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Research on the Overall Design Method of Missile Based on Model

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Abstract: *With the development of war, the complexity of missile weapon system has reached an unprecedented height, and the traditional document-based design method can no longer meet the overall design requirements of missile. At present, the best practice strategy in the field of systems engineering is the idea and method of model-based systems engineering, which has its unique advantages in dealing with complex system problems. It can be used to improve the overall design efficiency of missiles and enhance the overall optimization ability.*

Keywords: *Missile; Overall Design; MBSE; System Architecture*

1. Introduction

With the evolution of the war form and the progress of science and technology, the modern war form has undergone earth-shaking changes, and the requirements for weapons and equipment are becoming higher and higher. As an important weapon in modern Warfare, missiles have become more diversified in their missions, more complex in their application scenarios, significantly increased in system scale and complexity, gradually increased in unexpected and unpredictable interactions between system elements, and increasingly difficult in model development, and urgently need to strengthen top-level requirements analysis and comprehensive demonstration and evaluation means. Traditional document-based system engineering relies on a large number of documents as the basis for project information exchange, and R&D personnel need to devote limited energy to document maintenance, which makes it difficult to bring into play the initiative of personnel[1]. And the system engineering based on documents is limited by the ambiguity, fuzziness and subjectivity of natural language, which can not meet the requirements of system design in the demonstration, design, development and manufacture of large and complex industrial products[2][3]. The current best practice strategy in the field of systems engineering is model-based systems engineering (MBSE), which is based on the concept of applied systems architecture and serves as a rigorous, objective, quantitative, and measurable criterion for defining, analyzing, and building systems that apply advanced technologies. Therefore, the introduction of MBSE method into the overall missile design is of great significance to improve the overall missile design efficiency.

In 2007, in the International Council on Systems Engineering international conference, formally put forward the definition of MBSE: "Based on the model of system engineering is through formal modeling method, from the concept design phase can support system requirements, design, analysis, verification and validation activities, and continued throughout the follow-up research and development life cycle stage"[4]. Once MBSE was proposed, government organizations such as the U.S. Department of defense, NASA and ESA, as well as international aerospace companies such as Boeing and Lockheed Martin, carried out corresponding research, and ensured the rapid development of many aviation, aerospace and weapon equipment projects through MBSE. The development of MBSE method started late in China, and it was not until 2012 that the method began to be applied in different industries in China[5]. In the field of aerospace, relevant enterprises and colleges have also conducted corresponding research. He Wei et al. of Beijing Institute of Aerospace Systems Engineering and others proposed a model-based launch vehicle design framework[1]; Liu Hong-Jie et al. from Aerospace Dongfanghong Satellite Co., Ltd. proposed a modeling design solution for small satellite TT&C subsystem based on MBSE[6]. Song Yu et al. from Xi 'an Modern Control Technology Research Institute applied MBSE technology to the development of missile system[7], and proposed the ideal MBSE process activities, the composition of development support environment and key indicators, but did not give the system architecture suitable

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for the overall design of missile. On this basis, this paper introduces model-based system engineering design to the overall design of missiles, taking solid ballistic missiles as an example, designs and constructs a system architecture applicable to the overall design of missiles for the characteristics of the overall design of missiles.

2. Feasibility analysis of MBSE application in missile overall design

At present, the traditional "V" system engineering process commonly used in the field of system engineering is a phased serial research method. The problems of system design are often not exposed until the end of development or even delivery, flight testing and use phases[8][9], cause the whole system design process is iterative, greatly increased the system development of the economy and time cost.

In contrast, the essence of MBSE method is to decompose the top-level system problem into a variety of small problems that can be solved, then study and formulate solutions to these small problems, and then add these decomposed small problem solutions to the whole system layer by layer, and finally solve the problem at the top[10]. The method is characterized by model-based digital design, simulation-driven virtual verification and model-based early verification which realizes the transformation from the traditional " demand-design-manufacturing-test" mode to "demand-design-virtual synthesis -virtual verification-digital manufacturing-physical manufacturing".

To sum up, compared with the traditional serial system engineering method, MBSE method uses an integrated, clear and consistent model to convey information[11], and provides an overall parallel research method for system engineering through the demand based problem decomposition mode. When it is applied to the overall design of missiles, it can significantly improve the efficiency of system design and reduce the cost of research and development while freeing designers from the heavy work of document maintenance. It has broad development space and great development potential.

