Research on Civil Aircraft Design Based on MBSE

Yunong Wang[1], An Zhang[1](✉), Delin Li[1], and Haomin Li[2]

[1] School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China
wangyn@mail.nwpu.edu.cn
[2] Shanghai Aircraft Design and Research Institute, Shanghai, China

Abstract. Civil aircraft is a complex system. With the development of aviation industry, scale and complexity of the systems are getting larger and larger. Hence conventional design process can no longer satisfy the following requirements: integrality and consistence of information, capability of describing different activities and flexibility of requirements changes. However, MBSE (Model based System Engineering) has shown its potential of handling the challenges. Instead of natural language, MBSE adopts different models as the basic elements to storage and transfer data. Hence the relation between requirements of different design levels will be more intuitive and a faster response to requirements modification become possible. In this paper, from the top requirements of civil aircraft, we introduce a V&V activity model to the existing Harmony-SE to construct a both efficient and effective design framework. Comparing with conventional V design process model, our method enables the incremental and iterative developing method as well as a validation step after each design stage. These will produce better-quality aircraft within shorter development period.

Keywords: Civil aircraft design · MBSE · V&V activity model · Harmony-SE

1 Introduction

The main purpose of system engineering is to construct a system which can satisfy all the complex requirements. The system engineering in conventional civil aircraft design process belongs to TBSE (Text based System Engineering). The main outputs of TBSE is a series of "natural language" based texts [1]. Although the text is very expressive and can convey a lot of information, it might be ambiguous under some circumstance. Moreover, natural language is not capable to deal with specific cases in some complicated activities.

Civil aircrafts are very complex systems. They are non-linear combinations of more than one hundred subsystems. With the development of aviation industry, this number is still growing. These subsystems can accomplish their specific task, they also can make up a civil aircraft to accomplish more complex tasks [2]. During the conventional civil aircraft design process, reports, drawings, experimental data and financial information generated during the engineering process are mostly recorded in the form of text

X. Zhang (Ed.): APISAT 2018, LNEE 459, pp. 1273–1283, 2019.
https://doi.org/10.1007/978-981-13-3305-7_100

documents. Therefore, maintenance and managements of the information could be a big challenge. Also, there is no guarantee that during the transformation, the integrality and consistence of information can be well-remained.

The drawbacks of text drove people to consider different basic element to storage engineering information. And then MBSE came into being. Instead of natural language texts, MBSE adopts different models as the basic element of systems. Comparing to TBSE, it has many irreplaceable advantages, and there are major changes in modelling language, approaches and tools [3].

Besides the type of basic element, the design process itself also met some challenges. The whole design process of large civil aircraft is a complex and long-term work. Engineers usually adopt a traditional V model life cycle (Fig. 1) to organize their work. It can be roughly divided into the following steps: firstly, conceptual design will be determined according to the design requirements; the second is the preliminary design and detailed design; the final is the prototype test and experiment, flight test and finalization until mass production and put into use.

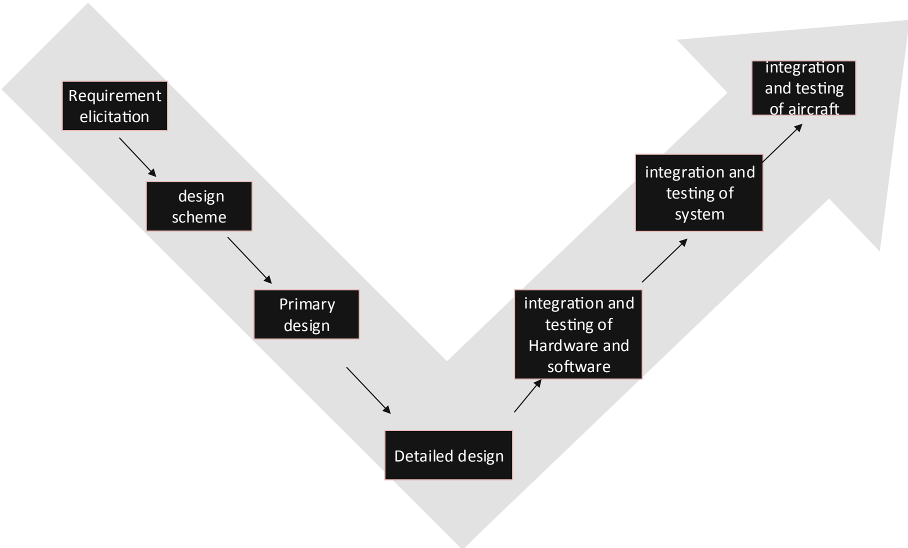

Fig. 1. Traditional V life circle model in civil aircraft design.

