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Research Article

Analysis of Security Window in Automatic Landing of the Carrier-borne Aircraft

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Abstract: Wave-off judgment research of carrier-borne aircraft in the landing process led by automatic landing system is made and the conception of security window in automatic Landing of the carrier-borne aircraft is proposed. Through the study of carrier-borne aircraft's landing process under the guidance of automatic landing system, considering on the impact from typical air-wake and aircraft carrier motion on carrier-borne aircraft's automatic landing, this paper analyzes aircraft's automatic safety window landing position, and calculates the boundary of safety window.

Keywords: Carrier-borne aircraft, leading system of automatic landing, safety window of automatic landing

INTRODUCTION

The landing of carrier-borne aircraft is different from that of land-based aircraft. Carrier-borne aircraft has many different factors which have harsh restrictions and effects, such as length of runway, ship motion, approach and environmental disturbance and so on. There are more difficulty and risk of landing when entering the field. In the landing process of carrier-borne aircraft approach, precise control of track is needed, with the right speed, stable attitude and accuracy on the ship at a predetermined position and landing gear is at the right point of landing which can safely arrest landing. The environmental disturbance is more complex with more control parameters, high control accuracy requirement, so the risk is particularly great. Especially the last 20 sec of a ship landing is accident-prone section. The main influential factors are the carrier motion and turbulence (Huff and Kessler, 1978).

When the aircraft is slipped into the section alignment in the angled deck, the carrier begins landing, then the carrier-borne aircraft lands safely guided by automatic landing system. Because the plane is different, this process takes about 20~30 sec. In this process, the carrier-borne aircraft is influenced by carrier air-wake, meanwhile carrier influenced by Ocean Sea. Under the double influence of carrier-borne aircraft carrier, the angled deck landing errors exist. Sometimes, the error is too large to make the aircraft achieve secure landing in the angled deck. In order to avoid the too large landing error, a destroyer commander is needed for the monitoring of the aircraft in the carrier-borne aircraft landing process. Once found the aircraft cannot achieve secure landing, the aircraft landing commander demands ships be stopped to fly again. In such a short period of time, the destroyer commander is demanded to accurately and quickly judge the condition of the plane. In order to meet this requirement, aircraft automatic landing safety window concept is put forward in this study, which provides convenience for aircraft landing commanders on the wave-off decision. This can also be used as reference of wave-off decision for artificial landing commander (Zhu, 2009; Qidan *et al*., 2012).

THE CONCEPT OF SAFETY WINDOW IN CARRIER-BORNE AIRCRAFT AUTOMATIC LANDING

When there is no impact from turbulence and carrier motion, the aircraft lands at the ideal landing point at the right angle, flight path angle and speed, then the track in the carrier-borne aircraft landing process is called ideal fall line, Fig. 1. The ideal landing point for the carrier-borne aircraft landing is between the second and third cable, Fig. 2.

In the carrier-borne aircraft landing process, carrier-based aircraft glide path has deviation from the ideal fall line due to the air-wake and carrier motion effects. When the deviation is too large, the aircraft cannot land in the range near the ideal point under the guidance of automatic landing system. In this case a destroyer commander gives a go-around signal, requiring the flight retrial of carrier-borne aircraft. Because this is the prior judgment a destroyer commander makes before aircraft landing, therefore a certain deviation range at the distance of ideal landing point is allowable. In the error range, the aircraft can land safely guided by the automatic landing system; but when the tolerance range is exceeded, an ideal landing point within a certain range cannot be achieved. The deviation range is just like a window fixed in the distance between landing point and ideal landing point, which is called the automatic

