Method for Identifying Defects in Requirements of Civil Aircraft

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Abstract. The development of civil aircraft is a complex systems engineering endeavor, where the quality of requirements directly impacts the aircraft's safety, airworthiness, and economic viability. This paper addresses typical deficiencies in civil aircraft requirements engineering and proposes a method for identifying quality defects in system requirements. The aim is to resolve issues such as incomplete, incorrect, or inconsistent requirements, as well as inadequate traceability, thereby ensuring a requirements-based forward design for civil aircraft. The effectiveness of the proposed method is validated through practical application in the requirements engineering of a specific civil aircraft model. Research results demonstrate that this method significantly improves requirement quality and reduces the costs associated with late-stage design modifications.

Keywords: Civil Aircraft, Requirements Engineering, Requirement Quality, Defect Identification.

1 Introduction

The development of civil aircraft involves numerous stakeholders (e.g., airlines, aviation authorities, manufacturers, etc.), resulting in a wide and complex array of requirements. These requirements are often documented in textual form, frequently leading to quality issues such as ambiguous phrasing, omissions, improper allocation, and non-standardized processes. Such problems negatively impact product quality, project timelines, and airworthiness certification efforts. Study data shows that the SE effort had a significant, qualifiable effort on project success, with correlation as high as 80%. Statistics show that requirement-related issues account for 48% of project delays or incomplete functionalities, and 70% to 85% of project rework[1] . The later a requirement defect is identified, the greater its cost impact on the project. Particularly for civil aircraft, requirements defects can lead to airworthiness issues and project cost overruns, affecting the commercial success of the aircraft. Therefore, it is essential to process unstructured textual requirements, identify definition flaws, and establish an effective method for detecting requirement quality defects to support system requirement engineers in their development work.

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The research of requirements management starts from the field of software. In recent years, requirements engineering technology has achieved development and widespread application in the field of civil aircraft. Zhu R X proposed requirement traceability method of aero-engine[2]. The quality of civil aircraft requirements has always been a topic of discussion, with various methods continuously being proposed to address the correctness and completeness of requirements. In Yvonne Bijan's paper, some methods about how to develop clear and unambiguous requirements are proposed, including use cases, (AHP), Five Whys, Concept Requirements List et al[3].Li Haoming proposed a functional requirements development and management approach applied to a civil aircraft program[4]. However, detecting and addressing requirements quality defects is critical for civil aircraft. The ARP4754B standard's release further underscore the significance of rigorous requirements capture[5].

This paper proposes a requirement quality defect identification method tailored to the characteristics of civil aircraft requirements. By analyzing defects in completeness and correctness during the requirement development process, the method aims to enhance requirement quality to meet both airworthiness standards and market demands.

2 Characteristics and Common Types of Requirement Defects

2.1 Characteristics of Civil Aircraft Requirements

The requirements for civil aircraft are characterized by the following key aspects:

- Multiple Sources: Derived from airworthiness regulations, airlines, passengers, airports, etc.
- High Safety-Criticality: Must comply with stringent airworthiness requirements.
- Long Life cycle: Requirements must account for operational and maintenance needs over 20-30 years.
- Complex System Interactions: Involves coordinated interactions among multiple systems (e.g., flight control, avionics, structures).

2.2 Common Types of Requirement Defects

The common types of requirement defects for civil aircraft are:

- Incomplete Requirements: Missing critical details or constraints.
- Incorrect Requirements: Errors in defined parameters or specifications.
- Ambiguous Requirements: Vague or open-to-interpretation phrasing.
- Inconsistent Requirements: Contradictions between different requirements.
- Unverifiable Requirements: Lack of measurable criteria for validation.
- Infeasible Requirements: Technically or economically unachievable.
- Non-Compliant Requirement Processes: Deviations from standardized development procedures.

3 Method for Identifying Requirement defects

3.1 Elements for Identifying Completeness Defects

The completeness of civil aircraft requirements is reflected in: the thoroughness of airworthiness regulation and standard analysis and translation; the completeness of lessons learned from previous aircraft; the integrity of top-level requirement decomposition and allocation; the comprehensiveness of operational scenario analysis. Key Aspects for Evaluation:

- Coverage of Airworthiness Regulations:

– *Compliance with CCAR-25, CCAR-33, CCAR-121, CCAR-91.*
– Inclusion of Advisory Circulars (ACs), Special Conditions, Issue Summaries, etc.