Although this model is quite straight forward, it cannot match the complex requirements of modern airplanes. The procedure is very classic, however, it's a one-way process. Hence an incremental iteration cannot be realized under this framework. Also, in this model, we expect that each work product created in every activity is complete, accurate, and correct at that stage.

Unfortunately, with the development of aviation industry, the function and complexity of civil aircraft are multiplying since the multi-disciplinary and multi-disciplinary technologies; however, the product development cycle is constantly shortening under market requirements. These ask for a both efficient and accurate design process. The key problems of current TBSE V circle model are as followed:

1. The quality of product. The large amount of engineering data cannot be described precisely by texts. Hence during the design process, the designing scheme cannot satisfy the stakeholder needs.
2. Long designing time. As we mentioned above, V circle doesn't allow incremental iteration. Therefore, regardless of where the modification occurs, the process will start again from the requirements analysis phase, increasing the design cycle and highly reducing work efficiency [4].
3. Large work quantity and poor efficient. During the conventional civil aircraft design process, the validation of engineering data will not begin until the whole design procedure is finished. These lead to defects in the design that cannot be detected in time, reducing work efficiency and affecting product quality.
4. Slow response to requirement modification. There is no traceability link between design requirements of different levels. If any of these requirements have been changed during the design process, researchers cannot find whole influenced requirements and adjust the requirements in time.

We think Traditional Systems Engineering can no longer handle the complex design process and a revolution is needed. Many engineers think a MBSE based framework can cope with most of these challenges. Although MBSE has been widely used in many areas, including aeronautics and aerospace industries, existing works mainly focus on small subsystems. Kaslow et al. verified how to realize the task of RAX CubeSat (Radio Aurora Explorer Cube Satellite) in outer space by establish executable MBSE model [5]. Pessa et al. use MBSE method to integrate CMs (Control Maintenance system) and Fs (Fule system) and emulate the integrated system [6]. Ferreiral and Gorlach exploited the controller of AGVs (Automated Guided Vehicles) based MBSE in Visual Paradigm software and realized the control in Microsoft Visual Studio environment. They utilized designed AVG realized the traction of tow truck according to the predetermined path [7].

The existing wildly-used variations of MBSE include Harmony-SE, OOSEM (Object-Oriented Systems Engineering Method) and RUP-SE (Rational Unified Process-Systems Engineering). Among all these, Harmony-SE is most suitable to solve some of our problems we stated above. In fact, this method has been widely used in aviation industry. Liu and Cao et al. researched the design methods of concept aircraft based SysML and Simulink. They taking the unmanned flight control system-Predator as an example, designed and emulated the concept aircraft [8]. Han et al. combining traits of spacecraft, put forward the MBSE method which regard IDS (Interface Data Sheet) as unified data source [9]. Xue et al. realized the design of avionic communication system by Harmony-SE method and finished the establishment of models of requirements, functions and architecture [10]. However, all these applications are limited to small subsystems.

But our purpose is to construct a framework for large civil aircraft design. In this large system, a validation step of each stage is needed to solve the problem we mentioned in the third problem of V circle model. Therefore, in this work, we combine the V&V active model with an existing method Harmony-SE, which will be discussed in next section, to construct a particle design process.

The paper is organized as followed: a brief introduction of MBSE and its variation Harmony-SE is placed in Sect. 2. Then, a detailed discussion of our novel framework will be given in Sect. 3. And we will conclude our work in Sect. 4.