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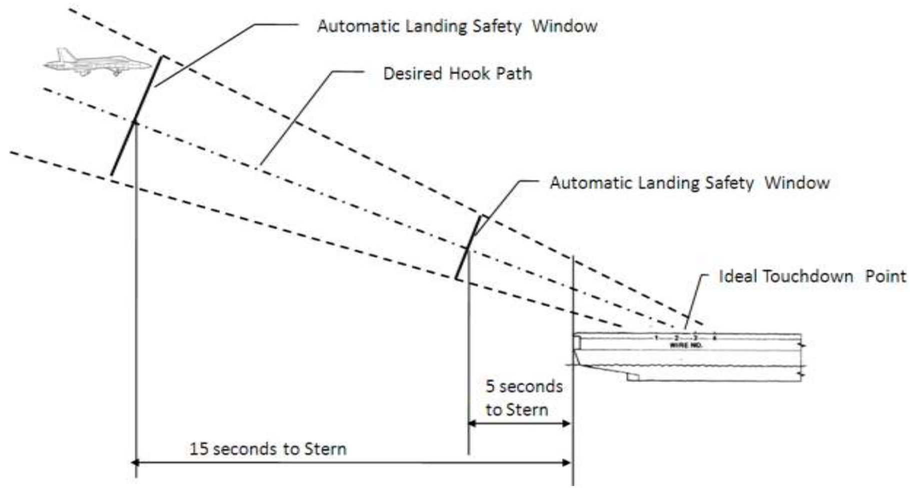

Fig. 1: Side view of automatic landing safety window

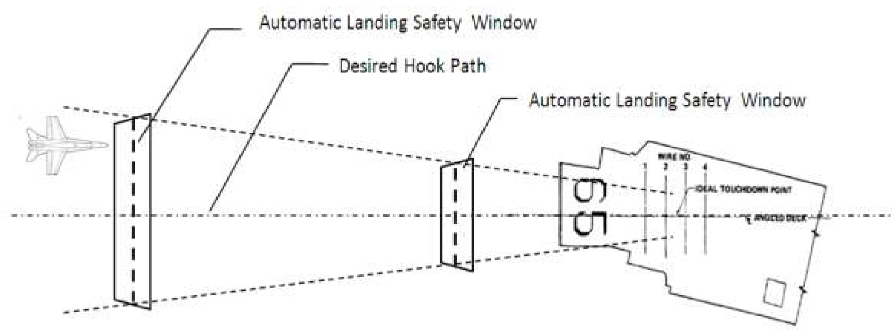

Fig. 2: Overlooking the map of automatic landing safety window

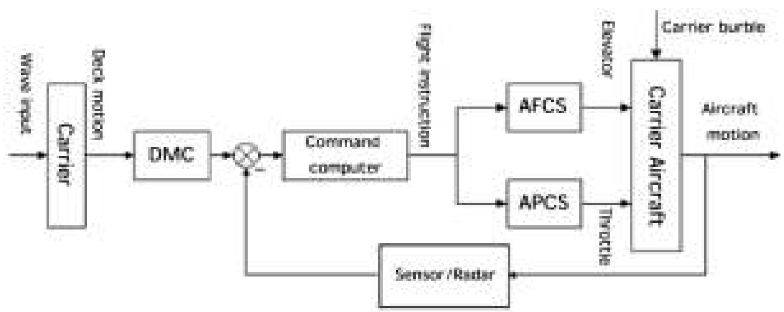

Fig. 3: The diagram of ACLS system structure

landing safety window in this essay, Fig. 1 and 2. Passing the window, the aircraft can safely land; out the window, secure landing is unable to reach, so retrial should be demanded.

INTRODUCTION OF AUTOMATIC LANDING GUIDING SYSTEM

Targeted goal of carrier-borne airplane ACLS (Automatic Carrier Landing System) is: in all kinds of weather conditions, to achieve automatic landing of the carrier aircraft on aircraft carrier movement deck.

Diagram of ACLS system structure principle is shown in Fig. 3.