- Coverage of Standards & Specifications

– Applicable international standards (e.g., DO-160, DO-178, DO-254.
– Industry standards (e.g., maintainability guidelines, grounding specifications).
– Corporate technical specifications.

- Incorporation of Lessons from Previous Models: Whether past design issues and operational experiences have been sufficiently considered.
- Coverage of Operational Scenarios

– Normal, abnormal, and emergency operational conditions.
– Extreme weather environments.
– Maintenance and servicing scenarios.

- Allocation of High-Level Requirements: Whether top-level system requirements are fully decomposed and allocated.
- Clear Definition of Interface Requirements: Proper specification of inter-system and inter-component interfaces.

3.2 Elements for Identifying Correctness Defects

The semantic correctness of civil aircraft requirements is reflected in their clarity, absence of ambiguity, measurability, verifiability, and feasibility. This is assessed by analyzing whether the conditions, subjects, events, and environments defined in the requirements comply with established rules. Key Aspects for Evaluation:

- Standardized Requirement Statement Expression: Whether the requirement is phrased in a structured and standardized manner.
- Standardized Terminology Usage: Whether terminology complies with industry norms and avoids ambiguity.
- Use of Non-Quantifiable Terms: Detection of vague terms (e.g., "adequate," "user-friendly") that lack measurable criteria.

- Semantic Consistency: Whether the meaning remains uniform across different requirements.
- Correct Requirement Hierarchy: Whether the requirement is properly classified (e.g., high-level vs. derived).
- Logical Conflicts: Contradictions with higher-level requirements, regulations, or standards.
- Non-Verifiable Requirements: Absence of measurable validation criteria (e.g., no testable thresholds).
- Unfeasible Requirements: Technical/process limitations or cost/schedule overruns beyond constraints.
- Redundancy & Duplication: Repetition of the same requirement in different sections.

Natural Language Processing (NLP) is applied to analyze requirement texts for grammar, semantics, and structure, detecting ambiguous, incomplete, or inconsistent expressions.

3.3 Elements for Identifying Process Compliance Defects

The process compliance of civil aircraft requirements is reflected in whether they adhere to requirement management protocols, including proper identification, traceability, and controlled changes for each requirement. Key Aspects for Evaluation:

- Correct and Complete Attribute Tagging: Whether all requirement attributes (e.g., priority, source) are properly labeled.
- Established Traceability Between Requirements: Whether bidirectional links (parent-child, peer dependencies) are defined.
- Traceability to Functions & Other Data: Whether requirements are linked to functional specifications, design elements, or test cases.
- Controlled Requirement Changes: Whether modifications follow formal review and impact assessment procedures.
- Missing Source for Derived Requirements: Whether lower-level requirements clearly reference their origin (e.g., regulations, high-level needs).
- Unvalidated Requirement Assumptions: Whether implicit assumptions (e.g., operational conditions) are explicitly verified.

3.4 Requirement Defects Identifying Flow

The flowchart for identifying civil aircraft requirements quality defects is shown in Figure 1.

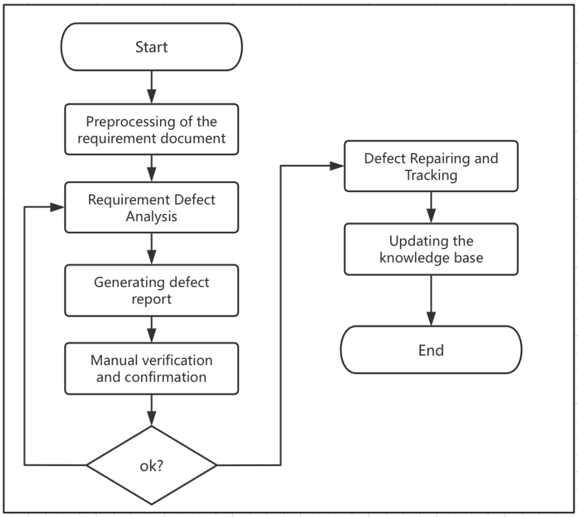

Fig. 1. Requirement Defects Identifying Flow

First, preprocess the requirement documents, including format standardization and terminology unification. Next, conduct automated tool analysis to perform completeness defect analysis, correctness defect analysis, and process compliance defect analysis.

