Analysis of Carrier-Based Aircraft Landing Glideslope Indications Consistency

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Abstract: The accurate guidance provided by landing guidance system for carrier-based aircraft landing is very important for safe landing. Aiming at the problem that the guidance deviation of each equipment in the system affects the safety of landing, an index of the consistency of the landing glideslope indications is proposed. The relationship between "meat ball" offset and aircraft glideslope offset is analyzed and calculated. When the guidance errors of optical landing aids and midline cameras occur, the impact of landing point and glideslope offset of carrier-based aircraft is analyzed and simulated. The consistency of glideslope indications is analyzed, and the "meat ball" offset caused by the inconsistency of guidance between optical landing aids and midline cameras is simulated and calculated. Through simulation, consistency index can be used as a basis for system calibration.

1. Introduction

In the final stage of landing, the carrier-based aircraft mainly relies on the cross-line image information provided by the midline camera for the landing commander and the optical landing aids for the pilot. [1-4] Only under the precise and consistent guidance of the two kinds of equipment and the precise command of the landing commander, can the carrier aircraft land safely on the carrier.

However, due to the carrier's long-term military mission at sea and the harsh working environment, the landing guidance system and the precision of its equipment will be greatly affected. With the increase of the carrier's service time, the aging of equipment, zero drift and other factors will lead to changes in the technical status and guidance accuracy of the system. To ensure the reliability and accuracy of the system, it is necessary to strengthen the technical state control of the system and calibrate the guiding equipment in time.

In the past, it was not necessary to calibrate the system if the accuracy of the single guiding device was within the allowable error range. [5-7] However, there will be inconsistent guidance. For example, the midline camera indicates that the carrier-based aircraft flies lower, and the landing commander asks the pilot to lift according to the guidance information provided by the midline camera. However, the light beam of the glide path given by the optical landing aid device that the pilot sees shows that he flies higher, needs to be adjusted downward, and the phenomenon of inconsistent guidance appears, which causes enormous psychological pressure on the pilots and causes landing safety accidents easily. Therefore, this paper presents an index based on the consistency of glideslope indication, which can be used as a basis for system calibration.

2. Kinematics Analysis of Relationships between "Meatball" Offset, Pilot Parallax Angle and Aircraft Glideslope Offset

First of all, explain the "meat ball", which is a body of light formed by the emitted light from the Fresnel lens lamp chamber into the human eye.[8-10] Because all the beams of the Fresnel lenses in the five light chambers are focused on a virtual image point, it seems to the pilot that the "meat ball" is emitted from a virtual image at 150ft behind the Fresnel lens. In the longitudinal and transverse working field of the gliding beam, the pilots can perceive the "meat ball" if they can see the light emitted from the surface of the lamp chamber. Because the position of the "meat ball" formed by the connection between the pilot’s eye position and the virtual image on the surface of the lamp chamber is proportional to the vertical deviation of the pilot’s eye relative to the light reference downslide line, the displacement of the "meat ball" seen by the pilot relative to the reference lamp can indicate the aircraft’s downslide deviation.

When landing on the ship, the pilot can see the "meat ball" moving smoothly up and down on the surface of the lamp room along with the deviation of the aircraft to the ideal landing path. When the plane is on the ideal slide, the pilot sees the "meat ball" at the same altitude as the horizontal reference light strip on both sides of the lamp room. When the plane is above the ideal slide, the pilot sees the "meat ball" above the horizontal reference strip. When the plane is below the ideal slide path, the pilot sees the "meat ball" below the horizontal reference light bar.

Based on the geometric relationship shown in Figure 1, the relationship between the deviation of the aircraft relative to the ideal glide path and the deviation of the "meat ball" relative to the horizontal reference strip can be deduced.

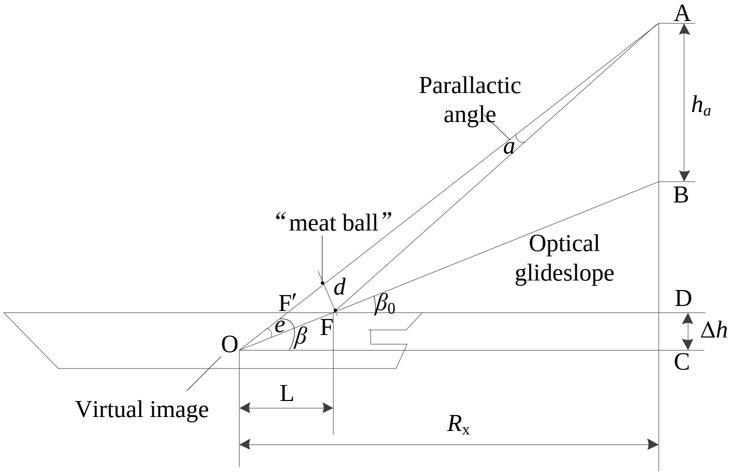

Fig.1 The Geometric Relation between Down-slip Deviation Angle and Down-slip Migration.

