Civil Aircraft Electrical System Development Using Model-Based System Engineering

Xinhai Liu[1], Yifan He[2], Shaojie Zhang[1]

[1] College of Automation Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, China.

[2] China Aeronautical Radio Electronics Research Institute, Shanghai 200241, China

Abstract. As one of the key systems of modern civil aircraft, Electrical System (ES) plays an important role in all flight phases of the aircraft. Considering the needs of the electrical system, based on the analysis of interaction process of civil Electrical System design and safety assessment, Doors and Rhapsody are used to accomplish the Requirement Analysis, Functional Analysis and Design Synthesis of electrical system in this paper. The use case model, function analysis model and verifiable state machine model of the electrical system are established to ensure the requirements are accomplished by system architecture. Finally, the interactive interface of panel diagram is developed to complete the simulation of the system model according to design requirements. The simulation shows that Model-Based Systems Engineering (MBSE) can greatly improve the efficiency and accuracy of the development of the electrical system.

Keywords: Model-based System Engineering; Electrical System; Rhapsody; System development.

1. Introduction

As all methodologies should claim it, the goal of system development is to reduce the time, improve efficiency, and ensure stability. At present, the traditional text-based system engineering design method is widely used in aircraft system design, and many documents in the form of words and pictures are used to describe the design ideas [1]. For the traditional design process of civil aircraft electrical system, the document-based approach is time-consuming and limits the understanding and calculation of changes in the system design. To reduce shortcomings of the traditional process, engineers are turning to model-based systems engineering.

Intuitive models are used to describe system in MBSE technology, which enhances the consistency of modifications and understanding between different developers. Meanwhile models can be read by computers which means frequently validation and verification can be performed through the whole development process [2-5]. Therefore, MBSE greatly solves the problem of inefficiency and enables the quality of system development.

In the design process of the ES, the primary performance considered is its safety, and the relevant airworthiness standards shall be strictly observed in the design, production, and operation process. This paper explores the application of MBSE technology in the design of civil aircraft electrical system. Using Rhapsody design software to complete the simulation and modeling of the electrical system, simulate the system working states and electrical control modules at different stages of system design. The simulation and analysis of electrical system characteristics, control functions and logic have realized.

2. MBSE Design Process

In order to develop the ES that conforms to the airworthiness regulations of civil aircraft, it is necessary to combine SAE ARP4754A “Guide for civil aircraft and system development” [6], we research the design process of civil aircraft ES based on MBSE.

In MBSE, model is the core of the design process, and the model is continually refined throughout the whole development process [7, 8]. MBSE provides an efficient methodology that abstract the system as a use case, all the development is centered on the use case. Harmony as a typical MBSE development method is widely used in practical engineering, the implementation process is divided into three phase, requirements analysis, functional analysis, and design synthesis, as shown in Fig. 1. In this paper, we use SysML to describe requirement analysis, function definition, simulation verification of system development.

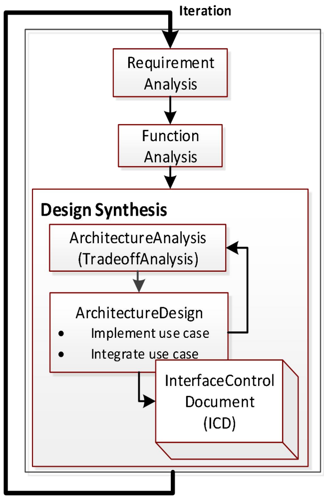

Fig. 1 System development process based on MBSE

The purpose of requirement analysis is to translate requirements of users into system requirements. Based on the knowledge of the electrical system, the designer analyzes the sorted user requirements, obtain the system functional requirements with clear layers and complete structure. In the requirement analysis phase, we mainly get the requirement model and use case model of the electrical system. The use case model mainly describes the behavior of external actors and the relationship between external actors and internal system use cases. Compared with traditional methods, the model structure can quickly locate requirements changes and avoid the “Butterfly Effect” caused by requirements changes.

