product data, data traceability and other requirements. At the same time, the document is a combination of natural language, the understanding of the system by related parties is prone to inconsistencies. During the design process, models need to be established from various aspects to describe the system in detail to accurately and completely describe the system.

Model-based system engineering integrates the concept of “everything is model-based” throughout the product life cycle. Through graphical, structured, and modeling methods, the entire system becomes
clear, standardized, and easy to maintain, and finally realizes project design and management process. This paper takes the air-to-ground audio communication function of the communication system as an example, introduces the basic theory of MBSE, and applies the methodology to the design of communication system to realize the top-down design.

2. Model-based System Engineering Method

MBSE is very different from traditional system engineering methods in the development and design of large civil aircraft. Model-based system engineering realizes the correlation and interaction between requirements (models) and system models. Through continuous development and description of the system model, the top-down design of system is realized: taking requirements as the context, from use case analysis → functional analysis → architecture design (logical realization of function) → physical design (physical realization of logical architecture), and through model simulation operation to ensure the satisfaction of the requirements and the compliance of the design MBSE. INCOSE and the object management organization, based on the unified modeling language, developed a system modeling language suitable for describing engineering systems.

2.1. Capture requirements

Civil aircraft design needs to analyze and define requirements first. Requirement is the first thing to be analyzed and defined in civil aircraft design. The work related to requirements capture mainly includes: identify stakeholders, capture stakeholder needs and requirements management. At present, the commonly used requirements management software is the DOORS software of IBM.

For civil aircraft, stakeholders mainly include aircraft manufacturers, civil aviation companies, civil aviation administration, airports, government departments, pilots, flight attendants, passengers, etc. After identifying the stakeholders of the project, it is necessary to obtain the original requirements from them through various research techniques. Typical research techniques include field study, questionnaire, interview and joint requirements planning.

2.2. Requirements Analysis

Requirements analysis begin with the analysis and improvement of stakeholder needs. The work product of this step is the stakeholder requirement specification. At this time, there is no need to determine boundary of the system and limit the solution to the user. The next step of the requirements analysis is to define the system use case, describing the system from a specific operational aspect. Finally, in order to ensure that all functional requirements and related performance requirements are covered by these
use cases, traceability needs to be established respectively.

- Focus on the analysis of needs and objectives, expected tasks and activities. It is to ensure that the system definition has good sufficiency in its practical operation.

Output: stakeholder needs are transformed into system requirements
- Requirements.
- Operational scenarios (size parameters, operational constraints, Safety, reliability, system life cycle, etc.)

2.3. Function Analysis
The main focus of the system function analysis stage is to transform the system functional requirements into a coherent system function description (operation). The purpose of functional analysis is to analyze the information interaction mode between the system and the outside and the operating status of the system itself without caring about the internal structure of the system, so it is called black box design. The analysis is based on use cases, that is, each use case confirmed in the previous requirements analysis stage is converted into an executable model, and the behavior of the use case module is defined. The modeling workflow is represented by SysML activity diagrams, sequence diagrams, and state diagrams. Activity diagram, also known as black box use case activity diagram, describes the overall functional flow of use cases. It organizes functional requirements in the form of activities and shows how these activities are related to each other; sequence diagram, also known as black box use case sequence diagram, describe a specific path through the use case and define the interaction (information or message) between operations and roles; the state diagram brings together the information of the activity diagram (function flow) and sequence diagram (interaction between roles).

![Figure 2. Function Analysis Workflow]

2.4. Design synthesis
Design synthesis is to analyze and design the architecture of the system on the basis of comprehensive consideration of all system functions. Each physical node selects multiple physical components to meet the requirements according to the requirements assigned by the logical node. There are usually multiple physical candidate architectures. Architecture analysis is to judge whether the architecture is feasible through objective evaluation of the designed architecture. For civil aircraft system engineering, the feasibility elements to be analyzed generally include technical feasibility, schedule feasibility, economic
feasibility, safety feasibility, etc.

After selecting the architecture scheme, the system is divided into several subsystems. To decompose and allocate each use case according to subsystem, it is necessary to identify the interaction between subsystem and external subsystems, and complete the state behavior definition of each subsystem. This process is also called white box analysis. The system structure generated by design synthesis is described by SysML's block definition diagram and IBD (internal block diagram).

3. Example Study
Avionics communication system undertakes the important task of all information interaction in avionics system. Through the analysis of the captured requirements, the functional requirements are selected, and the corresponding use cases are established according to the functional requirements to define the communication system boundary. All external elements that interact with the communication system are called participants, including pilots, air traffic controller, ground service, crew, etc., so as to clarify the interaction between the communication system and the external. The air ground audio communication runs through the whole flight phase, mainly including normal scenarios such as preparation before takeoff, taxiing, takeoff, cruise, descent and landing. Of course, there are some special operation scenarios, emergency scenarios and fault scenarios. The use cases in the figure 3 show the normal operation scenarios.

![Figure 3. Audio Communication Use Case Diagram](image)

Activity diagrams are used to describe the use case scenarios to clarify the system behavior. The normal scenario provides audio communication with the ground, including six sub activities: select communication mode, select audio communication channel, select HMI, receive SELCAL alert, receive SATCOM alert, complete communication, as shown in Figure 4.
Figure 4. Audio Communication Activity Diagram

Based on the results of functional analysis, carry out architecture trade-off analysis and architecture design. As shown in the table below, channel selection is realized by tuning components and VHF, HF and SATCOM components, HMI selection is realized by audio management components, and audio communication completion is realized by audio terminal and audio control components.

Table 1. Mapping of Functions to Physical Components

| Function                  | Integrated Tuning | VHF | HF | SATCOM | Audio Management | Audio Control | Audio Terminal |
|---------------------------|-------------------|-----|----|--------|------------------|---------------|----------------|
| Select Radio              | ✓                 |     |    |        |                  |               |                |
| Select Channel            |                   | ✓   |    |        |                  |               |                |
| Select HMI                |                   |     | ✓  |        |                  |               |                |
| Receive SELCAL Alert      | ✓                 | ✓   | ✓  |        | ✓                | ✓             | ✓              |
| Receive SATCOM Alert      |                   |     |    |        | ✓                | ✓             | ✓              |
| Complete Communication    |                   |     |    |        | ✓                | ✓             | ✓              |

The final communication system architecture scheme also needs to choose the optimal scheme through safety analysis and cost analysis. For example, for an aircraft that performs ocean-going flights, you can choose 2 sets of satellite communication or 2 sets of high frequency in the communication system architecture scheme, or 1 set of satellite communication and 1 set of high frequency solutions. In the case of cost analysis, high communication quality, and the need to leapfrog the polar regions, one set of satellite communications and one set of high-frequency solutions were finally selected.
Determine the physical components of the communication system according to the selected solution, allocate the functional analysis results of each scenario to the corresponding physical components, and define the interfaces between the subsystems for the physical architecture of the communication system. The Figure 5 uses the IBD diagram to describe the connection and interaction between the physical components of the communication system in order to realize the audio communication function.

4. Conclusions
Model-based system engineering is a new concept and new technology in the development process of civil aircraft, which can effectively solve the difficulties and problems faced by the traditional development process. This paper studies the basic ideas of the MBSE methodology, introduces in detail the requirements capture, requirements analysis, function analysis and design synthesis process, and analyzes the application of the MBSE method in the civil aircraft communication system with examples, and describes the use case diagram, activity diagram, and architecture in detail Model establishment and analysis process. The results show that the MBSE methodology is conducive to the collaborative work of the engineering team, taking requirements as input, supporting system design, analysis, verification and validation.

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