Requirements Management Applied in Airworthiness Certification in the Civil Aircraft

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Abstract. The civil aircraft certification is the process, which indicates whether aircraft design complies with airworthiness regulations, or not. In recent years, requirements management has been gradually implemented in civil aircraft design, showing a method, which can implement a series of stakeholder, needs or expectation including airworthiness into specific products through requirements definition, validation and verification. Requirements are hierarchical and structured, however, the lack of technical hierarchy of regulations as provisions results in a poor correlation between regulations and requirements. This paper focuses on the research about the application of requirement based engineering method in the development of civil aircraft, and exploring how to implement the regulations in the whole life cycle of the aircraft development to effectively ensure that the regulations are fully implemented into the product requirements, and fully interacted with the system development process. To a certain extent, avoid the disconnection between the airworthiness regulations and the development process, and reduce the risk that the development of civil aircraft does not meet the airworthiness regulations.

1. Introduction

The civil aircraft is a typical complex product system, with the characteristics of high and new technology intensity, strong interdisciplinary, high system integration, long development cycle, huge project investment and complex management\([1]\). It is necessary to creatively integrate professional technologies and systems in multiple fields to optimize the overall performance of the aircraft. With the further improvement of aircraft's demands for safety, economy, environmental protection and comfort, aircraft's functions are becoming increasingly complex and the information exchange between systems is getting bigger and bigger, which further increases the difficulty of aircraft design. In the face of new challenges, the exploration and application of new design methods and procedures to meet the needs of modern civil aircraft development, to ensure the comprehensive success of civil aircraft project development, airworthiness certification, market and operation, has become a common problem that aviation enterprises around the world urgently need to solve.

In recent years, we have gradually implemented requirement-oriented requirement engineering in the whole life cycle of civil aircraft development. Through the requirements definition, requirements validation and verification, we have implemented the needs or expectations of a series of stakeholders into specific products\([2]\). There are many stakeholders involved in creating a new airplane design, including the internal and external stakeholders like customer needs or regulations. New practices and processes have been implemented to ensure that every stakeholder's inputs are considered. However, regulations belong to case law, and not only the scope of regulations contains constraints on the
technical characteristics of products, but also puts forward demands on the process, method and use of product research and development, so it is difficult to establish the relationship between regulations and requirements.

This article is doing the research about the application of requirement based engineering method in the development of civil aircraft, and exploring how to implement the regulations in the whole life cycle of the aircraft development, to manage and control related design activities throughout the project lifecycle in strict compliance with aircraft requirements. Airworthiness demands are considered from the definition stage of requirements and considered as requirements in the whole process of aircraft development, so as to avoid the disconnection between airworthiness demands and research & development process and reduce the risk of civil aircraft development, which cannot meet airworthiness demands.

2. Generic civil aircraft development process and civil aircraft certification

2.1. The civil aircraft requirement based development process

Requirements definition and management should be throughout the whole life cycle of product research and development[3]. That is to say, requirements must be clearly defined for all products firstly, and all research and development management activities including project planning, design activities, evaluation testing, production delivery and trade-off analysis throughout the life cycle are driven by requirements from the beginning of the project to the testing and verification stage of the product. As figure 1 below, the needs of customers were captured through market research and other means in the early stage of design. On this basis, customer needs are analysed to help designers understand the market, customers and other stakeholders that make it can complete the definition of the top-level requirements of the product. To ensure that the defined requirements meet the customer's initial needs, it is necessary to check whether the defined top-level requirements are correct, complete, and fully meet the customer's needs. Then carrying out top-level design activities of products based on requirements, and allocating the requirements to the next level. Upon completion of this work, a review of the defined design schemas is required to verify that the design can meet the requirements at the appropriate level. After the concrete implementation of all the schemes, the corresponding requirements verification work should be carried out to verify that the developed products meet the requirements of the corresponding levels and the final integrated system meets the needs of customers.
2.2. **Airworthiness**

