MBSE-based Modeling Technology for Aircraft Assembly Tooling Design Demand

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Abstract. According to the detailed process of the development of the aircraft assembly tooling, a multi-level analysis of the user needs of the tooling is carried out through the concept decomposition and classification of the requirements. Firstly the specification system of the tooling requirements is established, so a clear link is constructed between the user requirements of the tooling and the system requirements. Secondly the demand transformation method based on QFD is proposed in order to the mapping model of demand transformation is constructed. Finally the description method of requirement model is established based on SysML.

1. Introduction
In the conceptual design of products, analysis and conversion technology of demand are the means by which electromechanical products respond quickly to changes in market demand. Qu Weigang [1] studied the product tooling data management in the CATIA/VPM concurrent collaborative design environment, and proposed a cross-product structure tree data organization management and related design method to achieve the relationship between the product model and tooling digital mockups to respond to the rapid adjustment of tooling design when the product's digital model changes. H.C. Yadav [2] is based on the Kano model and the structured approach of QFD integration, the user's emotional needs are used for the design process of the appearance product, then based on the fuzzy algorithm to build the Kano model, and ultimately the customer sentiment is converted into design parameters. Combining the quality of the function configuration Method, AHP and fuzzy set theory, Fung R. [3] proposes a user demand analysis method, which realizes the user's seeking mapping to product attributes. Mc Adams D.A. [4] builds relational matrices based on data from consumer products to establish the relationship between product characteristics and user needs. Combining the analysis of Kano models and user needs, Liang Hongpei [5] adjust the demand item coefficients to obtain the most popular product parameter through multiple Kano questionnaire surveys. Wu Fanchao [6] studied the conceptual design process model of electromechanical products and proposed the demand processing technology based on Kano/AHP model, which defines the requirements and functions, and proposes an effect-based function-structure mapping method in combination with TRIZ theory. Finally, based on the integrated QFD/TRIZ concept design method, the transformation of design requirements and the function-structure mapping are realized. Liu Yue [7] combined the Kano model with the customer taxonomy, which is applied to the analysis and conversion of requirements. Then the quality house model was improved to achieve the mapping between user requirements, functional requirements, and design parameters. The research on demand analysis at home and abroad is mainly aimed at applying the requirements into the parameters of product design or configuration. However, in the MBSE method, the analysis and transformation of requirements is more important.
Based on the transformed system requirements, the product design is clearly defined and turned them into system use cases, which is a basis for functional analysis and decomposition.

2. Tooling System Requirements Analysis and Specification System Establishment

2.1. Stakeholder Analysis of Requirements
The needs of the stakeholders are determined in order to understand hierarchically the needs of various users of the tooling. For the user of the tooling system, the system investor, user, maintainer, and interacting assembly object are the main stakeholders of the tooling.
In the demand engineering of the system, the involved roles are not only users of tooling, but also developers and demand engineers who communicate and convert user requirements to developers. The requirements engineer acts as a bridge between the user and the developer. Its role is shown in Figure 1. After coordination and communication with the user, the required specifications are obtained so that the user's needs are related to the system requirements and the subsequent transformation of the requirements.

![Figure 1. Roles and relationships involved in system engineering](image)

2.2. Conceptual Decomposition of Requirements
In order to systematically convert user requirements into system requirements, it is necessary to sort out and carefully categorize the user needs of the tooling and use this process to construct the tooling system requirements specification. The system requirements are clearly divided into two levels, namely the problem domain requirements and the solution system requirements; at the same time, the requirements for the users may be either the problem domain requirements or the solution system requirements. Another point is that users' demands are generally only part of the solution system, and others are mainly from the analysis and transformation of user needs. The method for demand transformation is given below. The source and relationship of the problem domain demand and solution system requirements are shown in Fig.2.