A use case describes a specific behavior perceived by the users and the message flow between the users and the use case. The input of the functional analysis stage is the use case model from the requirements analysis phase, and the output of the functional analysis phase is an executable use case model. The executable use case model also be called “Black-box” use case model.

Design synthesis integrates the model elements of the functional analysis phase, and then design the system architecture. Design synthesis is split into sub-phases: architectural analysis and architectural design. Architectural analysis describes the various situations of system trade-off analysis, through a series of system trade-off analysis, seeking the optimal architecture design scheme. The focus of the architectural design phase is refining “Black-box” use case model, expanding it to “White-box” model, and integrating “White-box” model to system architecture.

3. Design of Electrical System

The design of system with the MBSE method can effectively combine development, operation with debugging. This section uses the MBSE method to design civil aircraft electrical system.

3.1 Requirement Analysis

In ES requirement analysis phase, we select Doors as the requirement management platform and Rhapsody as the modeling and simulation platform. Requirement analysis mainly includes requirements acquisition, requirements allocation and traceability to use cases.

Designers based on understanding of electrical system, analyze user requirements, sort out clear and complete functional requirements, import user requirements and functional requirements to Doors in the form of text. In the subsequent model design, we need link user requirements text to functional requirements text one by one for maintain good traceability of requirements [10].

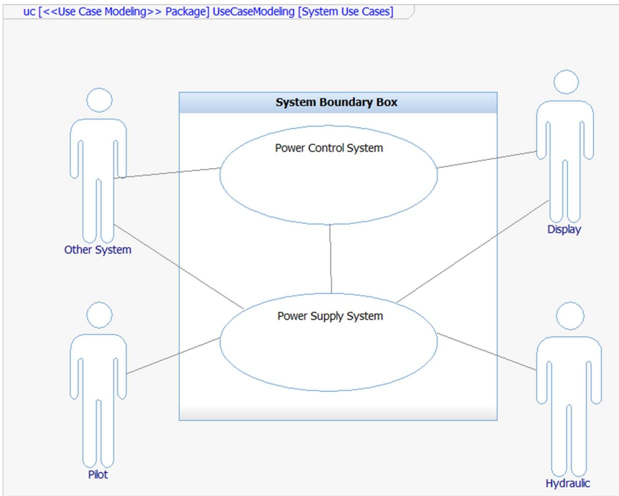

Fig. 2 Aircraft Electrical system function use case diagram

After requirements analysis and requirements import, we need translate functional requirements into several top-level use cases according to the electrical system requirements, including establishing corresponding functional use case, defining external role objects and boundary of system, determining the relationship between the two functional use cases or between use case and external roles. The results of requirements analysis need to be shown in the form of SysML use case model. Based on the results of functional requirement analysis, we establish ES use case diagram as shown in Fig. 2. Using Rhapsody Gateway import the ES requirements analysis text from Doors into Rhapsody project, and link the requirements text and functional use case one by one for complete requirements analysis.

3.2 Requirement Analysis

System functional analysis phase is based on use cases, the top-level functions of the system are transformed into use case models through the modeling tool Rhapsody, each use case is translated into an executable model. The model and the underlying requirements then are validated through model execution.

3.2.1 "Black-box" static architecture model

The ES functional analysis phase is the "Black-box" model phase. "Black-box" static architecture describes attributes, operations, and states of top-level use cases.

Based on top-level use cases, we use IBD (Internal Block Diagram) define context of use case model, establish event and data interfaces between use cases or between use cases and external roles, and complete the interaction of components according to control logic and data trend.

