Research on the Cognitive Mechanisms of Aural Alert Design in Civil Aircraft Cockpit

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Abstract. Research on the cognitive and behavioral response of flight crews to aural alerts is a challenging and critical area both in the fields of human factors and cognitive psychology. Studying the impact of aural alerts on crew recognition, understanding, task performance, and overall experience provides a theoretical foundation for the design of aural alerts.

This paper summarizes the design of aural alerts in the cockpit of civil aircraft while tracing the evolution of the aural alert system from simple aural alerts to multi-modal alert design leading to the trend of the development of aural alerts towards more user-friendly interaction between humans and computers was concluded. Besides, this section proposes design points for aural alerts, including sound types, cancelable modes and persistence characteristics. It also explores the design features to improve pilots' perception of flight status and their ability to cope with emergencies. Finally, this study analyzes the cognitive mechanism of aural alerts with the methodology of cognitive psychology and human factors engineering. The study evaluates the effects of different designs of aural alert information elements on crew perception, understanding, and task execution. The design of the cockpit aural alert system is crucial for the pilot's understanding of the flight situation and response speed to emergencies, which serves as a vital link between the pilot and the aircraft. Therefore, the design of aural alerts should focus on human-computer interaction and pilots' experience. The cockpit aural alert system must balance flight safety and pilots' experience, improve operational efficiency and enhance overall experience in stressful environments.

Keywords: Aural alerts · Human-computer Interaction · Aircraft Design · Cognitive Mechanisms

1 Overview of Cockpit Aural Alerts Design for Civil Aircraft

The cockpit of an aircraft plays a critical role in civil aviation. It attracts the attention of the flight crew and informs them of abnormal system states that require attention, as well as current fault attributes or corrective action guidance. Aural alerts on civil aircraft consist of two main types, including the tone alerts and the voice alerts.

The design process for aircraft models involves key considerations such as the selection of tone types and the content of the voice alerts. Aural alerts used in civil aircraft

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contain two main types, namely tones and speech. Table 1 gives the tones commonly used in aural alerts for civil aircraft, and Table 2 gives the voices commonly used in aural alerts for civil aircraft.

Table 1. Tone types of aural alerts commonly used in civil aircraft

Number	Aural Alert Content (Tone)	Comment
1	Trim Clacker	Aircraft trim work instructions
2	Cavalry Charge	The autopilot disengagement
3	Chime	General alerts when alert level alerts occur
4	Triple Chimes	A warning alert occurs
5	C Chord	Alert deviation from the pre-selected height
6	Beeper	APU limit
7	High Low Chime	Cabin emergency calls
8	Siren	Overspeed alerts
9	Fire Bell	For fire alert

Table 2. Voice types of aural alerts commonly used in civil aircraft

Number	Aural Alert Content (Voice)	Comment
1	"STALL"	Stall alert
2	"LEFT Engine Fire"	The left fire alert
3	"Right Engine Fire"	The right fire alert
4	"APU Fire"	The APU fire alert
5	"Smoke"	Used for detect smoke
6	"Configuration"	Used for takeoff and landing configuration alert
7	"Cabin Altitude"	The cabin height is too high
8	"Ice"	Ice alert
9	"Climb, Climb Now, Climb, Climb Now"	For Resolution Advisory

Major civil aircraft manufacturers, such as Boeing and Airbus, incorporate diverse design elements, including form and content. For instance, Boeing's aircraft designs primarily use horn sounds, accompanied by voice prompts featuring phrases like "Terrain Terrain Pull Up." In contrast, the alert tones in the Airbus design mainly consist of C chord tones. For instance, there are notable differences in the aural alert design among models for radio altitude alerts. Specifically, in the Boeing 737NG model, voice alerts are primarily used when the aircraft is at a low altitude, while in the Airbus A330 model, similar alerts are presented as 'C-chord' tones. The design of aural alerts can vary among manufacturers and is influenced by multiple factors.

From a perceptual standpoint, the recognition of aural alerts by crews constitutes a fundamental issue within the realm of aural alert perception, which is generally encompassed by the study of arousal and attention in cognitive science and human factors engineering. Begault et al. [1] from NASA (National Aeronautics and Space Administration) stated that continuous sounds possess greater alerting properties compared to discrete sounds. Kramer et al. [2] discovered a positive correlation between the crew's comprehension of the alert content and the number of repetitions of the main aural alert. Therefore, it is recommended to repeat the alert until it receives acknowledgment from the crew or until the alert state has ceased. Besides, Patterson [3] suggested that aural alerts should be reliable in capturing an individual's attention without being excessively loud, which could elicit a startle response and hinder primary task performance. Xin et al. [4] conducted empirical research on user experience through road VR environment simulation methods, which enhanced driver's experience and comfort, as well as advanced the development of future automated driving technology. Aural alerts should enable flight crews to understand the aircraft system status and situation, guiding them towards implementing optimal countermeasures to ensure the safe completion of the flight mission. As a result, it is important to consider the comprehensibility of alert messages.

