Analysis of Influence of Optical Glideslope Indicator Deviation on Carrier Aircraft Landing

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Abstract. The guidance provided by the optical glideslope for the carrier's safe landing is very critical. Several optical glideslope stable modes are analyzed. And the line stability mode is chosen as the research object. In the line stability mode, the guiding principle of the optical glideslope is analyzed. Under this mode, the optical glideslope indication deviation can be represented by the offset of the "meat ball" seen by the pilot. Through simulation and calculation, the influence of different "meat ball" offsets on the landing point of the carrier aircraft can be obtained, which provides a reference for the safe landing of the carrier aircraft.

1. Introduction
The deck runway of an aircraft carrier is very short and the pilot is not able to determine whether the aircraft is aligned to the center line of the runway until it is very close to the carrier, so it is prone to yaw accidents. At the same time, aircraft carriers are constantly moving at sea, pitching, rolling, sinking, driving, etc., making the aiming point of landing erratic, increasing the difficulty of pilot’s aiming at the landing point [1-3].

Only under the accurate guidance of the system and the guidance personnel, the carrier aircraft can safely and accurately complete the landing on the aircraft carrier. It is a complex and fine process for carrier aircraft to carry out landing, which requires multiple guiding devices and alternate guidance. [4]. In the final stage of landing, the pilot of carrier aircraft mainly relies on the optical glideslope provided by FOLS to visually land the ship.[5] Therefore, the guiding accuracy of the optical glideslope is directly related to the success rate of landing. It is very important to study the influence of the indication deviation of the optical glideslope on the aircraft landing.

2. Analysis of optical glideslope stability mode

2.1. Four stability modes
Optical aid-landing device, the major short-range guidance device in the landing guidance system, which adopts a certain stability mode, controls the motion of the aircraft carrier such as pitching, rolling and heaving by the corresponding compensation algorithm, so as to provide the pilot with a relatively stable optical glideslope to visually land the ship [6]. At present, there are four common stability modes, that is, point stability mode, angle stability mode, line stability mode and inertia stability mode. [7-9].

(1) Point stability mode: the whole glideslope beam only stays stable relative to a fixed point set by the lens, generally 2500 feet (762 meters). To maintain the stability of this point, translation and pitching...
motion of the glideslope are needed to carry out to compensate the change of the attitude angle of the ship.

(2) Angle stability mode: the pitch motion of the light box is controlled by a follow-up system, so that the angle of the glideslope beam remains the same in space, that is, no change in pitch, no compensation for the variation of the height of the glideslope caused by pitching, rolling and heaving of the ship.

(3) Line stability mode: through the compensation of the pitching and rolling of the ship by the follow-up system, the light array system, including the aiming light group and the auxiliary light group, is used to provide an optical glideslope beam for the aircraft returning to the ship, and to guide the pilot to conduct the visual landing. The glideslope is relatively stable in space and is not affected by the ship's pitching and rolling attitude, but only changes vertically with the ship's heaving motion.

(4) Inertial stability mode: the glideslope is kept absolutely stable in the inertial space, free from aircraft carrier’s pitching, rolling and heaving motion, also known as point and line stability.

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2.2. Stability mode analysis
Point stability and angle stability cannot guarantee the complete stability of the sliding path in space. Pilots will feel that the downslide beam is still moving up and down with the aircraft carrier moving up and down, and the closer the plane is to the ideal ship point, the more intense the downward slide beam moves.

The compensation for sinking motion is added to the inertial stability mode on the basis of line stability mode. The aircraft maneuvering is reduced, and the handling load of pilots is reduced. However, when the aircraft carrier rises or sinks 1 meter, it will cause the landing point to move towards the stern or bow \( \frac{1}{\tan \beta_0} \) meters along the center line of the runway, which has a huge impact on the landing safety (\( \beta_0 \) is the base slide beam angle).

Therefore, this paper analyzed and studies the influence of optical glideslope indicator deviation on carrier aircraft landing in line stability mode.

3. Analysis of working principle of line stability mode
Line stability mode, in fact, is a inertial stability mode without floating and sinking compensation. With the linear stability scheme, the pitch and roll motion of the downslide beam relative to the aircraft carrier can be kept stable, but it will move vertically with the aircraft carrier sinking or floating. As shown in Figure 1, the intersection between the sliding beam surface and the vertical plane passing through the bevel deck centerline remains stable in inertial space.

The inner light source of optical aid-landing device 5 monomer light boxes, through the aperture, Fresnel lens, cylindrical lens and other optical components, cast out into the sky a 5-level for 3 kinds of color of beam. The middle light box casts out an orange beam of light (considered as a light plane for convenience). The light plane intersects a plane, which is perpendicular to the deck and passes thought the center line of the runway, and a straight line is obtained. This is the optical glideslope guiding the pilot to land. In the process of landing, the pilot adjusts the vertical deviation between the plane and the glideslope by real-time judging the relative position of the light bulb of the aiming lamp group and the light column of the reference lamp group, and adjusts horizontal deviation by aligning the centerline of the runway, so as to track the glideslope to landing. When the ship is swaying, the device receives the pitch and roll parameters of the aircraft carrier and calculates the rotation angle information of the corresponding aiming lamp group, which is compensated by the beam of the lamp box of the follow-up system.[10]
4. Analysis of the optical glideslope indication deviation