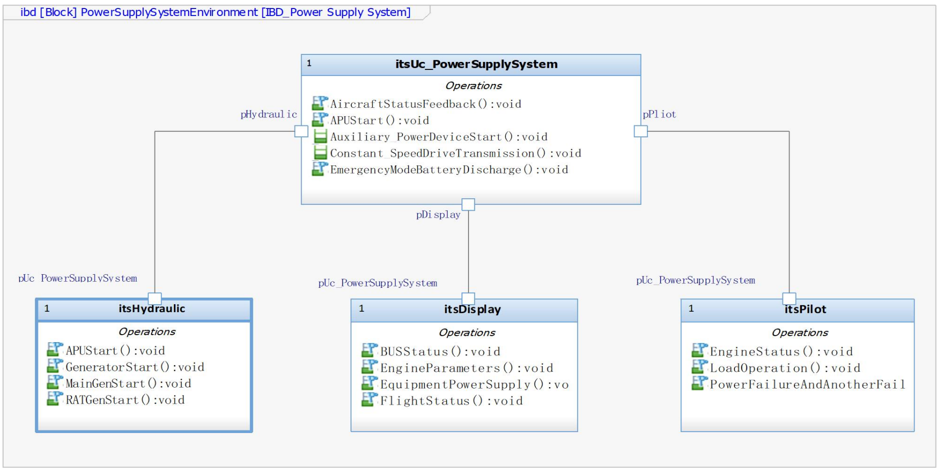

Fig. 3 ES Power supply use case "Black-box" static architecture model

The functions of Power supply mainly include checking the status of the aircraft generator; receiving the control command from the pilot; controlling the start of the engine through the hydraulic module; receiving the components status information of the display system; adjusting the aircraft power supply equipment; changing the power supply mode to ensure the aircraft normal power supply. Defining Power Supply System and 3 external role, characteristics of power supply function, interaction between system and external roles, interface as shown in Fig. 3.

3.2.2 "Black-box"dynamic behavior model

After modeling the static structure, we need establish SysML activity diagram, sequence diagram and state machine diagram to describe ES more details from two aspects of system: activity flow and state behavior. For example, according to the operation of black-box static structure, defining function flow of Power supply use case to get Power supply use case activity diagram, exporting sequence diagram based on events interaction of activity diagram and driven by events to design state machine diagram for describing power supply use case components state change.

3.3 Design Synthesis

The design synthesis phase is the detailed design for each sub use case, and expands "Black-box" to "White-box", until the physical architecture of the whole electrical system is defined, obtain the final architecture model and system behavior model, and simulation verification.

3.3.1 "White-box" static architecture model

In this phase, the "Black-box" static model need be subdivided into sub-systems or sub-components with smaller level establishing relationship with the top-level system or component according to certain logic. Like the IBD of the "Black-box", IBD of the "White-box" also defines characteristics and interface of sub-systems or sub-components. Interaction between sub-systems and sub-systems or between sub-systems and external roles according to the actual operation of the electrical system as shown in Fig. 4.