Then, generate a defect report, including defect classification and severity levels. The defect classification is shown in Table1. To ensure the accuracy of the results, perform manual verification and confirmation to exclude false positives and supplement any omissions. Assign responsible persons for the defects and track the defect resolution status.

Finally, update the knowledge base and optimize inspection rules based on the defects identified.

Table 1. Defect Classification

ID	Text	Defect Type	Defect Nature	Criticality Level
XXX	XXX	a. Completeness Defect b. Correctness Defect c. Process Compliance Defects	a. Ambiguity Defects b. Incompleteness Defects c. Inconsistency Defects d. XXX	a. Catastrophic b. Major c. Minor

3.5 Requirement Defects Identifying Tools

The system adopts a layered modular architecture to support full-lifecycle defect detection from requirements capture to certification. It is divided into the following core layers, as shown in Figure 2:

- Data Layer: Stores and manages requirements data and associated information.
- Core Engine Layer: Executes defect detection and analysis logic.
- User Interaction Layer: Provides a human-machine interface and collaboration support, including manual verification and validation review functions.
- Integration Layer: Enables interaction and integration with external tools (e.g., PDM/PLM).

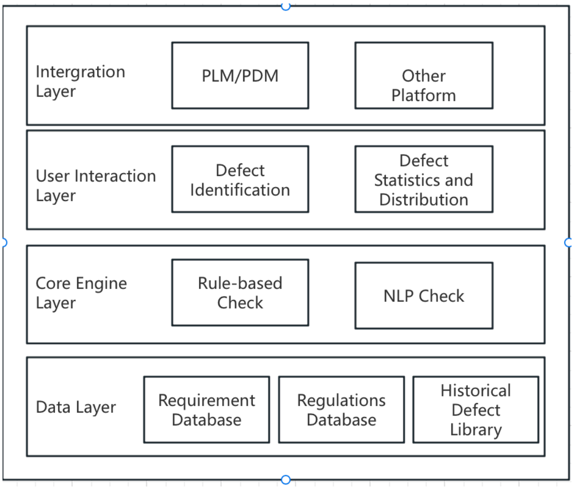

Fig. 2. Requirement Defects Identifying Tools

4 Application

Perform data cleaning on the requirements document for the Flight Control system for an aircraft. Identify and analyze the applicable CCAR-25 airworthiness regulation clauses for the system. Analysis of Issues from Previous Models of the System. Decomposition of High-Level Requirements. Analyze functional and performance requirements allocated to the system from higher-level requirements. Decompose them into functional requirements based on typical operational scenarios and system architecture design. Analyze constraints from higher-level requirements (e.g., weight, safety, reliability, maintainability, testability, environmental conditions, and physical installation requirements) to derive non-functional requirements. Conduct a completeness defect analysis to verify coverage., as shown in Table 2.

Table 2. Completeness Defect Analysis of System Requirements Example

ATA	Text	Defect Type	Defect Nature	Criticality Level	Details	Manual Check
27	The flight control computer shall receive airspeed signals from the atmospheric data system	Completeness Defect	Incompleteness Defects	Major	The flight control computer shall receive airspeed signals from the atmospheric data system	OK

Semantic Diagnostic Analysis of System Requirements. Check whether requirements are unambiguous (e.g., no vague terms, standardized terminology, clear phrasing, defined responsibility, concise expression).Verify that the requirement level (e.g., aircraft-level, system-level, equipment-level) is appropriate and accurately reflects the intended scope. Ensure requirements are verifiable, with clear criteria to confirm fulfillment. Check whether applicable conditions are specified and avoid absolute/unrealistic wording. Conduct a correctness defect analysis to validate semantic quality, as shown in Table 3.

