Integrated Requirements Management of Civil Aircraft

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Abstract. Civil Aircraft is a typical complex product system, which has high integration and complex management. In the initial stage of the project, identifying market and customer needs and defining high quality requirements are the key to develop products. Meanwhile, civil aircraft needs to meet the airworthiness regulations to ensure the safety of the aircraft. From the perspective of commercial operation and airworthiness compliance, it is necessary to use requirements management method to develop civil aircraft. For civil aircraft, the requirements have the characteristics of hierarchy, variety and traceability. In this paper, an integrated requirements management method and platform are proposed based on the characteristics of civil aircraft requirements. And an application of certain type aircraft is given.

1. Introduction

The Standish Group has been produced their CHAOS report in project success and failure since 1994, which shows that the reasons for project failure are 21.8\% related to requirements and the project success factors are 44\% related to requirements\cite{1}. For civil aircraft development, the requirements are the basis and keys throughout the whole lifecycle, defining what the stakeholders\texttt{(users, customers, suppliers, developers)} need and what the systems must do\cite{2}. There are thousands of requirements in aircraft development. How to ensure that stakeholders’ requirements are effectively delivered to the right person and how to control the change of requirements with suppliers?

The requirements management can help us to manage the requirements, support the development of a safe and certifiable civil aircraft in limited time, and minimise the development costs. Requirements management is a part of design assurance system which can also help us to show the satisfaction of regulations to the airworthiness and reduce the risk and cost of certification\cite{3}. It can also help capture requirements of all stakeholders correctly and completely and control the change of requirements throughout the whole lifecycle.

The research of requirements management starts from the field of software. Yvonne Bijan’s paper gives the current state of the methodology for developing complex systems requirements, including the methods of facilitation, the methods of prioritizing needs, the methods of transforming fathered data into requirements and other methods\cite{4}. In Annabella Loconsole’s paper\cite{5}, a requirements management measure method is introduced to help control changing software requirements and estimate the cost of changing requirements. She mentioned that requirements development is a learning process rather than a gathering process because we can not specify exactly what customer wants at the beginning of a project. In Guo bozhi’s paper\cite{6}, the application of requirements management in civil aircraft development is introduced. Also, there are some research about the requirements management tool\cite{7-8}. But for the civil aircraft, a typical complex product system, it is necessary to connect requirements management with other technologies and management to avoid...
becoming an information island. Only when all activities are connected, can we effectively implement and play the most role of requirements management.

In this paper, we analyze that the requirements management of civil aircraft have the characteristics of hierarchy, variety and traceability. The requirement information architecture, types of aircraft and traceability network shall be built. And the requirements management process is defined and the relationship between requirements management and other activities are discussed. Based on these, the integrated requirements management platform are introduced to help manage the requirements and improve quality.

2. Integrated Requirements Management

2.1. Requirements Characteristics

2.1.1. Hierarchy. For aircraft, there are different layers of requirements including stakeholder needs, aircraft level requirements, system level requirements, sub-system requirements and so on, as shown in Figure 1. The high level requirements will be allocated to the low level requirements. From the top level to the low level, the number of the requirements are rising exponentially. In the early stage of project development, the requirement information architecture of the project shall be determined during the requirements management planning, including defining the scope of management and the decomposition[9].

![Figure 1. Requirement Information Architecture](image)

2.1.2. Variety. As a management concept and solution centered on stakeholder requirements, the types of requirements cover the whole life cycle of design, manufacturing, service, test, and recycling. The following is included but not limited for the types of requirements:

- Safety requirements
- Functional requirements
- Customer requirements
- Operational requirements
- Performance requirements
- Physical and installation
- Maintainability requirements
- Interface requirements
- Airworthiness requirements
- Derived requirements
- Manufacture requirements
- Support requirements
- Test Requirements
2.1.3. Traceability. In the development of civil aircraft, the requirements can trace to the high-level and the low level requirements. And they can also link to the related functions, solutions and V&V matrix. The requirements can be the key to link all other data in the development of aircraft. All these data are a network from which it is easy to know the relationship of each requirement. The requirements are always changing, but the traceability relationship can help us to do the change impact analysis. And it is very important to link all of the data in whole life cycle.