3. Model-based missile design framework

The overall missile design based on MBSE mainly includes two aspects: product design and integration verification. According to the professional division of missile design and the characteristics of missile system, MBSE method is integrated into the overall design of missile on the basis of fully referencing the existing missile design methods, and the model-based overall design framework of missile is constructed as shown in Figure 1. The architecture consists of four parts: model-based database, system design and verification platform, model-based system architecture and performance verification model.

3.1. Model-based database

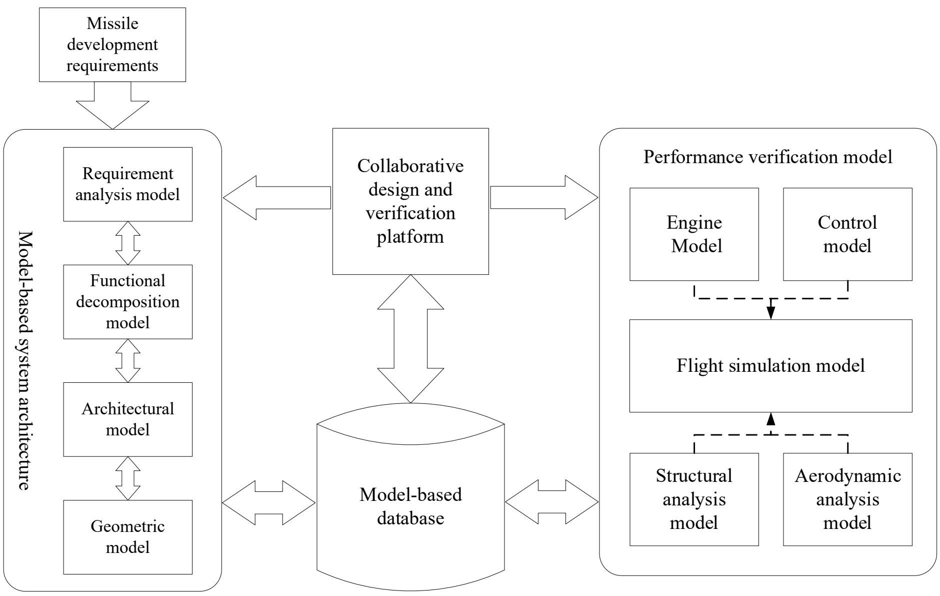

Figure 1: Overall design framework of missile.

ISSN 2616-5767 Vol.6, Issue 6: 65-71, DOI: 10.25236/AJETS.2023.060610

Build a unified database based on model to realize the unified management of data. On the one hand, building a model-based database storing the design schemes of historical missile models can provide an important reference for the research and development of new missiles, which can improve the reliability of the overall design scheme of missiles and speed up the development progress of models. Adopt the unified database for research and development, on the other hand, the design of the data found in the unified relation management, to ensure that in the process of research and development of different professional analysis, the consistency of the data when each subsystem design, the design process of the interaction between the Shared data and database, realization of the design process data can be recorded and traceable.

3.2. Collaborative design and verification platform

A system engineering framework based on MBSE is constructed to define the flow template of missile overall design, which can control the data flow of database based on missile design requirements and platform as the main body. It is of great significance to improve design efficiency and avoid human error caused by document transfer to realize data transfer among different specialties and subsystems through collaborative design. At the same time, the platform is used as the integrated scheduling center of the whole framework, through which the integration of design data and the control of design and verification progress are realized.

3.3. Model-based system architecture

According to the development cycle and the function of each model, the system architecture based on the model is divided into four parts: requirement analysis model, functional decomposition model, architecture model and geometric model. The requirement analysis model mainly includes three types of requirement models: user requirement, system requirement and physical requirement. By itemizing the design indicators and taking them as the input of the whole system, studying the derived relationship between each requirement model and establishing the requirement association diagram, the consistency of functional requirement transmission can be verified. By defining the interaction between the missile system and other systems, the functional decomposition model clarifies the use scenario of the missile system, and realizes the refinement of the demand for the missile system and the concretization of the missile system functions. On this basis, the system functions are decomposed into each relevant part of the system layer by layer, and the corresponding indexes are calculated. The architecture model is mainly divided into the logical architecture model as an example. The logical architecture model maps the functional requirements of each part to the logical framework, and carries out the interaction between each module by defining the interface between each module. The physical architecture model inherits all modules of the logical architecture model to further refine the related attributes of each module. The geometric model is the CAD model of the design scheme, which is used to express the geometric dimension and geometric constraint relation and realize the visualization of the model.

