Research on the Method of Safety Warning for Shipboard Aircraft Landing

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Abstract. In order to ensure the landing safety of the shipboard aircraft, it is necessary to monitor the landing process of the shipboard aircraft, and give an alarm in time for the situation that may endanger the flight safety. This paper mainly studies the use of human (Landing Signal Officer and Flight Crew) and Aircraft Environment Surveillance System (AESS) and compares the defects of these two methods. On this basis, a method of shipboard aircraft landing based on the probability of landing risk is proposed. By comparing the estimated value of landing guidance error with the warning threshold of landing guidance error in the vertical and lateral direction respectively, the warning is determined according to the comparison results.

1. Introduction

Shipboard aircraft is an important force to capture and maintain the air and sea power in the 21st century. Approaching and landing is a major technical problem faced by shipboard aircraft. After several hours of flight or operation, the shipboard aircraft pilots may not be able to complete a set of actions required for landing [1], and because the carrier flight deck is too short and narrow compared with the airport, and the ship body has dynamic characteristics such as movement and swing, the shipboard aircraft landing is faced with great risks.

According to the data of landing accidents published by the US military, 80% of the shipboard aircraft accidents occurred in the landing stage [2]. In 1964, the day and night landing accidents of the U.S. Navy's shipboard aircraft were 0.031% and 0.1% respectively [3-4]. During 2011-2012, the U.S. Navy had 11 landing accidents of Class A [5]. Therefore, the research on the flight safety of shipboard aircraft landing process has important theoretical and practical significance. Especially with the development of aircraft carrier industry in China, the naval strategy has gradually changed from coastal defense type to ocean attack and defense type. It is necessary to carry out in-depth research on the method of flight safety warning in the process of shipboard aircraft landing.

2. The warning method for landing flight safety of shipboard aircraft based on human

Currently, in the field of shipboard aircraft landing, there is no automatic flight safety warning method, mainly through the visual inspection of the landing commander on the ship or the observation of the environmental reference of the crew on the aircraft, or through the auxiliary information of the instrument to judge the position of shipboard aircraft and compare the current spatial position of aircraft with the ideal position to get the position deviation, and finally compare the position deviation with the maximum allowable deviation threshold. When the position
deviation is greater than the warning threshold, the landing commander orders the pilot to go around, or the pilot can go around autonomously.

There are three disadvantages in the visual alarm of landing commander or the crew on the aircraft: first, the alarm process mainly depends on the subjective experience of people (landing commander and flight crew), and there are large errors in observation, judgment and decision-making, which leads to the uncertainty of alarm timing and judgment criteria, which is easy to cause flight accidents; second, due to that there is a lot of pressure on the landing commander and flight crew during the landing process, in order to ensure that no dangerous accident occurs, the alarm is conservative, which is not conducive to the efficient recovery of the shipboard aircraft; thirdly, the landing commander and flight crew are highly stressed during the landing process, and the workload is very heavy, which is not conducive to the realization of efficient and accurate alarm.

3. The warning method for landing flight safety of shipboard aircraft based on aircraft environmental monitoring system

In the field of civil aviation, there is automatic warning technology in the process of aircraft landing. A typical scheme is Aircraft Environment Surveillance System (AESS). The aircraft environment monitoring system is to detect the dangerous area in advance and give an alarm by monitoring the surrounding environment of the aircraft, so as to avoid major accidents. The operation of the aircraft environmental monitoring system alarm system is shown in the figure below (Figure 1).

![Figure 1. The operation of the aircraft environmental monitoring system alarm system.](image-url)

Environmental state space: this part includes the environmental states that need to be monitored by the aircraft environmental monitoring system, such as terrain threat, traffic conflict, weather conditions, etc.

Sensor: it transforms the environmental status to information that can be analyzed and processed by the aircraft environmental monitoring system, for example, the radio altimeter used to obtain the aircraft radio altitude.
Pilot: after the aircraft environmental monitoring system gives an alarm, within a certain reaction delay, the pilot usually takes actions according to the system instructions to avoid accidents.