2 Key Points in the Design of Civil Aircraft Cockpit Aural Alerts

The research on the cognitive and behavioral response of crew members to aural alerts is a hot spot topic and a challenge in the field of ergonomics and cognitive behavioral research. The study of the impact of the design elements of aural alerts on crew perception, understanding, task execution and experience can provide a theoretical basis for aural alerts information design, which is highly significant for the design of cockpit aural alerts.The design points for aural alerts in human-computer interaction are proposed based on research.

2.1 Types of Aural Alerts

An aural alert can be a separate tone, a voice, or a combination of both when a crew alert uses an aural alert as one of the sensing methods. To help the crew quickly determine the urgency of the alert, different tones are used for different types of alerts. The volume of the alert can be adjusted by the crew in accordance with the ambient noise level. As a result, the alert can be heard in all conditions and the frequency and duration of alerts are appropriate to their urgency and importance.

2.2 Cancellation Method for Aural Alerts

To prevent aural alerts from inadvertently disturbing the cockpit environment, the flight crew can cancel the currently triggered aural alerts by pressing a button. The alert can be manually canceled by the flight crew via the cockpit control panel or other designated equipment. However, when the problem is resolved or the situation is no longer an emergency, the alert should be automatically canceled in the system.

2.3 Persistence Characteristics of Aural Alerts

Aural alerts can be classified into three types: single-trigger, multi-trigger and continuous-trigger. Each type may require different durations to ensure that the flight crew has sufficient time to take necessary action. In terms of important but non-urgent alerts, intermittent reminders can be used to prevent the flight crew from ignoring them. Besides, when it comes to some unsolved issues which caused the alerts, the system should periodically repeat the alert to ensure that the flight crew is aware of it.

3 Cognitive Mechanism of Aural Alert Based on Human Factors Engineering

Factors Engineering Design guidelines and design databases serve as typical design management tools, providing standardized and reusable design solutions to improve the efficiency of design and development efficiency. This paper discusses the core elements of aural alerts, with a primary focus on alert tones and voice alerts. To identify parameters for each aural alert, the study focuses on analyzing design elements such as frequency, volume, intensity, amplitude, spelling, pitch, intonation, speech rate, repetition frequency and interval duration (see Fig. 1).

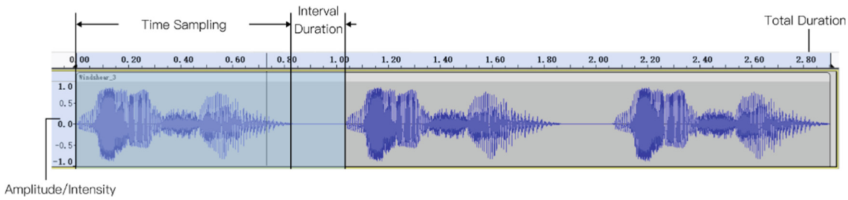

Fig. 1. The design features of aural alerts

The cognitive mechanisms of aural alerts provide the theoretical basis for designing such alerts. Human factors engineering suggests that alert tones should be clear and easy to distinguishable to ensure the flight crews can quickly identify and understand the problem. This paper analyzes the relationship between the design elements of aural alerts and crew cognition, focusing on dimensions such as crew cognition, crew performance and crew comfort. The impact mechanisms of these design elements on crew cognition are explored by analyzing aural parameters and cognitive performance (see Fig. 2). The following conclusions are drawn from the analysis:

- Frequency:
  The tone frequency should be between 200 Hz–4500 Hz which can be distinguished from cockpit noise frequencies, such as those from vibration dampers. The tone should consist of at least two frequencies. Besides, in the case of a single frequency, the tone should be distinguished by other characteristics like intervals between tones).
- Volume:
  The volume of the tone should be sufficient to ensure that it can be easily perceived by the crew in the most severe cockpit noise environments, but not so loud as to interfere

with the crew's ability to take necessary action. If the volume is adjustable, either manually or automatically, the minimum volume should still be perceived by the crew in all cockpit noise environments. Automatic volume adjustment is commonly used to maintain an appropriate signal-to-noise ratio.

