Integrated Design and Verification of Civil Aircraft Cockpit Crew Alerting System Based on System Engineering

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Abstract. The cockpit crew alerting system is an important part of the modern cockpit and the only channel for the flight crew to obtain the status of the aircraft system. With the development of avionics, aircraft systems are becoming more and more complex, and more and more information needs to be obtained by the flight crew through the cockpit crew alerting system. So, how to make the flight crew correctly and efficiently obtain the required information becomes the design difficulty of the cockpit crew alerting system. This paper applies system engineering theory and methods to propose a forward design and verification method for the cockpit crew alerting system. This method reduces design changes due to incomplete demand capture, reduces product development costs, and provides a reference for the integrated design and airworthiness verification of the cockpit crew alerting system in the future.

1. Introduction
The cockpit crew alerting system is an important part of the modern cockpit. It is a system with automated and intelligent processing capabilities, and it is also a carrier for the flight crew to obtain abnormal or unexpected changes in aircraft and system status. In terms of function, the cockpit crew alerting system provides visual, aural and tactile alerting information to the crew. In terms of human-computer interaction, the cockpit crew alerting system can provide critical alerting information to the flight crew at a suitable flight phases through the integrated design of alerting, so as to avoid unnecessary alerting from interfering with the flight crew and reducing workload. Timely and appropriate alerting are extremely important for the flight crew to control the aircraft and deal with faults.

2. Development and Characteristics of Crew Warning System in Civil Aircraft Cockpit
Before the 1980s, due to the limitation of avionics technology, the cockpit crew alerting system was mostly composed of warning lights, signal lights, and warning flags. The main features are: the warning system is relatively independent, decentralized, and is in a state of "self - administration"; the warning system has no suppression function and cannot achieve "Don't alert when the timing is inappropriate", which distracts the flight crew and affects flight safety [1].

After the 1980s, with the development of avionics technology, two typical cockpit crew alerting systems appeared: Electronic Centralized Aircraft Monitoring (ECAM) and Engine Indicating and Crew Alerting System (EICAS). Both of these systems monitor the aircraft system status in real time through electronic computers, provide alerting information, and even provide corresponding disposal procedures. Its main features are: centralized computer monitoring; use of alerting suppression
function to achieve intelligent alerting processing; follow the design principles of quiet and dark cockpit, no fault, no alert.

3. Design of Civil Aircraft Cockpit Crew Alerting System Based on System Engineering

Civil aircraft is a typical complex high-end product system. With the continuous growth of market and customer demand and the rapid development of technology, the system complexity of aircraft products is still growing. System engineering provides an effective method for the integration of highly complex aircraft products.

According to the International Council on System Engineering (INCOSE) definition: System engineering is an interdisciplinary method and means that can contribute to the success of the system. System engineering focuses on defining customer needs and required functions in the early stages of the development cycle, documenting the requirements, and then performing design synthesis and system verification when the complete problem is considered. System engineering aims to provide high-quality products that meet the needs of users, while considering the business and technical needs of all users [2].

Because the cockpit crew alerting system is cross-linked with all systems on the aircraft, it is a typical high-complexity aircraft system. This article applies the theory and method of system engineering to forward design and verification of the cockpit crew alerting system.

3.1. Cockpit crew alerting system stakeholders need to capture

Although the cockpit crew alerting system is mainly for the flight crew, it should also take into account the needs of all users throughout the life cycle. For example, consider the needs of regulators in design, the needs of airlines in delivery, the needs of flight crews in flight, the needs of maintenance personnel in maintenance, the needs of training departments in training, and so on. Therefore, the stakeholders of the cockpit crew warning system and their needs are shown in Table 1.

| number | Stakeholder                      | needs                                           |
|--------|---------------------------------|-------------------------------------------------|
| 1      | Airworthiness Supervisor        | Meet airworthiness regulations.                 |
| 2      | airline                         | Meet operating regulations.                     |
| 3      | Flight crew                     | Identify the status of the aircraft and guide the crew to deal with faults. |
| 4      | maintenance personnel           | Identify the status of the aircraft and help the maintenance personnel deal with the failure. |
| 5      | Training department             | The system is easy to use and the training cost is low. |