Basic working principle of ACLS system is as follows: the deck movement of the aircraft carrier caused by wave causes changes of the ideal landing point, filtering position changes of the ideal landing point through the Deck Motion Compensator DMC, the deck motion compensation instruction and carrier-based aircraft position information input into shipboard instruction computer, which combines both, giving instruction of landing trajectory/attitude command through control equation in the longitudinal. This instruction is transmitted to carrier-borne aircraft by wireless data link, at the same time, the aircraft carrier air-wake signal input and Automatic Flight Control System of AFCS and Approach Power Compensation System APCS control elevator and throttle respectively, making the flight go on track instruction.

In the process of aircraft automatic landing, ACLS can greatly reduce the carrier-borne airplane longitudinal error and transverse error and ensure the efficient completion of carrier-borne aircraft's batch landing, greatly improving the carrier-borne aircraft safety, accuracy and degree of automation. After using ACLS, carrier-borne aircraft has gained greater freedom, so safe landing can be achieved regardless of day, night, sunny day, rainy day, even in conditions with zero visibility.

As shown in Fig. 3, the aircraft is an important link in ACLS. Different types of aircraft also have different ACLS. This study studies the F/A-18A carrier-borne aircraft of American army. Through the establishment of the closed-loop landing system, it analyzes location and boundary of automatic landing safety window, as well as impact of the stern flow and carrier motion on carrier-borne aircraft in the height deviation of ship security window.

ANALYSIS OF AUTOMATIC LANDING SECURITY WINDOW

Analysis of window position: Carrier-borne aircraft enters the automatic landing stage at a distance of 0.75 to 1 nm under the guidance of the landing equipment. In the process of aircraft decline, warship device may not be ready due to various reasons, or timely accurate correction cannot be made when aircraft is greatly out of the track in the glide path, so the plane must be immediately pulled up and fly again, otherwise a ship accident may take place, or even severe. The aircraft safe overshoot has certain limitations and requirements and a destroyer commander should make timely wave-off decision and give the pilot go-around instruction according to the aircraft flight state and these limitations. Envelope and the ideal slide-way typical position of the window can be used to decide the retrial flight. When the aircraft goes through the window in the decline process, it is thought that carrier-borne aircraft can successfully land on the deck. When the aircraft passes through the window, retrial flight is determined.

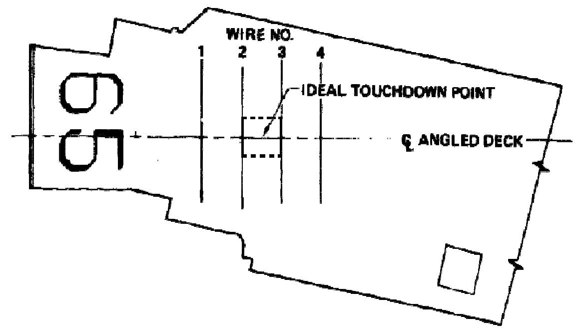

Fig. 4: Schematic diagram of ideal landing area

General wave-off decision regions are within the horizontal distance of 180~960 m from the stern of the ship (Yu *et al*., 2002). This study uses the F/A18 plane to make analysis. F/A18 aircraft usually lands at a speed of 136 knots, with glide angle of 3.5°. Aircraft speed is 25 knots. The angle between aircraft carrier and deck angle is 9° (Susan and Stephen, 2005). After calculating the wave-off decision region can be seen as distance of 3.2~16.0 sec from the F/A18 carrier-borne aircraft to the stern of the carrier.

The authors (Davies and Noury, 1974) tells the judging distance for F/A18 in automatic carrier guided landing system is 5~13 sec from the stern of the ship.

After comprehensive analysis, the establishment of two automatic landing safety windows at 15 and 5 sec from the stern can help make retrial decision, Fig. 1 and 2. When the aircraft enters security window 15 sec distant from the stern in automatic landing, the aircraft completes automatic landing under the guidance of automatic landing system, the pilot makes zero error in the operation, only considering environmental factors. When the aircraft goes through safety window 15 sec far from the stern in automatic landing and if it cannot land within the ideal landing range under the guidance of ACLS, so at this time retrial flight should be in operation. Five seconds from the stern of automatic landing security window, the last go-around judgment is made, if through the window, the landing is allowable; otherwise the pilot should retry the flight of the aircraft.