4.1. Formation and deviation of “meat ball”

The so-called "meat ball" is actually the light body formed by the reverse focusing of the light emitted from the surface of the lamp chamber through the human eye. In the longitudinal working field of the glide path beam, the pilot can perceive the "meat ball" as long as he can see the light coming from the surface of the light chamber. In the view of the pilot, the "meat ball" seems to be emitted from a fixed point behind the Fresnel lens, which is actually a virtual image, because all the light beams of the Fresnel lens of the five lamp chambers are focused on the virtual image point, as if they are all emitted from this virtual image [11]. Because the virtual image is oval, the "meat ball" the pilot seen is also oval. Since the position of the "meat ball" formed on the surface of the light chamber by connecting the virtual image with the pilot's eye position is proportional to the vertical deviation of the pilot's eye from the light reference glide line, the displacement of the "meat ball" seen by the pilot relative to the light reference glide line can be used to represent the aircraft's glide deviation, as shown in Figure 2.
4.2. Analysis of the optical glideslope indication deviation influence on landing

If the carrier aircraft follows the base glideslope, the tail hook can successfully hook the blocking cable. However, if there is a certain deviation in the optical aid-landing device, the optical glide path indication error will be caused, resulting in the deviation of the "meat ball" from the reference position, and the deviation of the "meat ball" will also cause the deviation between the actual landing point and the ideal landing point, as shown in Figure 3.

In the figure, O represents the position of the virtual image and F represents the position of the horizontal reference light, also known as the ideal landing point. The horizontal distance between them is L. Point A represents the pilot eyes, point B is light falling benchmark line and vertical plane intersection point, through the pilot eyes C point for point A vertical plane and the location of the point O horizontal plane intersection, D point for point A vertical plane and F point location in the horizontal plane intersection, \( OC = R_c \), \( CD = \Delta h \), \( d \) represents "meat ball" offsets, \( h_a \) represents the decline in the aircraft offsets, \( \beta_0 \) represents aircraft’s ideal slide angle, \( \beta_a \) represents aircraft’s actual slide angle. The difference between the two angle is the slide angle deviation \( e \).

\[
\tan(\beta_a) = \frac{L}{\Delta h} \\
\tan(\beta_0) = \frac{L}{R_c}
\]

As can be seen from Figure 3, \( FF' \) is the deviation of the landing point. According to the geometric relationship shown in the figure, the below can be obtained.

\[
FF' = L - \frac{L \tan \beta_0}{\tan(\beta_0 + e)}
\]

5. Simulation and calculation

Set slide reference beam angle for \( \beta_0 \) (unit: °). "Meat ball" is located in the intersection of the slide and \( L \) meters front of the horizontal reference light in vertical plane (due to the confidentiality of the data, the corresponding data is represented alphabetically). The position of the virtual image is lower than the horizontal plane of the reference light.

Table 1 shows the relationship between glide deviation angle \( e \) and "meatball" offset \( d \).
Table 1. Relation between Slip deviation angle $e$ and “Meat ball” offset $d$

| Slip deviation angle $e$ (°) | “Meat ball” Offset $d$ (1 “Meat ball” Height) |
|-------------------------------|---------------------------------------------|
| 0.75                          | 2                                           |
| 0.375                         | 1                                           |
| 0.067                         | 0.1787                                      |
| 0                             | 0                                           |
| -0.75                         | -2                                          |

Thus, according to the geometric relationship shown in Figure 4, the relationship between the glide offset and the "meatball" offset can be deduced as below.

$$h_a = \frac{3}{8} \times \frac{R_s}{57.3} d$$

Through simulation, the relationship between the glide offset and the "meatball" offset and the carrier aircraft's distance from the ideal landing point is shown in Figure 4, in which the "meatball" offset and the glide offset are both high Numbers.

Figure 4. Relationship diagram of glide offset, "meatball" offset and distance from the ideal landing point.

The relationship between the landing deviation and the "meatball" deviation is shown in Figure 5. The landing deviation is positive in the bow direction and negative in the stern direction.
From the above simulation results, it can be concluded that the glide offset is directly proportional to the "meatball" offset and the carrier aircraft's distance from the ideal landing point. The landing offset is also proportional to the meatball offset. With the increase of "meatball" offset, the deviation between the actual landing point and the ideal landing point becomes larger and larger. When the "meatball" is high, the actual landing point is in front of the ideal landing point; On the low side, the actual landing point is behind the ideal landing point.

When the maximum allowable deviation value for safe landing is reached, the optical landing aid shall be calibrated to better guide the pilot to safely and smoothly land on the ship.

6. Conclusion
The safe landing of carrier aircraft is a prerequisite of carrying out a sea mission, and the safe landing of carrier aircraft relies to a great extent on the guidance of optical glideslope. In this paper, the influence of the indication deviation of the optical glideslope on the carrier aircraft landing in the line stability mode is analyzed, and the corresponding landing error of different "optical ball" offsets is quantitatively given by simulation, which provides an auxiliary role for the pilot landing, and can also be used as a basis for the calibration of the optical aid-landing device.

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