- Quantity:
  In civil aircraft, the number of tones should not exceed 10 to reduce crew workload and training requirements, as an excessive number of tones can increase cognitive difficulty for flight crews.

Besides, in emergencies, aural alerts should be designed to prevent confusion and minimize the cognitive burden on the flight crew. Different alert levels should be associated with different sounds or sound patterns to help the crew quickly distinguish the importance of the problems. For instance, high-frequency or high-volume sounds may be used for urgent alerts. The design of aural alerts should take into account

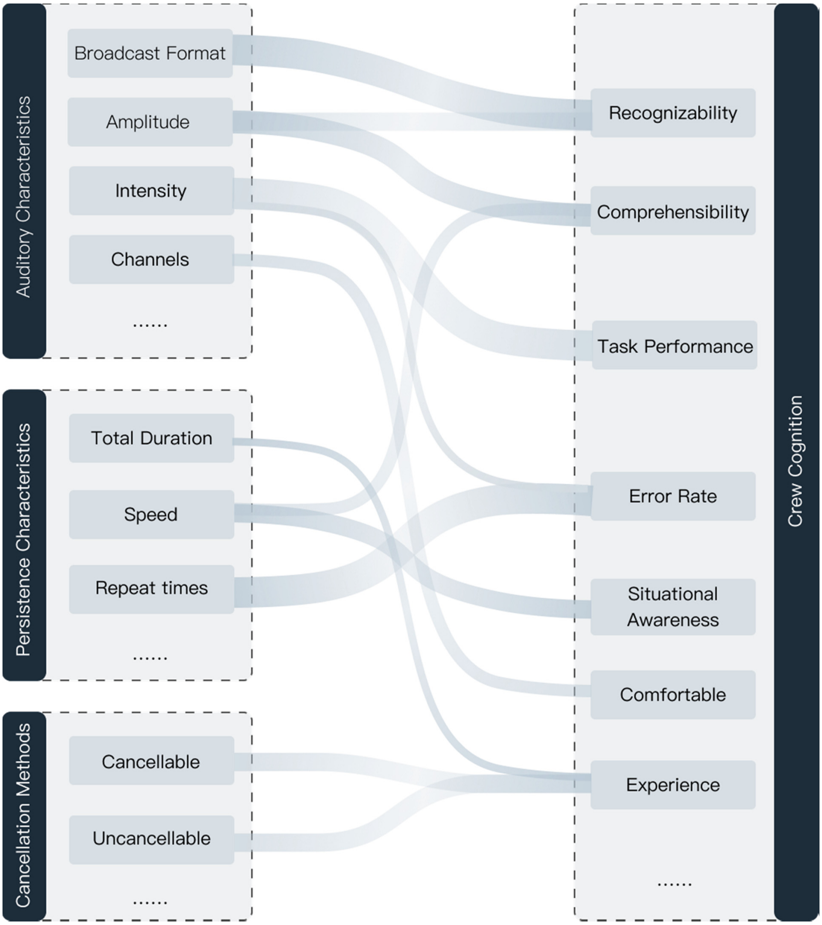

Fig. 2. Mapping of aural alerts characteristics to crew cognition

human physiological characteristics, such as the frequency range and sensitivity of human hearing.

In the aircraft cockpit, a large amount of information is integrated into a limited space, with complex scenarios and high cognitive load. Combining complex task scenarios for user evaluation and validation of the effects on how flight crews perceive, understand, perform and have an overall experience supports the design of aural alerts that more closely match the cognitive characteristics of the flight crew.

4 Conclusion

Cockpit aural alerts are a crucial aspect of communication between pilots and aircraft, directly impacting pilots' understanding of flight situations and their response speed to emergencies. This paper provides an overview of the design of aural alerts in civil aircraft cockpits, revealing trends in the development of aural alerts towards more friendly human-machine interaction. Besides, this paper analyzes the cognitive mechanism of aural alerts with the methodology of human factors engineering, proposes key points for the design of aural alerts and discusses design features to improve pilots' perception of flight status and response capabilities in emergencies. In future developments, cockpit aural alerts should consider human-machine interaction and user experience while balancing safety and operational efficiency, thereby enhancing the overall experience of aircraft crews in high-pressure environments. This holds significant social implications and industrial value for ensuring aviation safety.

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