![Figure 2. Sources of problem domain requirements and solution system requirements](image)

2.3. Tooling System Requirements Specification System Construction
Through the analysis of multi-level user requirements, the problem domain requirements for tooling can be derived. Three levels analysis of investor, user, and maintainer needs are finished. The problem domain specifications and solution system requirements specification are shown in Fig.3.
Tooling system problem domain requirements specification content

1 Description of expected assembly behavior
   1.1 Assembly Objects and Goals
   1.2 Assembly Actions and Activities
   1.1.1 Assembly Interactive Environment
   1.1.2 Assembly activities
   1.1.3 Assembly Process
2 Expected assembly capacity requirements
   2.1 Assembly accuracy
   2.2 Assembly efficiency
3 Expected assembly assurance description
   3.1 Area Constraints
   3.2 Worker Operation Guarantee
   3.3 Production and Maintenance Costs

Tooling system solution system specification content

1 functional requirements
   1.1 System functions
   1.2 Data relationships between functions
2 performance requirements
   2.1 Overall performance index
   2.2 Local performance index
   2.3 System attribute requirements
   2.3.1 Security
   2.3.2 Reliability
   2.3.3 Maintainability
   2.3.4 Maneuverability
   2.3.5 Human factors
3 Structural requirements
   3.1 Parts size requirements
   3.2 Process requirements
   3.3 Interface requirements
4 Technical standard requirements
5 Others
   5.1 Facilities support requirements
   5.2 Equipment protection requirements
   5.3 Others

Figure 3. Tooling domain requirements and solution system requirements specification content

To sum up, during the demand analysis stage of the V-model, the user needs are first categorized as the problem domain requirements and the solution system requirements, and then the user requirements are further excavated according to the requirements specification system. After the demand is completely transformed, all the system requirements must be verified.

3. Conversion of Tooling Requirements Based on QFD

Based on the above content, this paper presents the method and process of demand transformation for tooling development. As shown in Fig.4, after obtaining initial user requirements, the collected user needs are first categorized into problem domain requirements and solution system requirements. The requirements should be directly given by the user's requirements. Therefore, the coverage of the problem domain requirements after the initial classification is checked by using the problem domain requirement specifications. If the coverage can not be fully covered, the needs of the user will continue to be tapped; otherwise, the output will be complete. The problem domain needs, while using the quality function deployment method to solve the system needs transformation. After the conversion, use the content of the solution system requirement specification to verify the integrity of the solution system requirements. If it is not completely covered, it needs to be completed through the omitted problem domain requirement transformation or technical design constraints; otherwise, Direct output. The result is a complete system requirement that contains the complete problem domain requirements and solution system requirements.

Figure 4. The demand transformation process of tooling development
Combining the transformation process of the figure above, taking the development project of the digital flexible assembly tooling for aircraft wall panels as an example, this article carries out demand transformation research based on the QFD method. Based on the above seven steps, the quality house model is constructed. The requirements importance, relationship matrix, and correlation matrix construction mainly reflect the strengths of the relationships between requirements. The construction process is not described in detail, and the user needs are categorized and transformed.

### Table 1. Requirements and classification of aircraft panels assembly tooling users

| No. | Req name             | Req instructions                                                                 | Req classification       |
|-----|----------------------|----------------------------------------------------------------------------------|--------------------------|
| 1   | Positioning          | The tooling positioner can move to the specified position and accurately position the panel. After the fixture accurately positions the assembly, the clamping module can stably hold the panel and does not damage the panel surface. The assembly process should meet a certain degree of accuracy, and the maximum deformation of the component positioning point after assembly is only 0.1 mm. During the operation of the equipment by the operator, the industrial computer displays clear and easy-to-understand information, the positioning and clamping functions are clear and easily operated, and long-term uncomfortable operation postures can be avoided. | Problem domain requirements |
| 2   | Clamping             | Tooling needs to be limited to a certain size of site. Tooling is mainly used for the assembly of single-curvature panels, with a radius of curvature of ≥ 2m, and the planar size of the corresponding panel is within 2m*2m. In the process of clamping the panels, the movement mechanism will not cause collision with the panels, nor will it cause interference between the movement mechanisms, and there will be no safety accidents such as electric shocks during manual operation. When a breakdown occurs, system failures are easily detected and displayed, and maintenance can be performed safely. | Problem domain requirements |
| 3   | Assembly accuracy    |                                                                                   | Problem domain requirements |
| 4   | Easy to operate      |                                                                                   | Problem domain requirements |
| 5   | Installation site    |                                                                                   | Problem domain requirements |
| 6   | Product size         |                                                                                   | Problem domain requirements |
| 7   | Safety               |                                                                                   | Solution system requirements |
| 8   | Maintainability      |                                                                                   | Solution system requirements |