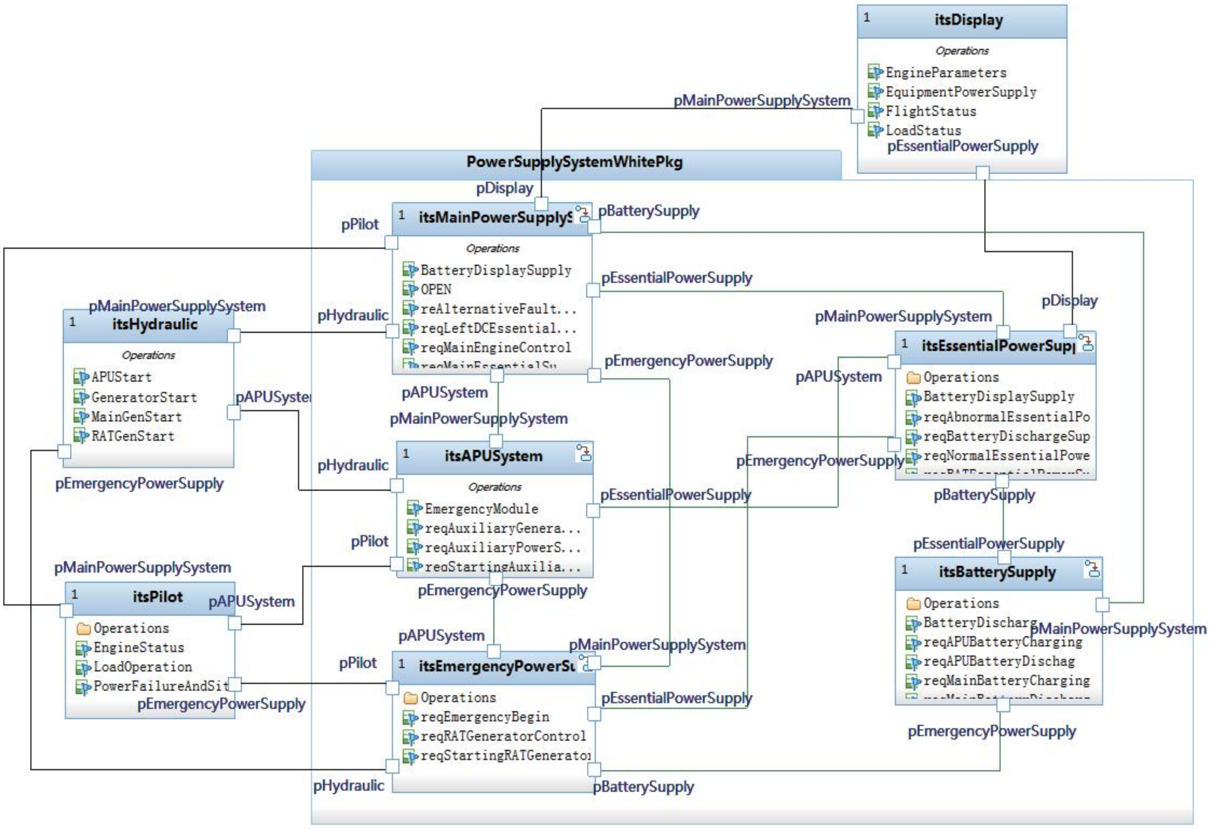

Fig. 4 ES Power supply use case "White-box" static architecture model

3.3.2 “White-box” dynamic behavior model

“White-box” dynamic behavior model also need to establish SysML activity diagram, sequence diagram and state machine diagram for describing ES. Power supply use case “White-box” activity diagram as shown in Fig. 5, the operations of the Power supply case are assigned to the sub-components of the swimlane, and activity flow of each swimlane corresponds to sub-components.