Airworthiness is an attribute of a civil aircraft, it means that the aircraft or aviation components meet the necessary demands for flying in a safe state within the permitted restrictions. The certification process of modern civil aircraft is a process to show the conformity of design to airworthiness regulations. The development process of modern civil aircraft and the certification process interact and proceed synchronously. From the planning stage, airworthiness certification will affect the final attributes of products at different levels including aircraft, system, equipment, hardware and software through the interaction with relevant technical management process, technical assessment process and design process based on requirements. Therefore, the regulations have multi-levels. At the same time the types of regulations are diverse, there are technical demands, management demands, and demands on the relevant process. According to the regulations demands of the technical attributes of the product, it can directly enter the system development process and participate in the system development as the technical requirements. According to the regulations demands of management activities and technical process, it is necessary to enter the relevant technical and management process. And ensure adequate interaction with the system development process so that the regulations are fully implemented [4].

2.3. **Relationship between regulations and requirements**

Based on the multi-layered and diverse features of regulations and combined with the development process of the whole life cycle of civil aircraft, the transmission path from regulations to requirements was established as figure 2. First of all, regulations are identified as the needs of stakeholders at each level in the early requirements definition stage. Through the technical path interpretation of the regulations by airworthiness team, identify the responsible parties for the regulations and assign the regulations. The responsible parties of the regulations accept the regulations demands through consensus with airworthiness professionals, and carry out to design after requirements definition and validation. And in the subsequent verification activities to ensure that the design of the product can meet the requirements, so as to meet the regulations.

3. **Requirements management**

Requirements Management is a process performed throughout a system’s life to elicit, identify, develop, manage, and control requirements and associated documentation in a consistent, traceable,
correlatable, verifiable manner[5]. It ensures solution compliance with stakeholder needs and expectations using allocation, verification, and adaptation to and control of changes.

After the regulations are transformed into requirements, the requirements transformed by requirements can be taken as the management objects by adopting the requirements management method. Scientific and orderly management and monitoring to the captured requirements from the beginning of the concept phase to the end of the life cycle of the product, which can ensure that all product activities are focused on the regulations demand and the project objectives are achieved accurately and efficiently.

3.1. Requirement validation
The purpose of requirement validation is to ensure that the defined requirements are correct and complete[2], which can meet the needs of customers and stakeholders. In general, requirement validation must be completed before formal product design activities to ensure that all design activities are correct and complete those are driven by requirements. But in the process of complex product system development, requirement validation and design is a dynamic process of mutual iteration. Improving the correctness and completeness of requirements in the initial condition can effectively reduce the design iteration, shorten the development cycle and reduce the development cost.

After the identification of the items transformed into requirements, requirement validation strategy, deliverables, validation activity schedule, executor and other contents shall be formulated according to requirements type, requirements orientation and other characteristics, those are the basis of requirement validation plan to be formed. The requirement validation plan is used to guide the definition of specific requirement validation activities, which can only be carried out after the requirement validation plan has been approved.

3.2. Implementation verification
Implementation verification is the scientific method of showing that the implementation at each level meets the specified requirements[2]. For complex products, the implementation verification should provide a systematic verification approach and a complete evidence system to show stakeholders that the final product meets their functional and performance expectations. The input of the verification work is the validated requirements of the product or system, and the designed product or system is verified to meet the requirements of the corresponding level by means of inspection, review, analysis, test, modelling and other methods.

After the regulations are confirmed into the content of the requirements, it is necessary to define the verification strategy, deliverable, verification activity schedule and roles & responsibilities, taking into account the requirements, which have been validated. This shall be recorded in the implementation verification plan. The implementation verification plan will be established with the support of domain experts since it will guide the definition of specific verification activities. During the development and implementation of the validation plan, the requirements definition team also needs to work closely with the airworthiness team to clarify the work plan of meeting the requirements. Determine how compliance work will be performed, and define certification plan. At the same time, capture the evidence of conformity to satisfy the regulations.