3.2. Establish a functional model of the cockpit crew alerting system

Function is a intended behaviour of a product based on a defined set of requirements regardless of implementation [3]. Therefore, to analyse the function of the cockpit crew alerting system, it must first be identified and defined. Different stakeholders have different needs for the cockpit crew alerting system. On the basis of the list of needs, after screening and selection, the cockpit crew alerting system function can be abstractly established, as shown in Table 2.

| Stakeholder                  | Needs                                                                 | Functions                                         |
|------------------------------|-----------------------------------------------------------------------|---------------------------------------------------|
| Airworthiness Supervisor; airline | Meet the requirements of airworthiness regulations (such as CCAR 25); Meet the requirements of operation regulations (such as CCAR 121). | Crew alerting function;                           |
| Flight crew                  | Identify the status of the aircraft and guide the                      | Crew alerting function;                           |
crew to deal with faults.
Electronic checklist function
Crew alerting function

The cockpit crew alerting system has many functions, which can be broken down into several levels. Construct a functional decomposition tree of the crew alerting system, which is related to the specific system architecture scheme, as shown in Figure 1.

![Figure 1. Decomposition tree of cockpit crew alerting function](image)

3.3. Demand analysis of cockpit crew warning system
Requirements analysis is the process of converting the captured stakeholder needs and the results of functional analysis into formal requirements. This is also a process of transforming needs into design goals and requirements, and then decomposing them into system-level design requirements. In order to carry out demand analysis, the captured needs should be iterated into the corresponding aircraft operation scenarios, to carry out the specific demand analysis of the cockpit crew alerting system. Take the captured flight crew cockpit crew alerting system requirements as an example to carry out specific requirements analysis.

The ATA2300 standard defines 19 flight phases [4]. In different flight phases, according to the needs of the crew mission, conduct demand analysis and output the corresponding design goals and requirements of the cockpit crew alerting system. Here we select the key task stages for analysis, as
shown in Table 3.

Table 3. Cockpit crew alerting system demand analysis

| Crew mission stage                  | Needs                                      | Demand analysis                                                                 |
|-------------------------------------|--------------------------------------------|----------------------------------------------------------------------------------|
| SAFETY EXTERIOR INSPECTION PRELIMINARY COCKPIT PREPARATION | None                                       | The cockpit crew alerting system correctly indicates the status of the aircraft system. |
| EXTERIOR WALKAROUND COCKPIT PREPARATION | None                                       | The cockpit crew alerting system correctly indicates the status of the aircraft system. |
| BEFORE PUSHBACK OR START            | Understand the status of the aircraft system and determine whether it can perform this flight mission. | The cockpit crew alerting system correctly indicates the status of the aircraft system. |
| ENGINE START                        | Understand the status of the aircraft system and determine whether the engine can be started. | The cockpit crew alerting system correctly indicates the status of the aircraft system. |
| AFTER START                         | Understand the status of the aircraft system and determine whether the engine starts normally. | The cockpit crew alerting system correctly indicates the status of the aircraft system. |
| TAXI                                | Understand the status of the aircraft system and determine whether the state can perform this flight mission. | The cockpit crew alerting system correctly indicates the status of the aircraft system. |
| BEFORE TAKEOFF                      | Understand the status of the aircraft system and determine whether the aircraft can take off. | The cockpit crew alerting system correctly indicates the status of the aircraft system. |
| TAKEOFF                             | Understand the status of the aircraft system and determine whether the aircraft needs to be rejected. | The cockpit crew alerting system correctly indicates the system status of the aircraft that needs to be rejected. |
| CLIMB                               | Understand the status of the aircraft system and determine whether the aircraft can continue to perform this flight mission. | The cockpit crew alerting system correctly indicates the status of the aircraft system. In the case of superimposed faults, the cockpit crew warning system can guide the crew to deal with it. |
| CRUISE                              | Understand the status of the aircraft system and determine whether the aircraft can continue to perform this flight mission. | The cockpit crew alerting system correctly indicates the status of the aircraft system. In the case of superimposed faults,
Crew mission stage | Needs | Demand analysis |
--- | --- | --- |
Descent | Understand the state of the aircraft system and determine whether the aircraft can descend. | The cockpit crew warning system can guide the crew to deal with it. The cockpit crew alerting system correctly indicates the status of the aircraft system. In the case of superimposed faults, the cockpit crew warning system can guide the crew to deal with it. |
Approach | Understand the status of the aircraft system and determine whether the aircraft can approach. | The cockpit crew alerting system correctly indicates the status of the aircraft system. In the case of superimposed faults, the cockpit crew warning system can guide the crew to deal with it. |
Landing | Understand the status of the aircraft system and determine whether the aircraft can land. | The cockpit crew alerting system correctly indicates the status of the aircraft system. In the case of superimposed faults, the cockpit crew warning system can guide the crew to deal with it. |
Go-Around | Understand the status of the aircraft system and determine whether the aircraft can go around. | The cockpit crew alerting system correctly indicates the status of the aircraft system. In the case of superimposed faults, the cockpit crew warning system can guide the crew to deal with it. |
After Landing | Understand the status of the aircraft system and determine whether the aircraft needs maintenance work and whether it can perform follow-up tasks. | The cockpit crew alerting system correctly indicates the status of the aircraft system. |
Parking | Understand the status of the aircraft system and determine whether the aircraft needs maintenance work and whether it can perform follow-up tasks. | The cockpit crew alerting system correctly indicates the status of the aircraft system. |
Deplane | None | None |