2 MBSE Methodology

MBSE is a methodology which will lead to a "model-based" or "model-driven" system engineering. It's a summary of methods, working-flow and tools used in corresponding systems. In the framework of MBSE, we build demand models, functional models, and architectural models through UML (Unified Modeling Language) to realize the decomposition and allocation of requirements, functions and architectures. MBSE is a formal application of modeling methods that enable modeling methods to support system requirements, design, analysis, validation, and validation activities, starting with the conceptual design phase and continuing through design development and all subsequent life cycle stages [11]. As a better approach than text specification, models are introduced to create, manage, and validate engineering data. The model used by MBSE, including dynamic information of requirements, structure, behavior, and parameters. The model enables a more intuitive understanding and expression system for all types of professional engineering and technical personnel throughout the organization, ensuring that the entire model is delivered and used based on the same model.

Also, we can implement "validation" and "confirmation" of system requirements and functional logic through model. And it can drive co-simulation, product design, implementation, testing, synthesis, verification and validation.

The INCOSE (the International Council on Systems Engineering) Joint OMG (Object Management Group) developed a SysML (System Modeling Language) suitable for describing engineering systems based on the UML (Unified Modeling Language). The company also developed the corresponding tools to support SysML, and integrated the SysML modeling tools with existing professional analysis software such as FEA, CAD, etc. And they also proposed the overall solution of MBSE, which has the basis of the actual development engineering system [12].

Under the framework of MBSE, all parties work on demand analysis, system design, simulation, etc. around the system model to facilitate the collaborative work of the engineering team, so that the entire design team can make better use of the advanced results of models and software tools of various professional disciplines.

The Harmony-SE method extends the life cycle of the traditional V model and transforms it into an incremental iterative periodic activity stream, as shown in Fig. 2.

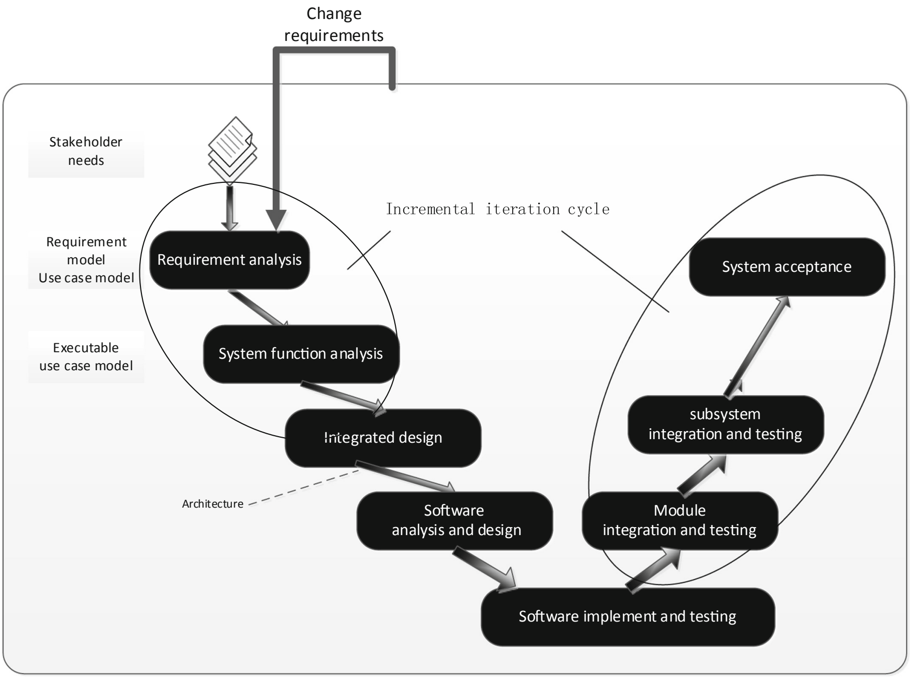

Fig. 2. Flow-chart of Harmony-SE.