In Figure 1, O represents the position of the virtual image, which is lower than the level of the horizontal reference bar. F represents the position of the horizontal reference lamp, and the horizontal distance between them is L. A denotes the pilot’s eyes. B denotes the intersection point of the light reference glide line and the vertical horizontal plane passing through the pilot’s eyes. C is the intersection point of the vertical plane passing through A and the horizontal plane where O is located. D is the intersection point of the vertical plane passing through A and the horizontal plane of the deck. $\mathrm{OC} = R_x$, $\mathrm{CD} = \Delta h$, d denotes the "meat ball" offset. β_0 is the ideal glide angle of the aircraft, β is the actual glide angle of the aircraft, and. The difference of the two angles is the downward slip deviation angle e.

Table 1 shows the relationship between the declining deviation angle and the "meat ball" offset. [11]

Tab.1 Corresponding relationship between deviation angle and offset.

Slip deviation angle (°)	"Meat ball" offset (in units of 1 "meat ball" height)
0.75	2
0.375	1
0.067	0.1787
0	0
-0.75	-2

From Table 1, the relationship between downward deviation angle and offset can be obtained.

$$d = \frac{8}{3}e \tag{1}$$

Due to

$$\tan(e+\beta_0) = \frac{h_a}{R_x} + \tan\beta_0 \tag{2}$$

Because the downward reference angle β_0 is smaller, $e+\beta_0$ is also a smaller angle, so it can be approximated.

$$\begin{cases} \tan(e+\beta_0) \approx e+\beta_0 \\ \tan\beta_0 \approx \beta_0 \end{cases}$$

So, we can get

$$e \approx \frac{h_a}{R_x}(\text{rad}) \tag{3}$$

The relation between offset and offset can be deduced.

$$d = \frac{8}{3} \times \frac{h_a}{R_x} \times 57.3 \tag{4}$$

or

$$h_a = \frac{3}{8} \times \frac{R_x}{57.3} d \tag{5}$$

After simulation, the relationship between the slip offset and the "meat ball" offset and the ideal landing distance of the carrier-based aircraft is shown in Figure 2.

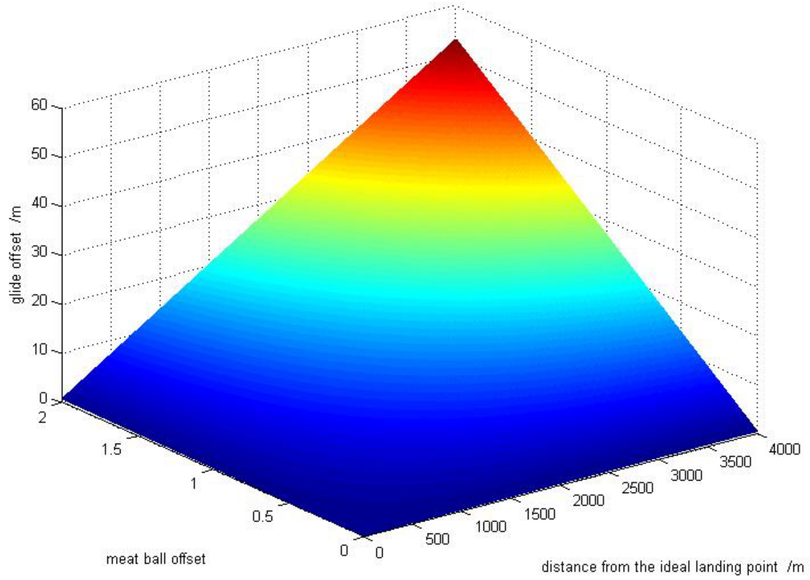

Fig.2 Graph of relationship between downward slip offset and "meat ball" offset and ideal landing point distance of carrier-based aircraft.