Display module: the module has two functions: on one hand, it can display the current environmental spatial state in real time, such as meteorological cloud map display, forward-looking terrain display and traffic situation display; on the other hand, when the threat is detected, it can forcibly obtain the driver's attention through visual and auditory channels, and provide solutions, for example, when the forward-looking terrain conflicts, it can mark the dangerous terrain red and report it. The warning light flashes and an audible indication of the pull-up are given.

Executive device: this part implements the avoidance decision of the pilot, for example, when the pilot controls the pull-up, the aircraft climbs.

AESS danger detection and alarm module: this part will process all the information obtained, and compare it with the set threshold according to a certain relationship, and decide whether to send an alarm according to the calculation results.

There are two main disadvantages in the application of aircraft environmental monitoring system for warning: first, the accuracy is not high, the runway of civil aviation aircraft is long and wide, and thus the requirements for the accuracy of aircraft landing point are not high. When the warning method is applied to shipboard aircraft landing, the system can only be used to monitor obstacles, and it cannot be used to monitor the safety risks caused by flight deviation. Therefore, this system is not suitable for shipboard aircraft landing.

4. The warning method for landing flight safety of shipboard aircraft based on landing risk probability

4.1. Determine the probability value of landing guidance risk

According to the statistical value of historical safety accident rate and the required value of mission success rate, the probability value of landing guidance risk is determined.

The statistical value of historical safety accident rate refers to the probability value of landing guidance safety accidents since there is data record; for example, since there is data record, the probability value of landing guidance safety accidents in a country is 13.8%.

The required value of mission success rate refers to the success rate of shipboard aircraft recovery landing required by carrier operations; for example, in a certain mission, the success rate of shipboard aircraft recovery landing required by carrier operations is 85%.

The probability value of landing guidance risk refers to the probability that the guidance error exceeds the safety range without warning. The theoretical expression is as follows:

\[ P_{\text{mi}} = P_{\text{over}} P_{\text{noalarm}} \]  \hspace{1cm} (1)

In this formula,
- \( P_{\text{mi}} \) is the probability value of landing guidance risk;
- \( P_{\text{over}} \) is the probability that the landing error of shipboard aircraft exceeds the safe range;
- \( P_{\text{noalarm}} \) is the probability of no alarm.

The probability value of landing guidance risk must meet the requirement of mission success rate, i.e. less than the probability of mission failure. At the same time, the probability value of landing guidance risk should be less than the statistical value of historical safety accident rate, thus it should meet the following requirements:

\[
\begin{align*}
P_{\text{mi}} &< P_{\text{ac}} \\
P_{\text{mi}} &< 1 - P_{\text{s}}
\end{align*}
\]  \hspace{1cm} (2)

Here, \( P_{\text{s}} \) is the statistical value of historical safety accident rate;

\( P_{\text{ac}} \) is the required value of mission success rate.

The probability value of landing guidance risk is mainly set by the onboard flight commander.
The smaller the value is, the higher the cost of shipboard aircraft reclaiming is.

4.2. Probability value decomposition of landing guidance risk

The probability value of landing guidance risk is divided equally into vertical and lateral directions:

\[ P_{mv} = P_{ml} = \frac{P_m}{2} \tag{3} \]

Here \( P_m \) is the confidence probability value of the estimation value of landing guidance error;

\( P_{mv} \) is landing guidance probability in vertical direction, that is the probability of landing guidance vertical error exceeding safety range without warning;

\( P_{ml} \) is landing guidance probability in lateral direction, that is the probability of landing guidance lateral error exceeding safety range without warning.

4.3. Estimation factor calculation of landing guidance error

Landing guidance error estimation factor refers to the calculated factor used to estimate the landing guidance error using the landing guidance risk probability value as the confidence probability value of the landing guidance error estimation value, including landing guidance vertical error estimation factor and landing guidance lateral error estimation factor. The specific method is as follows:

\[ K_{mv} = Q^{-1}(P_{mv}) \tag{4} \]
\[ K_{ml} = Q^{-1}(P_{ml}) \tag{5} \]

Here, \( K_{mv} \) is the landing guidance vertical error estimation factor;

\( K_{ml} \) is the landing guidance lateral error estimation factor;

\( Q^{-1} \) is the Gauss inverse function.