Boundary calculation: The ideal area of the carrier-borne aircraft on the angled deck is a rectangular range ±6.1 m (Anderson, 1996) or so from the ideal landing point around, see Fig. 4.

Deviation appears when the carrier-borne aircraft passes through the automatic landing safety window and the error can be eliminated under the guidance of the automatic landing system to ensure the aircraft to land at the ideal landing area. The maximum deviation is the window boundary. Figure 5 and 6 are respectively the aircraft's position at a distance of 15 sec from the stern

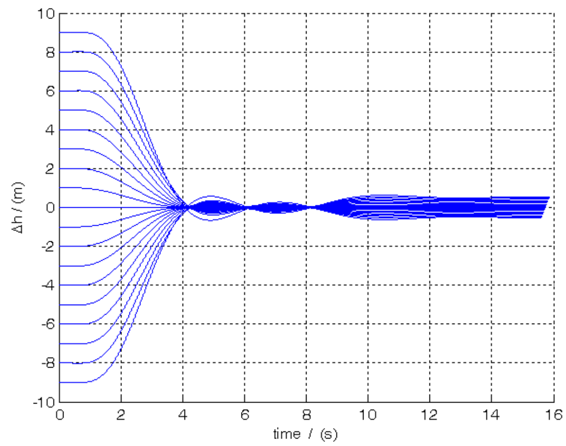

Fig. 5: Different longitudinal deviation path curve of carrier-borne aircraft in position of 15 sec from the stern

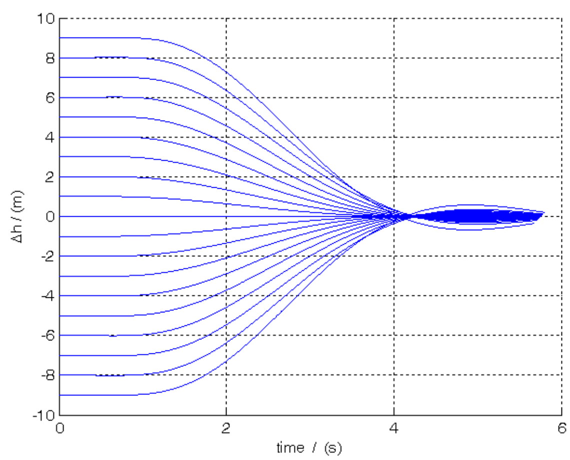

Fig. 6: Different longitudinal deviation path curve of carrier-borne aircraft in position of 5 seconds from the stern

Table 1: Five seconds from the stern

The edge of the window	Distance from the ideal glide trajectory
Window on the boundary	6.89 m
Under the window boundary	-6.69 m
The left window boundary	-10.50 m
The right window edge	10.70 m

Table 2: Fifteen seconds from the stern

The edge of the window	Distance from the ideal glide trajectory
Window on the boundary	7.27 m
Under the window boundary	-6.99 m
The left window boundary	-10.10 m
The right window edge	11.40 m

and that of 5 sec, with vertical deviation from -9 to 9 m, in full automatic the path curve under the guidance of landing system.

FLateral deviation calculation method is the same. Through calculation gets the window boundary 5 sec (Table 1) and 15 sec (Table 2) from the stern of the aircraft.

ENVIRONMENTAL FACTORS

Carrier motion model: Carrier motion is affected by the motion of the sea, so it is a kind of environmental factors. The spectrum of carrier motion at sea is a typical frequency narrowband process, generally not changing with the state of motion, the frequency range focused from 0.2 to 0.8 rad/sec and the changes of the external conditions can only change peak power, peak and bandwidth and frequency spectrum form is almost not affected. So it is possible to find a simplified fitting method, which gives the general form of carrier motion spectrum at sea, used on analytic expression of the measured spectrum (Peng and Jin, 2001).
The pitch frequency transfer function:

$$G_\theta(s) = \frac{0.045s}{s^2 + 0.24s + 0.62} \tag{1}$$

Vertical spectrum transfer function:

$$G_Z(s) = \frac{0.03s}{s^2 + 0.13s + 0.53} \tag{2}$$

Sway spectrum transfer function:

$$G_Y(s) = \frac{0.006s}{s^2 + 0.2s + 0.45} \tag{3}$$

Roll spectrum transfer function:

$$G_\vartheta(s) = \frac{0.042s}{s^2 + 0.62s + 0.81} \tag{4}$$

This fitting method of simplifying carrier motion at sea power spectrum is very intuitive in use, simple calculation process involved, calculation amount small, so it is a very practical, effective engineering method for fitting narrowband stationary random process spectrum.

Aircraft carrier air-wake model: Air wake's effect on carrier-borne aircraft landing is caused by the air flow rate in the stern flow changes, so the air-wake model must be able to reflect the changes of the wind speed in stern flow field with different influence factors. Many factors affect the air-wake of the carrier-borne aircraft, which often has nonlinear, unsteady and randomness characteristics, so it is complex.

What is commonly used is MIL-F-8785C turbulence model. Total disturbance velocity components of the disturbance model are as follows.

Random free atmospheric turbulence: Free sea surface atmospheric turbulence is free atmospheric turbulence component in low sky independent of the position of aircraft and aircraft carrier which is anisotropic.

Steady-state carrier wake disturbance: The static component of carrier wake.

Periodic motion caused by carrier motion: It is induced by carrier periodic longitudinal carrier wave and heave motion, with the change of the pitch frequency, amplitude, pitch deck wind and the distance from the carrier-borne aircraft to the carrier.

The random carrier air-wake disturbance: Random atmospheric turbulence caused by the existence of aircraft carrier, power measurement of the spectra shows that this part of the atmospheric turbulence is anisotropic.

CONCLUSION

The carrier-borne aircraft is affected by air-wake and carrier motion at the position of 5 and 15 sec from the stern, which causes standard deviation from ideal slide-way:

In position of 5 sec from the aft: the standard deviation is 0.41 m in height, lateral standard deviation 0.32 m.

In position of 15 sec from the aft: the standard deviation is 0.12 m in height, lateral standard deviation 0.14 m.

Because the deck compensation opens 12 sec from the stern, before the opening aircraft is only affected by the stern flow; after the opening, carrier motion can affect the aircraft motion through the movement of aircraft ACLS system, so aircraft is both affected by the turbulence and the carrier motion. Therefore, difference of height standard and lateral deviation at the position of 5 sec from the stern is greater than those of 15 sec.

In order to ensure the safety of carrier-borne aircraft landing, the practical window border is subtracting the standard deviation caused by the external environmental factors from the original window boundary. That is:

$$X = \begin{cases} X_0 - \sigma & X_0 \geq 0 \\ X_0 + \sigma & X_0 < 0 \end{cases} \quad (5)$$

According to data from above section, automatic landing safety window boundary can be gained with the influence of air-wake turbulence and carrier movement (Table 3 and 4).

Table 3: In the position of 5 sec from the stern

The edge of the window	Distance from the ideal glide trajectory
Window on the boundary	6.48 m
Under the window boundary	-6.28 m
The left window boundary	-10.18 m
The right window edge	10.38 m

Table 4: In the position of 15 sec from the stern

The edge of the window	Distance from the ideal glide trajectory
Window on the boundary	7.15 m
Under the window boundary	-6.87 m
The left window boundary	-9.96 m
The right window edge	11.26 m

The actual environmental factors that affect carrier-borne aircraft are mainly carrier motion and turbulence of air-wake. Therefore the automatic landing safety window boundary calculated with effects of turbulence and carrier motion can be seen as the actual available automatic landing safety window borders. Through the automatic landing safety window, a destroyer commander can make a convenient and quick decision of flying judgment, improving the safety index of carrier-borne aircraft automatic landing.

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