This extension is performed though introducing an extra incremental iterative periodic activity stream. Traditional V model life cycle use this life cycle for only one time. For example, only when all requirements were analyzed, the work of system function analysis can begin. However, in the Harmony-SE life cycle, the activities can be executed for several times, and the engineering data can be transmitted to the downstream engineering incrementally. During the design process, researchers divide use cases into several parts, and every part of requirements begin to work solely. When requirements be changed, researchers only need to analyze the changed requirements.

Harmony-SE method has its specific process norm and tools of designing. IBM specializes in the Harmony-SE toolkit, leveraging Rational Rhapsody's execution capabilities to perfectly implement the Harmony-SE process. Like we wrote in Sect. 1, Harmony-SE has been adopted by aviation induction for years. For instance, Harmony-SE-based Rhapsody series tools are currently widely used in the industry, and its users include COMAC (Commercial Aircraft Corporation of China Ltd) and some subsidiaries of AVIC (Aviation Industry Corporation of China) [13].

Nevertheless, Harmony-SE is designed for small systems. For a complex project like civil aircraft design. It lacks a validation step of each design phase. Based on this idea, we are going to design a model database which can perform real-time inspection of engineering data to improve the efficiency and accuracy of civil aircraft development.

3 Civil Aircraft Design Process Based MBSE

To handle all the challenges, we propose the civil aircraft design process as shown in Fig. 3.

Firstly, model-based engineer data transformation method can ensure the veracity and integrality of engineer data, reduce possibility of losing and inaccurate describing data during the transfer process. Meantime, researchers can manage the requirements by establishing the traceability link. Once any of the requirements have been changed, researchers will make a risk assessment in time and change the rest influenced requirements.

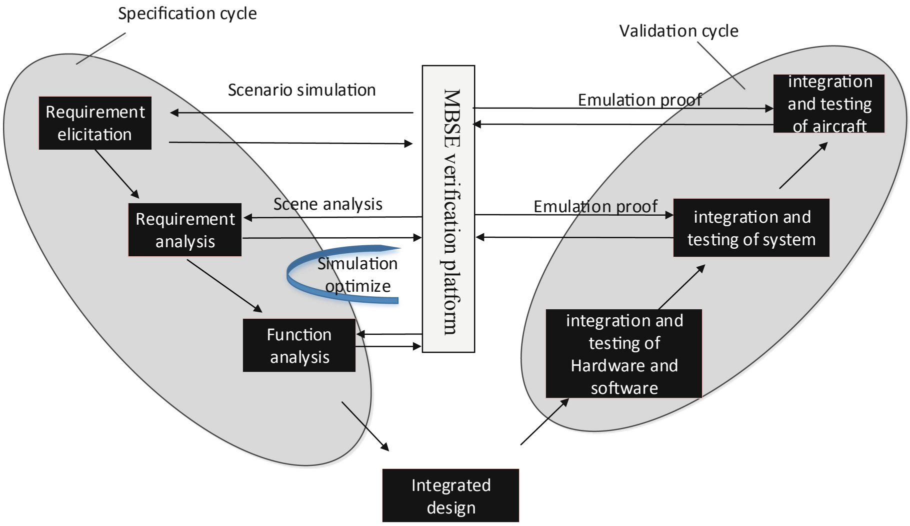

Fig. 3. Civil aircraft design process based MBSE.

Aiming to the problem of slow response to requirement modification, we adopt the flow path based on Harmony-SE, using incremental activities to reduce response time and lead time. To solve the problem that cannot find the inaccurate design in time leading a mass of rework, we adopt V&V model life cycle, establish the MBSE verification platform. This will verify the data during the design process, and insure the validity of engineer data. Researchers will find the inaccurate design and amend them in time, avoiding the rework and reducing the workload.

Based on the V model, we establish a V&V model and introduce a verification work at each stage. In the left half of the large "V" process, the data is post-tested by a small "V" to ensure the correctness of the design requirements. In the right half of the large "V" process, a small "V" is used for the priori process, looking for problems in the simulation and avoiding unnecessary losses. A virtual simulation test that puts the model into a defined simulation scenario for inspection can more clearly verify that the design meets the requirements. After each stage of work is completed, the model data is placed in the MBSE verification platform for inspection to ensure that the engineering data meets the requirements before proceeding to the next stage of work.