2.2. Requirements Management Process

For aircraft product development, requirements are the design basis of each stage of aircraft design, which affect the design, implementation and verification of products. The definition process of requirements is the process of key factors and indicators, as shown in Figure 2, including serialization, diversity, function, performance, safety, reliability, supportability, comfort, cost, cycle, production capacity and supply chain, etc[10]. In order to implement requirements management in aircraft program, firstly the requirements management plan shall be defined. In requirements management plan, the requirement information architecture shall be defined to cover all needs of stakeholders, including customers, airworthiness, support, manufacture, suppliers and etc.

Based on fully understanding the stakeholders needs, the requirements are expressed through a concise and common engineering language. The purpose of requirements identification is to identify all requirements, their levels and characteristics in the whole life cycle of the project. The requirements writing shall meet specific rules[9].

Validation of requirements is the process of ensuring that the specified requirements are sufficiently correct and complete so that the product will meet the needs of customers, users, suppliers, maintainers and certification authorities, as well as aircraft, system and item developers (e.g. flight crews, as users, may have a need for a certain system behavior for thrust control and a level of performance for that behavior. Certification authorities may have a need for a constraint on undesired operating behaviors)[2].

Requirements monitoring is to monitor and manage the quality and status for all levels of requirements. It helps the requirement manager to know the status and find problems so that the engineers can correct them in time.

Changes to requirements need to be thoroughly evaluate to determine the impact on architecture, design, interface, high level requirements or low level requirements. All changes must be reviewed and approved to maintain traceability and ensure that the impact of changes is fully evaluated.

![Figure 2. Requirements Management Process](image)

3. The Relationship between Requirements Management and Others

3.1. The Relationship with Configuration Management

After the requirements are baselined, it will be controlled by the change control process. If no change control, the requirements received by the lower level will be out of data. And maybe the receivers got
different versions of requirement documents which would cause massive problems. Requirement change control is a part of configuration change control. Requirements management should obey the rules of configuration management.

3.2. The Relationship with Other System Engineering Activity
The specific generation process of requirements is as follows: first, identify and capture the stakeholder requirements correctly, once the stakeholder requirements are confirmed, it is necessary to establish a requirement baseline; after the initial determination of the requirement baseline, carry out functional analysis and establish a functional architecture. The functional architecture is established by iterating in the process of functional decomposition and allocation. Then the requirement analysis shall define how to allocate the requirements. The relationship between requirements management and other system engineering activity, like function analysis and requirement analysis is as shown in Figure 3. The requirements management activity is throughout whole life cycle.

![Figure 3. The Relationship with Other System Engineering Activity](image)

3.3. The Relationship with Project Management
For the development of civil aircraft, the main manufacturer supplier mode is used. In the early stage, some suppliers like engine supplier are involved in the requirement specification. And between the developer and suppliers it is a balance between what you need and what you offer. In the critical design phase, if the wrong or incomplete requirements are passed to the suppliers, it would cause the cost rising to change requirements in contract. For the program, it will affect the deadline and risk. So the requirements management will affect the risk management and plan management.

4. Intelligent Integrated Requirements Management Platform and Application
The requirements management platform is the foundation of the parallel collaborative development mode of civil aircraft, which is mainly to manage a series of requirements data effectively and provide decision support for the development process through data analysis. The platform can support stakeholders, main manufacturers and suppliers to provide a unified requirements source, and can provide support to show the design assurance process to airworthiness. In the early stage of product
design, customer interaction is realized in the form of communication, website forum, market investigation, etc. Through information acquisition, description, processing and analysis, product functions, performance and customized structure information of customer requirements are obtained[11]. The design, manufacturing, market, project and customer service are combined together to define the top-level requirements and objectives of the product under the support of integrated requirements management platform, taking the customer requirement information as a guide. The top level requirements and objectives will be decomposed layer by layer. In this paper, an integrated requirements management platform is proposed which includes template, attribute and rules database. And the coordination, decomposition tracking, change, monitoring of requirements can be realized based on the integrated requirements management platform which is able to connect with other platforms, such as PDM platform, ERP platform, etc. In order to improve the efficiency and quality of requirements, the intelligent function, like semantic analysis and knowledge database should be included in the platform.