3.4. Performance verification model

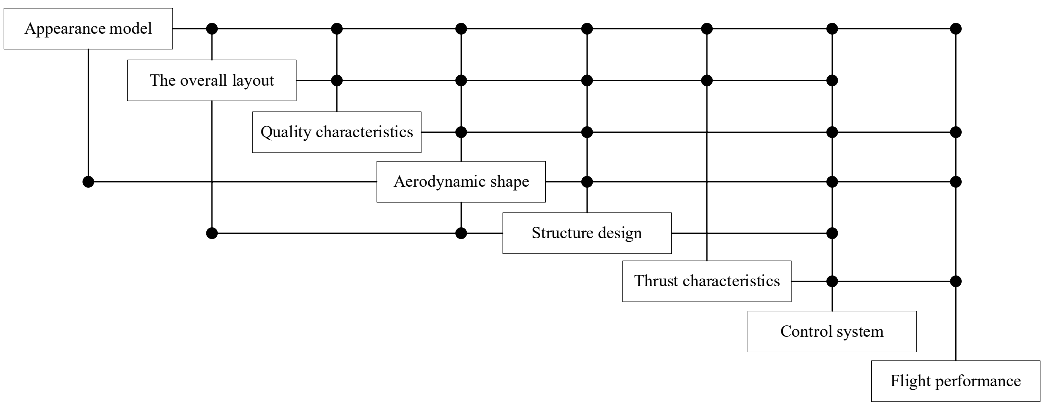

Figure 2: Coupling relationship among disciplines.

Missile design involves a number of disciplines, and each discipline is closely coupled together, the coupling relationship is shown in Figure 2. According to the related disciplines covered by missile overall design, combined with the characteristics of missile overall design, the missile overall design performance verification model can be divided into five analysis verification models: engine model, control model, structural analysis model, aerodynamic analysis model and flight simulation model. These models mainly analyze and calculate the part or the whole of the missile design scheme through the relevant theoretical knowledge of each single-subject analysis, and integrate the single-subject model into the multi-subject analysis model by analyzing the coupling relationship between each model and setting the state variables. On this basis, the overall design and collaborative platform are used for unified scheduling, and the design parameters and analysis results can be transferred and shared quickly, and the design scheme can be updated iteratively.

4. Model-based missile overall design solution

According to the above overall design framework and the design idea of "architecture independence and data fusion", a model-based overall design specification process of missile is formed: Taking the missile design requirements as the traction, the overall design parameters of the missile are obtained through the demand analysis model and functional decomposition model. On this basis, the design indexes of the missile body structure, control system and engine system are calculated, and the development requirements of each subsystem are put forward, and the fine design of each subsystem is carried out. After the subsystem design is completed, the model based subsystem verification is carried out. After each subsystem meets the design requirements, the relevant parameters of the subsystem are integrated for overall verification, and the scheme is iteratively optimized according to the verification results.

4.1. Acquisition of overall parameters

The overall parameter design of missile is to obtain the overall configuration of missile oriented to flight mission through demand analysis and functional decomposition model, and to determine the design scheme of each subsystem. In the program demonstration stage, the overall configuration depends on the missile's strike range, warhead mass, engine characteristics and other input conditions, which are historical and depend on the historical model development data and test data. The overall design model is calibrated by calling the historical model design scheme and other data stored in the database, and the preliminary missile overall design parameters are obtained for the overall design. In the subsequent development stage, the overall parameter model can be optimized and iterated continuously according to the product model obtained from the detailed design of each specialty, and gradually approximates the real state of the missile.

4.2. Engine model design

Although the structure of solid state engine is relatively simple, the principle simulation model of solid state missile engine is complex, and the calculation is large, and the design of solid state missile engine is relatively independent, the power system is the focus of the missile overall design is whether it can meet the system requirements. Therefore, according to the overall development requirements of the power system, the engine performance parameters and architecture model of historical models are used to design the power system, and according to the verification results of the power model, the power system agent model is established to output the data needed for flight simulation for the system and improve the speed of flight simulation.

4.3. Control model design

The design of missile control system has great limitations, such as the pitch Angle control scheme and the on-board power supply design scheme, which are restricted by the development of control theory and battery materials, and are often limited to a limited number of candidates in the overall design. Therefore, when designing the control system, the scheme based on model base can be adopted. According to the functional requirements of the missile, the program that meets the design requirements is selected from the model base. According to the selected design scheme, the standard trajectory scheme is generated by calculating the flight program Angle of the missile, and based on the standard trajectory scheme, the equivalent model of the control system is constructed to provide the control force and control moment needed in the flight process of the missile for flight simulation.