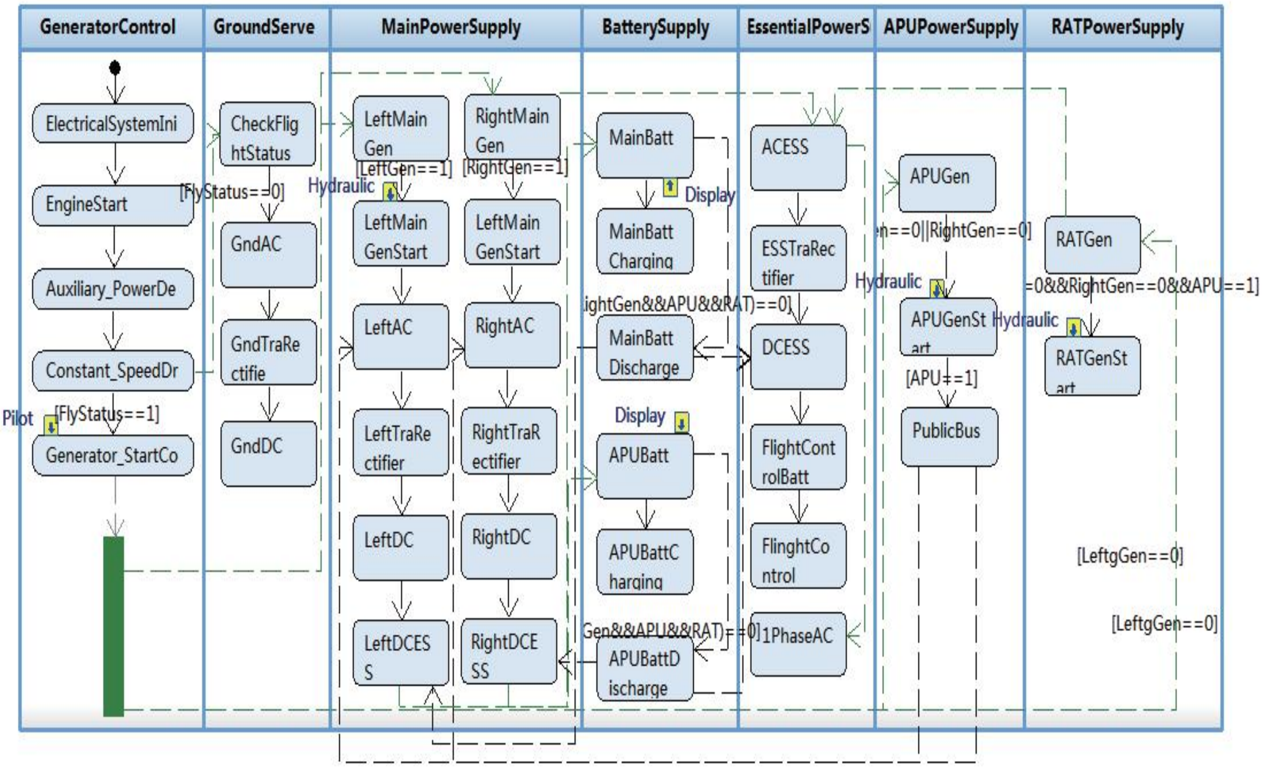

Fig. 5 ES Power supply use case “White-box” activity diagram

“White-box” sequence diagram is exported after the “White-box” activity diagram, defining data port of sub-components to describe use case scenario of events interaction sequence. “White-box” needs establish state machine diagram for each sub use case, and the above sub use case state machine diagrams are not completely independent, the parameter or event changes of a sub use case can affect all subsystems, only if subsystems interact perfectly, the whole function be fully realized.

After modeling all use cases, we can integrate the whole system model to get a complete civil aircraft ES architecture.

4. ES simulation

After completing the ES modeling, dynamic behavior, operation logic and data of input/output need to be displayed and verified. Power supply interactive interface as shown in Fig. 6, design interactive interface through simulation panel of Rhapsody platform, simulation panel relates to parameters of ES “White-box” State machine diagram to provide necessary ES model data. Sending events to the model through the interactive interface, and displaying the data or event changes in the form of visualization on interaction interface to verify the logic and data of ES model.

6 “Black-box” architecture model, 15 “White-box” model were established and 3 simulation models were established in system development. Elements were reused in different model, improving the efficiency of architecture design and analysis. The uniqueness of element attributes also ensured data consistency.

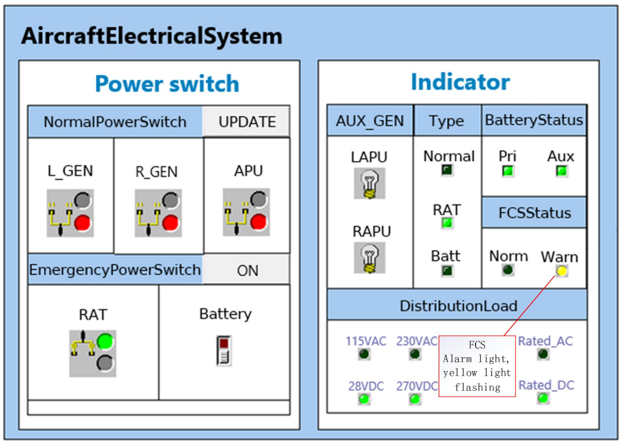

Fig. 6 Power supply interactive interface

5. Conclusion

Traditional design method of ES is text-based system engineering. However, this method has low development efficiency and cannot meet the high-quality design requirements. So, the model of civil aircraft electrical system is established and simulated by MBSE, it is of great significance to realize the modeling design of the whole aircraft system.

In this paper, Rhapsody, SysML and SAE ARP4754A are combined with the physical architecture of the electrical system, we provide model design and simulation of the electrical system. Through the model-based system engineering, the designers can evaluate the design scheme in the early phase, eliminate the ambiguity and errors, as to avoid the repeated engineering development.

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