In the above table, after the user needs are collected and sorted, they are classified according to the definition of the problem domain requirements and solution system requirements, and the integrity of the problem domain requirements specification content is confirmed. Then the QFD method is used to transform the problem domain requirements. The process and results are shown in Table 2.

### 4. Rhapsody-based Tooling Demand Model Construction

The input in the conceptual design phase of the MBSE is the user needs. Through the analysis of the requirements and the mapping of the requirements specification, the system requirements are completely defined. That is, the constraints and performance requirements for the design goals are converted to the expressions of the system requirements. The correlation between the demand model and other follow-up models can achieve the validation feedback for the demand.

The demand analysis is the first part of the MBSE method V model. It mainly collects, sorts, and transforms the tooling requirements put forward by users. Therefore, its main needs can be reflected in the project contract, and the following user needs are as follows.
Through the analysis of the problem domain requirements in the table, we can fully cover the expected assembly behavior description, expected assembly capability, and expected guarantee description of the requirements specification requirements. Then, based on the QFD method, we convert the problem domain requirements in the table to system requirements (as shown in table 1). Through the verification of the requirements specification system, the user solution system requirements and design constraints and missing items are supplemented. So the documentation of system requirements is obtained. Then all the requirements document information is imported into Rhapsody's requirement package, and the requirement map is constructed based on the relationship between the SysML standardized definition requirements in Table 2 as shown in Fig.5. The demand graph is the manifestation of the demand model, and it is also a reflection of the different levels of demand and its relationship in many requirements.

**Table 2. Demand conversion table**

| No. | problem domain requirements | Quality factor level one | Solution system requirements |
|-----|-----------------------------|-------------------------|----------------------------|
| 1   | Positioning Functional elements | Directionality, Interference, Moveability, Resistance, Directionality | Positioner in space can move direction, Locator interference alarm, Locator position reading and movement speed control, Locator force feedback, Space clamping module can move direction |
| 2   | Clamping Functional elements | Moveability, Resistance, Directionality | Clamping module position reading and moving speed control, Clamping force control, Mechanism motion error, Motion mechanism high |
| 3   | Assembly accuracy Functional elements | Operability | locater high-precision positioning, Account password login, Manually enabled, Controller connection status display |
| 4   | Easy to operate Functional elements | Visualization, Human factors stability | Manual clearing, Start manually, Column positioning, The system is stable and reliable |
| 5   | Installation site Environmental elements | Site restrictions | Assembly activities involve space, Locator positioning point range, Number of locators |
| 6   | Product size Functional elements | Assemblability, Deformability | Positioning mode, Clamping mode |
Figure 5. Importing system requirements information in rhapsody software

5. Conclusion
This article focuses on the transformation of tooling requirements. In the demand analysis stage, firstly, the concept of demand is decomposed and classified, and then the stakeholder needs of the tooling are analyzed at multiple levels so as to build a demand specification system for the tooling. Secondly, a demand mapping model is constructed based on the quality function deployment method. Thirdly, through the verification of the requirements specification system, the complete transformation from the user requirements to the system requirements is achieved. Finally, the tooling demand model is fulfilled in SysML software.

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