The process is divided into the following stages:

1. Requirements elicitation: Requirements are the first analysis and definition in civil aircraft design. At this stage, researchers should identify the stakeholders and capture stakeholder needs from stakeholders. Stakeholders are any living or non-living things that are affected by the system. The designer divides the stakeholders into deterministic stakeholders, prospective stakeholders, and potential stakeholders based on the number of stakeholder ownership of the company's legality, rights, and urgency. For civil aircraft, the identified stakeholders are mainly aircraft developers, civil aviation companies, civil aviation bureaus, airports, government departments, pilots and various flight attendants. The prospective stakeholders mainly include people who have boarded the aircraft and competitors etc. Potential stakeholders are all the people. After identifying stakeholders in systems engineering projects, researchers need to obtain their original needs from stakeholders through a variety of survey research methods. Typical survey research methods include field survey, questionnaires, interviews, and joint requirements planning.
2. Requirements analysis: By refining and formalizing the captured requirements, the model is built and simulated in the virtual scene to generate detailed development requirements. Due to the more functional requirements of the civil aircraft, DODAF (Department of Defense Architecture Framework) was introduced. According to DODAF, the requirements analysis and definition of the civil aircraft were carried out, and the requirements were captured in the scene to obtain the design requirements of the civil aircraft system. The design requirements use an engineering-oriented technical language representation that describes the behavioral state of the system in detail.
3. Function analysis: Detailed design requirements are obtained through function modeling, function analysis and other methods. Function analysis is based on use cases, creating use cases based on the development requirements of the requirements analysis stage output. The use case is an intermediate point that connects requirements and functions. To ensure that all functional requirements and related performance requirements are covered by these use cases, it is necessary to establish a connection and provide traceability. The workflow to the use case is shown in Fig. 4.

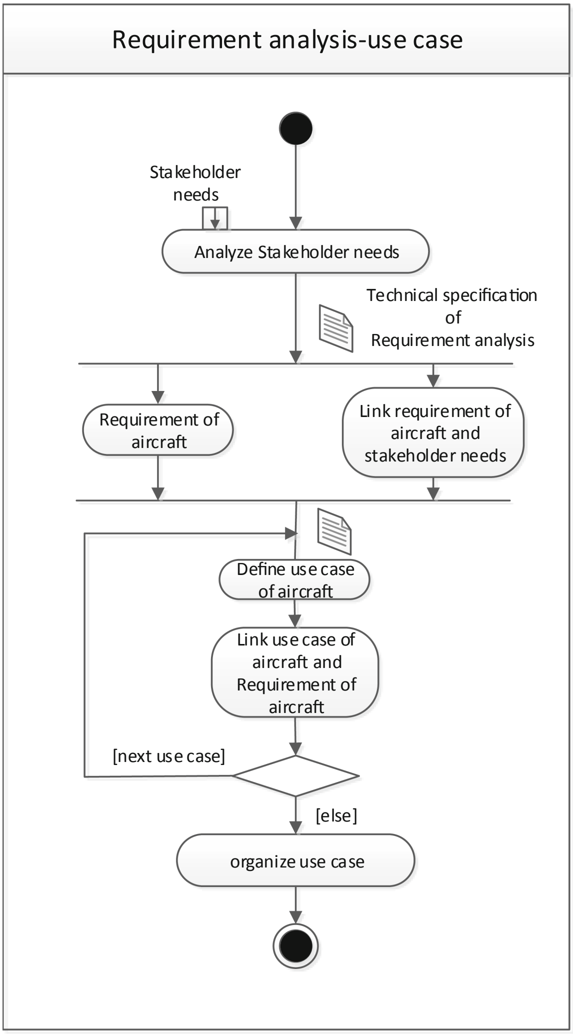

Fig. 4. Requirements-use cases workflow

Function analysis creates executable models to describe continuous and concurrent behaviours and events that occur over time in each use case. Through the logical relationship of these behaviours, the specific activities and resource/data flow and activity interface information are determined to generate specific design requirements. The function analysis workflow is shown in Fig. 5.