3.3. Requirements management database
The traditional conventional file management method cannot meet the needs of practical use because of the large scale, complex system and big quantity of civil aircraft. Under this background, the application software focusing on requirements management came into being[6]. IBM Rational DOORS is an application that is widely used for requirements management and enables the management of requirements on an itemized basis to facilitate requirements tracking and change analysis, see as figure 3. We can quickly grasp the relationship between regulations and requirements by using this function to establish the link between regulations and requirements in an itemized way. In addition, the verification status can be recorded through the database, and the compliance evidence
can be provided to meet the regulations by building a bridge between regulations, requirements and verification evidence.

3.4. Process monitoring

Process monitoring is the process of monitoring one or a series of activities in real time, usually in order to achieve a specific goal or achieve a specific phase state. The product system of civil aircraft is complex and the development period is long. It can effectively help project managers to control project progress, stage results, technical status and other contents for the introduction of process monitoring in the development process of the whole life cycle of civil aircraft. Reduce project risks, labour, time and financial input by Identifying key issues through data.

In the process of requirements management, the process monitoring implemented is carried out on the basis of requirements. By tracking key metrics over time to ensure that requirements are executed according to requirements management processes and methods. Conduct scientific and quantitative inspection and control analysis through different indicators, so as to display to quality, design, test and other departments, check the implementation effect of requirements in each stage, and provide management data and decision basis for project management. These are called KPI (Key Performance Indicator).

During the transformation of regulations into requirements, two KPI indicators can be defined based on the process described above: regulations allocation rate and requirements linking rate to regulations. Regulations allocation rate indicates whether all the regulations that need to be converted into requirements and entered into the design are allocated. Link rate indicates whether all the assigned regulations are linked with corresponding requirements to ensure that the requirements are in line with the terms. And through the form of visual report pictures, clearly show the relation between regulations and requirements, see as figure 4.

![Figure 3. Airworthiness module in requirement management database.](image-url)
4. Applications

Taking CCAR25 899(a) as an example, this paper describes in detail how the regulations are translated into requirements and managed, see as figure 5. CCAR25 899(a) includes the demands of electrical bonding and protection against static electricity. According to the interpretation of the technical path by airworthiness professionals, the discharge device or electric lap should be installed on the aircraft to ensure the minimum of electrostatic accumulation. Thus, identify the structure or E3 team associated with completing the design, which consider the demands of regulations in the requirement definition phase and capture the requirements.

**Figure 4.** Regulations allocation KPI displaying

**Figure 5.** Example of regulation transformation process.
In order to effectively manage requirements for regulations transformation, store regulations and requirements in the requirements management platform, DOORS. After the above interpretation of the technical path of the article has clarified the relevant technical team, the technical team can be assigned in the platform. At the same time, the technical team stored the requirements captured based on regulations in the requirements module and the validation and verification evidence of the requirements in the matrix module through using the DOORS platform's linking capabilities to establish compliance links for regulations, requirements, and evidence, see as figure 6. In the requirements definition stage, airworthiness research is considered comprehensively and systematically in the whole life cycle of product development, so as to facilitate the definition of conformity ideas and conformity methods in the subsequent certification plan definition stage.

5. Conclusions
In this article, according to the requirements based civil aircraft development process and the characteristics of airworthiness regulations, realize the implementation of provisions into requirements in the whole life cycle of civil aircraft development, and ensure that the transformed requirements into the design and product through the means of requirements management. At the stage of requirement definition, airworthiness research is considered comprehensively and systematically in the whole life cycle of product development to reduce the risk of airworthiness research not meeting airworthiness requirements. It is convenient to plan airworthiness compliance verification plan from aircraft level and solve the correlation and reference relationship between different professions and teams in solving airworthiness compliance verification of airworthiness regulations, so as to achieve full coordination, no repetition and no omission in the verification.

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Figure 6. Applications of regulations in DOORS.