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4.4. Structural analysis model design

The body structure of solid propellant missile usually includes the body, engine, interstage, war-head and so on. According to the requirements of the overall index, the missile structure design model based on the model is constructed to realize the functions of structural scheme selection and parameter optimization design, structural system fine design, structural strength checking and so on. After determining the structure scheme of the missile body, the parametric modeling of the missile can be realized according to the design parameters of the missile body, and the mass characteristics of the missile and the moment of inertia about each axis can be calculated according to the mass distribution of the missile body.

4.5. Aerodynamic analysis model design

The aerodynamic characteristics of the missile determine the stability of the missile flight. According to the needs of missile flight simulation, the aerodynamic analysis model is constructed, the structure of the missile model is analyzed, the position of the pressure center and the aerodynamic parameters are calculated, and the aerodynamic parameter proxy model is fitted on this basis.

4.6. Flight simulation model design

Flight simulation model is the core of performance verification model. According to the theory of ballistics related flight simulation model was constructed, by receiving collaborative design and verification platform integration of design data, scheduling every single subject analysis model, realize the missile flight simulation, and through the interpretation of the results of simulation, verify the design scheme satisfy the design requirements.

5. Prospect of future development

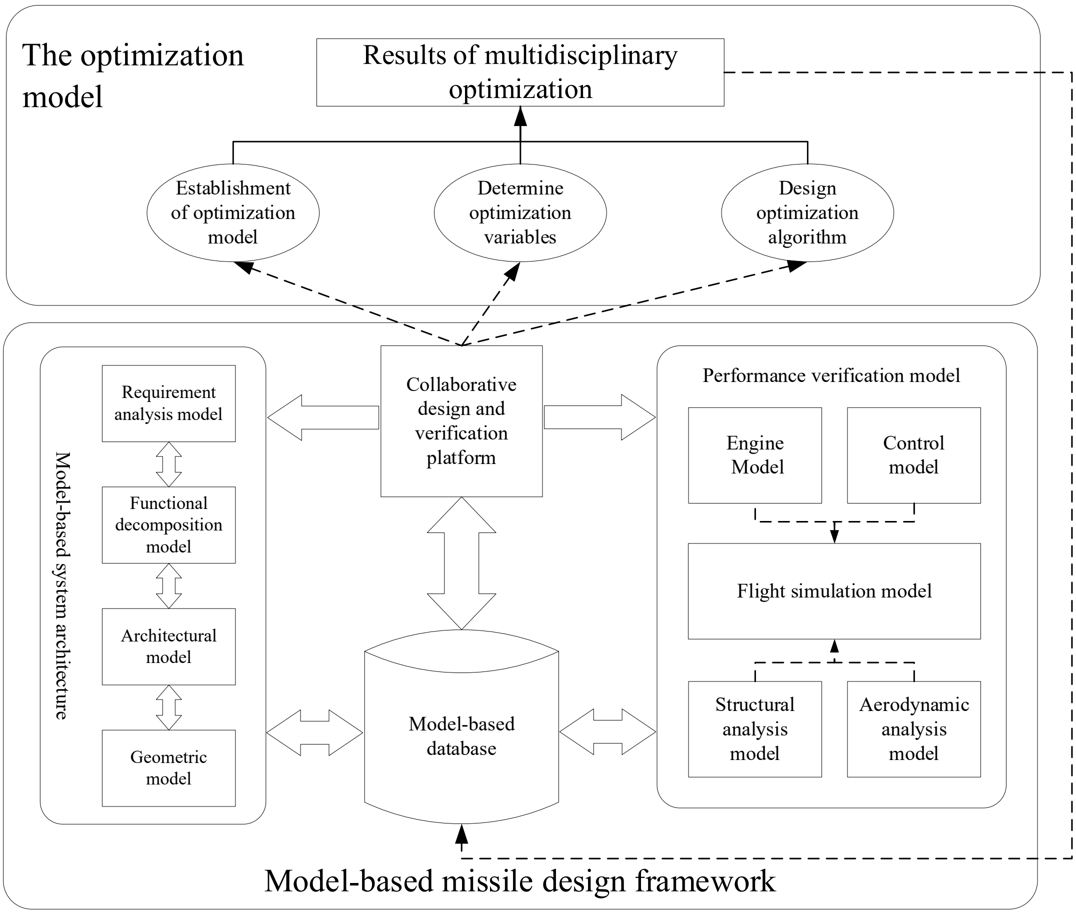

Figure 3: Multi-objective optimization framework of missile overall design.