4. Synthesize design: Comprehensive design according to design requirements. In the design process, the detailed design requirements and interface information determined in the function analysis stage should be designed to ensure consistency with the design requirements.

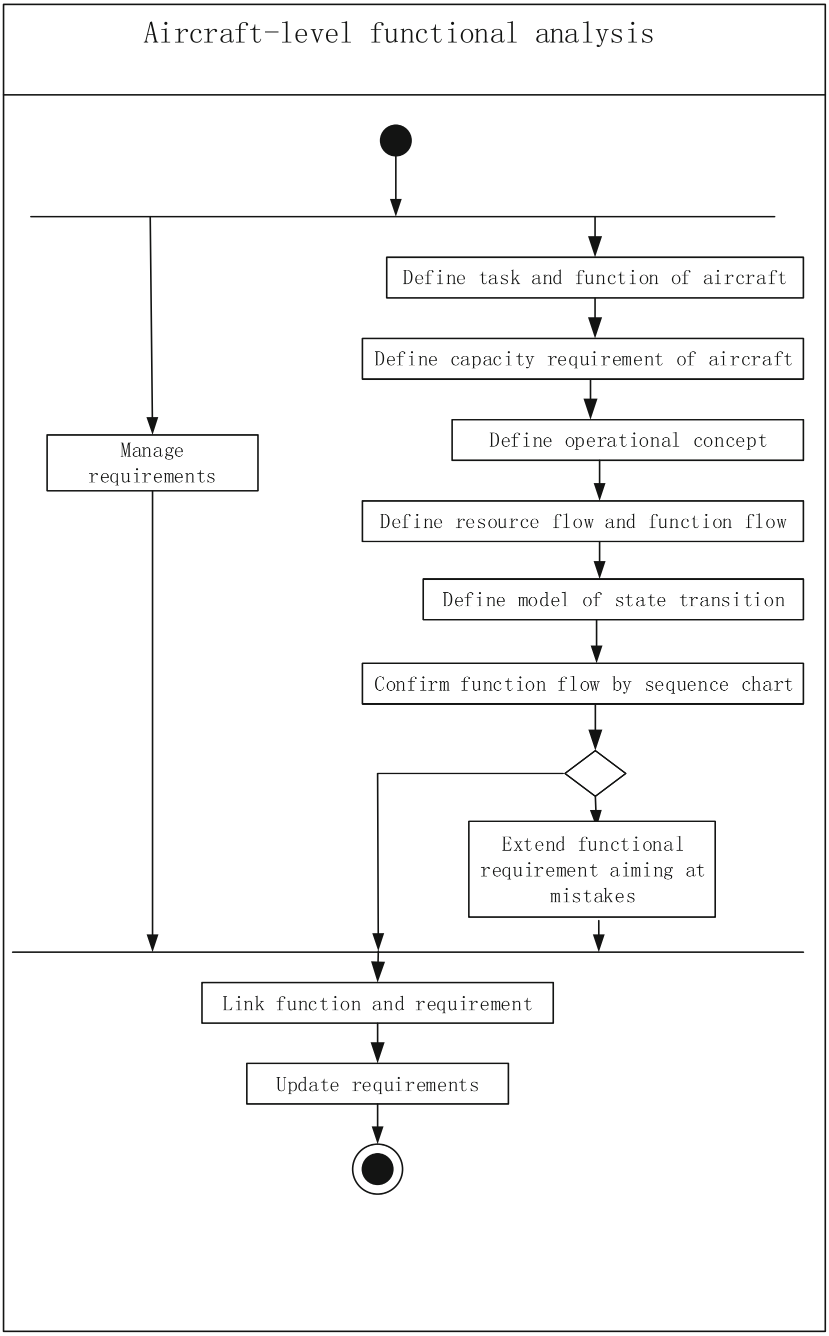

Fig. 5. The function analysis workflow of civil aircraft

5. Integration and testing of hardware and software: Test the software and hardware of the design, build models and save them.
6. Integration and testing of system: Before the physical integration and experiment, the model established in the previous stage is putted into the simulation scenario for verification. After confirming that the system is correct and meets the design requirements, the physical system is integrated and tested to ensure that the system does meet the requirements in the physical world.
7. Integration and testing of civil aircraft: Similar to the previous stage, the aircraft model is first simulated in a virtual scene and then related physical experiments are performed.