Table 3. Correctness Defect Analysis of System Requirements

ID	Text	Defect Type	Defect Nature	Criticality Level
XXX	The flight control system requirements “The rudder deflection rate should be ≥45°/second (to meet the requirement for rapid rolling)” and “The rudder actuator load must not exceed 8000N (to prevent structural overload)” are in conflict.	Correctness Defect	Conflict Defects	Major

Verify that requirement IDs are unique and attributes (e.g., type, source, allocation,link) are properly configured. Ensure traceability is established between lower-level and higher-level requirements. Assess requirement maturity based on the development phase and confirm that changes follow defined control processes. Conduct a process compliance defect analysis to ensure adherence to standards of one aircraft, as shown in Figure 3.

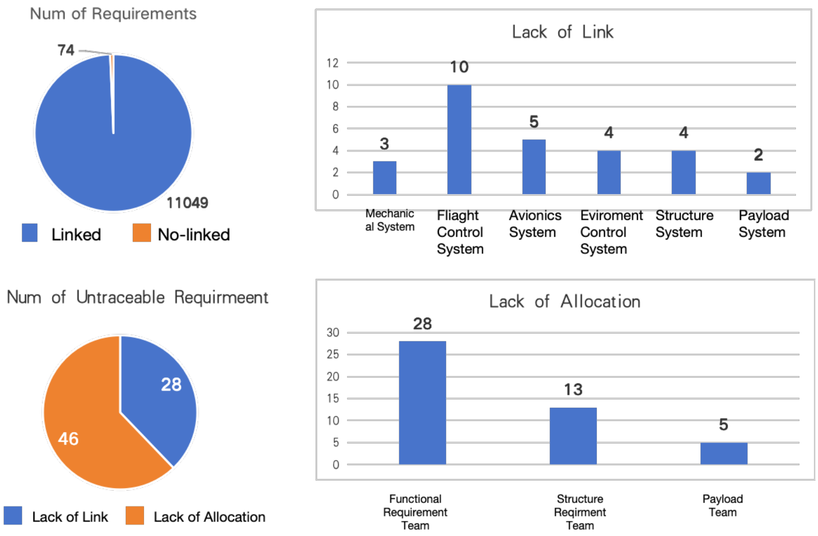

Fig. 3. Process Compliance Defect Analysis of System Requirements

In this case, during the flight control system requirements definition phase, issues with the correctness and completeness of the requirements were identified through requirements defect detection methods and effectively corrected in the early stages of the project. Compared with previous models, discovering these issues earlier and conveying accurate requirements to suppliers reduced project costs by 3%.

5 Conclusion

This paper proposes a requirements quality defect identification method for civil aircraft, based on ARP4754A/B standards and requirements authoring specifications. By implementing rule-based checks and automated tool validation, the approach systematically verifies requirements correctness, completeness, and process compliance. Compared to issues encountered in previous programs, such as inadequate consideration of airworthiness requirements, mismatched interface requirements, unclear requirement phrasing leading to supplier misinterpretation, and failure to trace requirements to higher-level objectives, the method proposed in this paper enables early identification and resolution of such problems during the initial phases of the new aircraft. This ensures effective communication, correct interpretation, and proper implementation of requirements. So this method significantly improves requirements documentation quality while reducing development risks and rework costs caused by defects. The hybrid strategy combining static analysis and dynamic validation provides a practical solution for requirements engineering in complex aircraft systems.

However, in practical applications, identifying completeness defects requires access to extensive knowledge base data for reference. This necessitates the establishment of comprehensive knowledge libraries for every system and discipline across the aircraft, posing significant implementation challenges.

Future research can be expanded in the following directions:

- AI-Driven Defect Prediction: Integrate AI techniques (e.g., few-shot learning, knowledge graphs) to enable early defect detection, overcoming the limitations of traditional rule-based methods.
- Full Lifecycle Feedback Loop: Incorporate operational data (e.g., Quick Access Recorder logs) into defect databases to enable continuous improvement.

Through the integration of AI-augmented analysis and certification-driven frameworks, next-generation defect identification methods will shift from reactive detection to proactive prevention

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