It can be seen from Formula (5) that even a smaller "meat ball" offset will cause a larger downward slip when R_x is larger, and the pilot should control the stick to adjust the flight altitude. However, as R_x decreases, smaller slip offset may result in larger "meat ball" offset. Pilots should be cautious to operate, and do not take a large correction, based on the instructions of the landing commander to decide whether to fly again.

3. Error Analysis of Optical Landing Aid Device

If the carrier-based aircraft glides down the base slide, the tail hook can successfully catch the arresting rope. However, if there is a certain deviation in the optical landing aids, the "meat ball" will deviate from the reference position, and the "meat ball" deviation is also reflected in the deviation between the actual landing point and the ideal landing point when the aircraft landed on the ship.

As can be seen from Figure 1, FF' is the landing point deviation. According to the geometric relationship in the graph

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

If the aircraft is sliding at a given reference sliding angle (data confidentiality), the landing point deviation is shown in Figure 3.

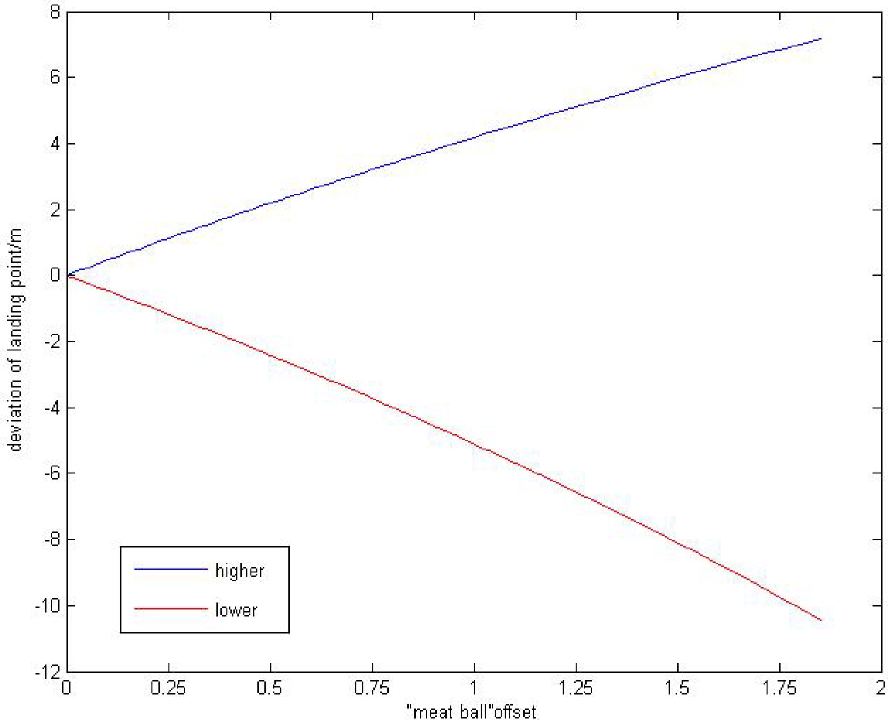

Fig.3 Effect of optical landing aids error on landing point deviation.

From the above simulation results, it can be concluded that the deviation between actual landing point and ideal landing point increases with the increase of downward deviation angle. When the "meat ball" is high, the actual landing point is in front of the ideal landing point; when the "meat ball" is low, the actual landing point is behind the ideal landing point. According to the accuracy index requirement of the landing guidance system for the single equipment of optical landing aids, the deviation of the corresponding ship is far less than the allowable error, which meets the requirement of landing. Even if the deviation is 1 "photosphere", the landing deviation is within the allowable error range of the system.

4. Error Effect Analysis of Midline Camera

The main function of the midline camera is to provide the landing commander with visual video information of the carrier aircraft aligning the downslide, and at the same time to obtain the angle information of the carrier aircraft. the system is equipped with two midline cameras, both on the midline of the ramp deck runway. The distance between the front-midline camera and the ideal landing point is x meters, and the rear-midline camera is y meters (data confidentiality). The two cameras are redundant backups in the process of landing surveillance. Only one camera is working.

The selection of working cameras is controlled by the monitoring station of takeoff and landing integrated television surveillance system.

In the final landing stage, the midline camera plays a vital role. It directly affects whether the carrier-based aircraft aligns with the midline of the runway, and ultimately affects the landing situation of the carrier-based aircraft. Because the two cameras are backup each other and have the same function, this paper takes the back-midline camera as an example, as shown in Figure 4, to analyze the downslide offset caused by the camera's indication error on the downslide of the carrier aircraft.