The civil aircraft development process can realize the verification and confirmation of system requirements and function logic through core technology links such as requirements analysis, system function analysis and synthesize design in the early stage of civil aircraft R&D. The definition of the product is clear and accurate early in the entire project, and the correctness of these data and models is continuously verified throughout the design process. In addition, due to the increasingly fierce market competition and the changing requirements, we require that the function architecture, logical architecture and interfaces of the civil aircraft system be flexible and can respond quickly to changes. Through the process of civil aircraft development, the requirements can be traced in real time. When a requirement changes, it can immediately find and amend the remaining levels of demand associated with it and conduct a risk assessment to assess the risk, improving design efficiency and shortening the development cycle.

4 Conclusion

In this paper, we analyse the conventional civil aircraft design process and summarizes the existing problems. In response to these problems, an MBSE-based civil aircraft design process is proposed. The process is based on the Harmony-se process. Establish traceability links between the various levels of requirements. When one of requirements changes, the remaining influenced requirements can be discovered in time, so that the researchers can conduct risk assessment and deal with the changed requirements. To improve the design efficiency and robustness of whole system as well as the quality of aircraft, we first introduce incremental iterative methods to the process to enable a simultaneous development of multiple activities. Moreover, a novel V&V activity model is employed to construct the MBSE integration platform. And this makes engineering data in each step of the activity process can be verified by real-time simulation, which will ensure the correctness of engineering data and improve product quality.

This process can greatly improve work efficiency, shorten the development cycle, and provide an effective method for civil aircraft development.

Acknowledgements. The research presented in this paper is supported by Ministry of Industry and Information Technology of the People's Republic of China, under Grant MJ-2016-F-02.

References

1. Zhu J, Yang H, Gao Y et al (2016) Summarize of model-base system engineering. Aeroengine 42(4):12–16
2. Li W.-j (2005) Aircraft configuration design. Northwestern Polytechnical University Press
3. Chen H-t, Deng Y-c, Yuan J-h et al (2016) Fundamental of model-base system engineering. Aerosp Chin 32(3):18–23
4. Hoffmann HP (2011) Systems engineering best practices with the rational solution for systems and software engineering, version 4.1. IBM Corporation, Somers, NY (US)
5. Kaslow D, Anderson L, Asundi S, et al (2015) Developing a CubeSat model-based system engineering (MBSE) reference model-interim status. In: IEEE aerospace conference, pp 1–16. IEEE
6. Pessa C, Cifaldi M, Brusa E, et al. (2016) Integration of different MBSE approaches within the design of a control maintenance system applied to the aircraft fuel system. In: 2016 IEEE international symposium on systems engineering (ISSE), pp 1–8. IEEE
7. Ferreira T, Gorlach IA (2016) Development of an automated guided vehicle controller using a model-based systems engineering approach. S Afr J Industr Eng 27(2):206–217
8. Liu X-h, Cao Y-f, et al (2011) Flight control system conceptual prototype design based on SysML and Simulink. J Electron Sci Technol 40(6):887–891
9. Han F-y, Lin Y-m, Fan H-t (2014) Research and practice of model-based systems engineering in spacecraft development. Spacecr Eng 23(3):119–125
10. Xue W, Jia C-q et al (2016) Application of MBSE in avionics communication systems. Electron Sci Technol 29(5):45–48
11. Friedenthal S, Griego R, Sampson M (2007) INCOSE model based systems engineering (MBSE) initiative. In: INCOSE 2007 symposium
12. Friedenthal S, Moore A, Steiner R (2006) OMG systems modeling language (OMG SysML™) Tutorial. In: INCOSE international symposium
13. Zhang Y, Ni Z-j, Xiao Z-b et al (2012) Research and application of harmony-based system modeling method in integrated data management system. Avionics Technol 1:42–47