The overall missile design is a typical multi-objective optimization problem, which involves the simultaneous optimization of multiple disciplines and multiple subsystems, and these systems are usually not independent but coupled together, restricting and influencing each other, and there is even a certain degree of conflict between the targets. Therefore, in the process of missile system design, it is necessary to use a variety of optimization criteria to balance and deal with the conflicting and contradictory objectives, so as to get the optimal design scheme that coordinates each element. Due to the complexity and nonlinearity of the missile system, it is difficult to obtain the optimal scheme that meets the design conditions at the beginning of the design. Therefore, it is necessary to continuously carry out iterative optimization of the design scheme in the design process. If the efficient data transmission capability of the model-based missile overall design method can be fully utilized in the process of optimizing the missile design scheme, the multi-objective optimization platform for missile overall design as shown in Figure 3 can be constructed on the basis of the research content of this paper. Achieving multidisciplinary design optimization through system models can enhance the speed of system iterative optimization, which is of great practical significance to further reduce missile development costs and shorten the development cycle.

On the other hand, MBSE technology MBSE technology will evolve from a single system to a complex system and from the local to the overall direction [12]. The missile weapon system is not only the missile system itself, and the application of model-based missile overall design method in the field of missile overall design will not be limited to the overall design of the missile system, but will be extended to the design of the whole missile weapon system including ground test, launch and other auxiliary support equipment.

6. Conclusion

This paper analyzes the development trend and prominent problems of missile system development, and puts forward a model-based missile overall design platform framework by studying the model-based system engineering method, and designs the model-based system architecture and the performance verification model based on the analysis model of various disciplines. The idea of unified management of process data and historical model data is realized by using the model-based database, which frees the designers from the heavy non innovative work of technical coordination, design confirmation, design document update and so on. While reducing the work of designers, it ensures the accuracy and unity of design to the greatest extent, and improves the efficiency and reliability of the whole research and development work. Although the current research on MBSE is still in the initial stage of capability formation and cannot fully realize the ideal process, the research shows that the model-based overall design method can significantly reduce the errors in design, reduce the dependence on flight test and test cost, improve the overall design ability of missiles, and promote the transformation of missiles from traditional design mode to digital mode.

References

[1] He Wei, Hu Jiuhui, Zhao Ting, Peng Yue, Tang Junjie. (2021)Research on Model Based Launch Vehicle Overall Design. Missiles and Space Vehicles, (01):12-17+32.

[2] Lei Chuan, 2021, Comparisons on MBSE Modeling Tools and Methodologies. In:33rd China Simulation Conference. Beijing. 151-156.

[3] Wu Xinfeng, Peng Qibo, Huang Ran, LI Jinglin.(2022) Research on escape and rescue strategy of crew launch vehicles ascending section based on MBSE. https://kns.cnki.net/kcms/ detail/ 11.2422.TN. 20220625.1310.004.html

[4] Jiang Wei, Luo Jiawei, Wang Zhendong. (2021)Application Research of spacecraft modeling based on MBSE. China Plant Engineering, (17):139-143.

[5] He Qiang, Liu Xiying. (2019) Tamp the foundation of systems engineering and steadily promot MBSE practice. Science & Technology Review, 37(07):22-29.

[6] Liu Hongjie, Dou Jiao, Shen Peng, Shi Lei, Wang Xuebin. (2022) A modeling design method of small satellite TT&C subsystem based on MBSE. Journal of Telemetry, Tracking and Command, 43(03):54-61.

[7] Song Yu, Zou Ruping, Wang Jun.(2022) On the Practice of Model-based System Engineering in Missile Development. Acta Armamentarii, 43(S1):97-106.

[8] Liu Bolong, Lu Xin, Long Xuedan, Hu Yun. (2021)Research on NASA Model Based Mission Assurance. Quality and Reliability, (06):58-62.

ISSN 2616-5767 Vol.6, Issue 6: 65-71, DOI: 10.25236/AJETS.2023.060610

[9] Zhang Lin, Wang Kunyu, Laili Yuanjun, Ren Lei. (2022) Modeling & Simulation based System of Systems Engineering. Journal of System Simulation, 34(02):179-190.
[10] Hu Jingyu. (2019)The Application of System Engineering Method Based on Model in Missile Overall Design. Science and Technology & Innovation, (11):153-155.
[11] He Minghao, Yao Liang, Zhu Xingxing. (2022)Application of MBSE in Aero Computer Requirements and Design iteration. Computer Programming Skills & Maintenance, (03):27-30.
[12] Guan Feng, Ge Ping, Zhou Guodong, Kang Yan, Ren Junjie, Jie Degang. (2022) Development Trend of MBSE and Investigation ofConcurrent Collaborative Demonstration forChinese Lunar Exploration Program. Chinese Journal of Space Science, 42(02):183-190.