4.4. Calculation of error estimate of landing guidance system

The error estimate of landing guidance system refers to the error estimate of shipboard aircraft measured by the guidance system, including the vertical error estimate and the lateral error estimate. The specific method to calculate the error estimate of landing guidance system is as follows:

\[ ESV = K_{mv} \sqrt{\sum_{i=1}^{N} s_{i,vert}^2 \sigma_i^2} \tag{6} \]
\[ ESL = K_{ml} \sqrt{\sum_{i=1}^{N} s_{i,later}^2 \sigma_i^2} \tag{7} \]

Here, \( ESV \) is the vertical error estimate of landing guidance system;

\( ESL \) is the lateral error estimate of landing guidance system;

\( N \) is the number of error sources;

\( s_{i,vert} \) is the weight coefficient of vertical error caused by the \( i \)th error source;

\( s_{i,later} \) is the weight coefficient of lateral error caused by the \( i \)th error source;

\( \sigma_i \) is the \( i \)th error source of landing guidance.

The error source of landing guidance system refers to the measurement error of landing guidance radar, photoelectric landing guidance equipment and satellite landing guidance equipment; the weight coefficient of error source refers to the contribution degree of each landing guidance error source to the error of landing guidance system under the environmental conditions in which the landing guidance system is used.

4.5. Landing guidance error warning threshold

Landing guidance error warning threshold refers to the maximum allowable value of the guidance error, which is the marginal value of the space area to ensure the safety of shipboard aircraft,
including vertical error warning threshold and lateral error warning threshold; landing guidance error warning threshold is determined by the maximum flight control ability of shipboard aircraft, which is directly quoted in this paper (Table 1).

**Table 1.** The landing guidance error warning thresholds.

| Position on shipboard aircraft | Vertical warning threshold (m) | Distance between vertical threshold and ideal position (m) | Lateral warning threshold (m) | Distance between lateral threshold and ideal position (m) |
|--------------------------------|--------------------------------|----------------------------------------------------------|-------------------------------|----------------------------------------------------------|
| Stern position                 | 0.93                           | Upper 0.56                                               | 5.4                           | Right 2.7                                                |
|                                |                                | Lower 0.37                                               |                               | Left 2.7                                                 |
| About 300 m from the carrier   | 3.0                            | Upper 1.8                                               | 9.2                           | Right 4.6                                                |
|                                |                                | Lower 1.2                                               |                               | Left 4.6                                                 |
| About 900 m from the stern     | 9.2                            | Upper 5.5                                               | 9.2                           | Right 4.6                                                |
|                                |                                | Lower 3.7                                               |                               | Left 4.6                                                 |

4.6. **Alarm decision method**

Compare the estimated error of landing guidance system in 4.4 with the warning threshold of landing guidance error in 4.5 according to the vertical and lateral directions respectively, and decide whether to alarm according to the comparison results. The specific methods are as follows:

If $ESV \geq VAL$ or $ESL \geq LAL$, it means that the estimated value of landing guidance error exceeds the limit, and the system gives an alarm;

If $ESV < VAL$ or $ESL < LAL$, it means that the estimated error of landing guidance is not over limit and the landing guidance system is not alarmed.

Here,

- $VAL$ is the vertical alarm threshold;
- $LAL$ is the lateral alarm threshold.

5. **Conclusions**

In this paper, aiming at the safety monitoring of fixed-wing shipboard aircraft during the landing process of floating platform, we compared the two traditional safety warning methods of shipboard aircraft in the field of aircraft landing. One of the safety warning methods is to observe the environmental reference through the visual inspection of the landing commander on board or the crew on the aircraft and another method is to monitor the surrounding environment of the aircraft by using the Aircraft Environmental Surveillance System (AESS). Then, it is available to detect the dangerous area in advance and to give an alarm. The defects of these two warning methods are explained.

In order to ensure the landing flight safety of shipboard aircraft, this paper proposes a shipboard aircraft landing flight safety warning method based on the landing risk probability. This method compares the estimated value of landing guidance error with the warning threshold of landing guidance error in the vertical and lateral direction respectively, and decides whether to give an alarm based on the comparison results. This method can make the shipboard aircraft give an alarm prompt in time when there is a large deviation in the landing process and the flight safety is endangered.

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