On this basis, based on the corresponding demand analysis results, clear design goals and requirements can be put forward.

3.4. Design synthesis of cockpit crew alerting system

Design synthesis is a creative work, mainly by defining and distributing product component elements, transforming the function structure and requirements into a physical structure [5].

The cockpit crew alerting function is an aircraft-level function, which needs to be decomposed into specific product carriers during the design synthesis stage.

A typical physical architecture realization of the cabin crew alerting system is shown in Figure 3.
3.5. Integration and verification of cockpit crew alerting system

The integrated design of the cockpit crew alerting system is based on the iterative optimization of design goals and requirements. Beginning with the formulation phase of the overall design plan of the aircraft, the preliminary design, detailed design, comprehensive trial production, and flight test certification phases all require confirmation and verification of the design requirements of the cockpit crew alerting system. Decompose the top-level design goals and requirements to the system level, and realize the design goals and requirements through system design.

When the design goals and requirements sink to the system level, the system formulates a system-level cockpit crew alerting design plan according to the design requirements, and carries out system integration and verification at the aircraft level.

The Federal Aviation Administration (FAA) issued a special advisory circular AC25.1322 for the cockpit crew alerting system [6]. The advisory circular gives the following suggestions on the integrated design of the cockpit crew alerting system:

- All cockpit crew alerts should be classified at the aircraft level;
- Warning and caution level alerts should be notified to the flight crew in at least two ways;
- When necessary, sequence the crew alerts;
- The cockpit crew alerts should be managed uniformly.

A typical integrated design of cockpit crew alerting system can be classified according to the definition of warning, caution, advisory and status [7]. The recommended level definition and alert form are shown in Table 4.

| Level definition | Form | Vision | Colour | Aural | Tactile |
|------------------|------|--------|--------|-------|---------|
| Warning          | Master warning light + Alerting text or characters | Red | Master warning tone or Voice or special homophony | Stick shaker or putter (usually used for stall warning) |
| Caution          | Master caution light + Alerting text or characters | Amber | Master caution tone or Voice or special homophony | N/A |
| Advisory         | Alerting text or characters | Amber/Cyan | Voice or special homophony | N/A |
| Status           | Alerting text or characters | White/Green | N/A | N/A |
The verification of the traditional cockpit crew alerting system is based on the compliance verification work carried out by airworthiness clauses, including explanatory documents (MOC1), safety assessment (MOC3), on-board ground test (MOC5) and flight test (MOC6) and other methods [8].

AC25.1322 uses assessment as a way to show the compliance of the cockpit crew alerting system [9]. Therefore, in the design process of the cockpit crew alerting system, verification work should be carried out simultaneously through evaluation. The content of the assessment should include the visual, aural, workload, and acceptable degree of operation in failure modes, which used by the cockpit crew alerting system. The evaluation methods can be: analysis, laboratory test, simulator test, flight test, etc.

4. Conclusion
Based on the theory and method of system engineering, according to the development phase and forward design mode of aircraft products, this paper proposes a design method of civil aircraft cockpit crew alerting system based on system engineering. Through process assurance, combined with existing design experience, complete as much as possible to capture stakeholder needs, and reducing late design changes, thereby reducing project development costs and better adapting to the development and production of complex aircraft products.

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