4.1. Template, Attribute and Rules Database
Each requirement has a variety of attributes, including requirement ontology, requirement ID, requirement source, requirement type, requirement allocation, assumption, etc. These attributes are necessary for the complete and accurate description of requirements. In the process of using database to manage different attribute contents of requirements. In the process of using platform to manage requirements, different attributes must be defined to manage different kinds of requirements. There are many kinds of files and attributes, different template must be defined for different files to meet the purpose of recording different levels of requirements and different types of data.

In the attribute database, defining the attributes of all kinds of templates, realize the functions of statistics, modification, modification report of all kinds of template attributes, will greatly improve the efficiency of defining module templates in the requirements management platform. And at the same time, the visualized attribute database can effectively reduce the errors that may be caused by the original working mode.

In order to help designer improve the quality of requirements, and help requirements manager improve management efficiency, the rule database is used to automatically check the link errors, format errors and attribute errors in the integrated management platform. Compared with manually searching for the errors, the rule checking database can automatically check the errors and the error information is clearly displayed to the users, which improves the efficiency of requirements preparation, facilitates the development of requirements validation and verification, and improves the quality of requirements.

4.2. Semantic Analysis
Requirements are generally described in unstructured natural language. However, there are some disadvantages: the nonstandard expression of requirements which may be ambiguous and inconsistent; the relationship between requirements is done by the system engineers manually which takes long worktime and huge workload. These will not only lead to quality problems of requirements, but also seriously affect the design quality of complex system development, which will lead to costly design changes and project delays. The intelligent semantic analysis can help to improve the language expression quality of requirements and can help do the linking analysis.

As a large number of products, enterprises, industries and other data will be involved in the development process of civil aircraft, and there are many departments and person to update and use the requirements data and related data. It is possible to establish a cloud data canter[12] to improve the management efficiency of data, strengthen the collaborative design between data, and establish a complete design assurance system.

4.3. Knowledge Database
The development of aircraft needs a lot of professional knowledge, and the compilation of good
requirements needs many years design experience. The establishment of multi aircraft requirements data knowledge database is conducive to the availability of requirements data, experience inheritance, knowledge analysis, avoidance of existing problems, and proposing better requirements for aircraft design. It can help to strengthen the communication between designers and customers, and form a good communication mechanism. The existing PDM organizes data through single product structures, which can not organize a series of data generated in the process of aircraft development, and can not effectively support knowledge management activities in the whole life cycle. Requirements knowledge database with semantic component can be established which can help overcome the deficiency of knowledge expression ability of database model. From the perspective of business process, knowledge and requirement design work are integrated to gradually form aircraft design process database and knowledge database that can support model development and future sustainable development.

4.4. Application
Based on the requirements management process and the relationship with other activities of requirements management, an integrated requirements management platform is established on a certain type of aircraft, as shown in Figure 4. Requirements capture, function analysis, requirements management, configuration management, project management, etc are effectively combined. On the basis of close combination of advanced methods and management tools, data management is carried out to ensure the only data source of requirements data in the whole life cycle, which plays a certain role in promoting the development of models.

![Figure 4. Integrated Requirements management Platform](image)

5. Conclusion
In this paper, the characteristics of requirements for civil aircraft and integrated requirements management process are introduced. Meanwhile, an integrated requirements management platform is applied in civil aircraft to help manage the requirements effectively throughout the whole life.

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