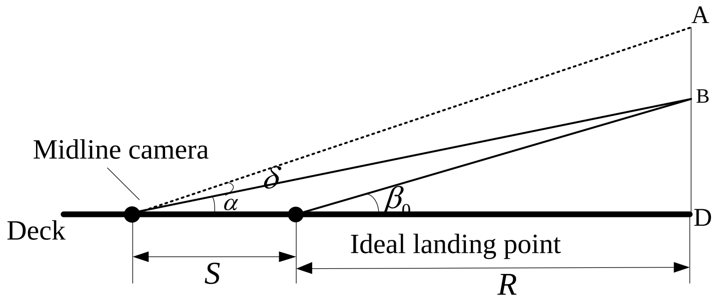

Fig.4 Indicating error schematic diagram of midline camera

B is the space point on the ideal slide path, β_0 is the ideal slide angle, α is the measuring angle along the midline camera on the ideal slide path; S is the distance between the ideal landing point and the rear midline camera, R is the horizontal distance between the space point B and the ideal landing point; D is the intersection point between the vertical plane of point B and the midline of the oblique deck. When measuring deviation angle δ exists, the target position measured by mid-line camera will be deviated, that is, when point A exists error in mid-line camera, the indicator points in current distance, AB is the downslide offset caused by the indicator error of camera on the downslide of carrier-based aircraft.

The relationship between the midline camera deviation and the resulting slip offset is given below.

$$R\tan\beta_0 = (R+S)\tan\alpha$$

$$\mathrm{AB} = (R+S)\tan(\alpha+\delta) - R\tan\beta_0$$

After calculation, the slip offset is shown in Figure 5 under the different indication errors of different distances and median cameras.

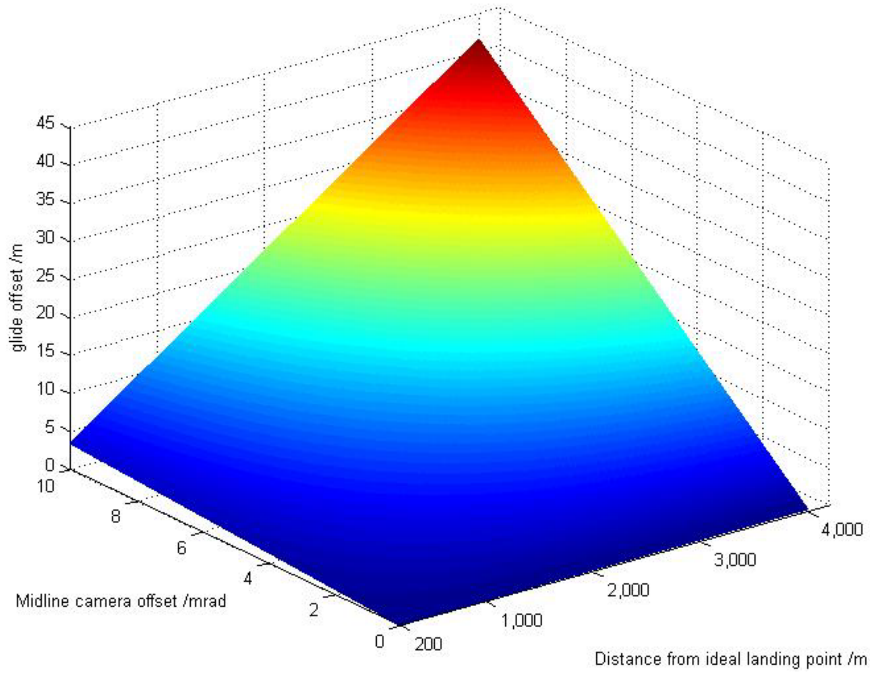

Fig.5 Slip Deviation of Indicating Errors of Cameras with Different Distances and Centrals.

5. Consistency Analysis of Glideslope Indications

The final stage of landing depends mainly on the visual ability of pilots, that is, pilots rely on "meat ball" to control the aircraft to land on the ship according to the instructions of the downslide. However, the guidance device in the system may cause inconsistent instructions due to its own errors. Pilots may see the "meat ball" on the high side and need to adjust the flight downward, but the midline camera indicates that the carrier-based aircraft flies on the low side. The landing commander requires the pilot to lift according to the guidance information provided by the midline camera. This section mainly analyses the guidance consistency of the optical landing aids and the midline camera.

Figure 6 is a schematic diagram of guidance consistency of optical landing aids and midline cameras.

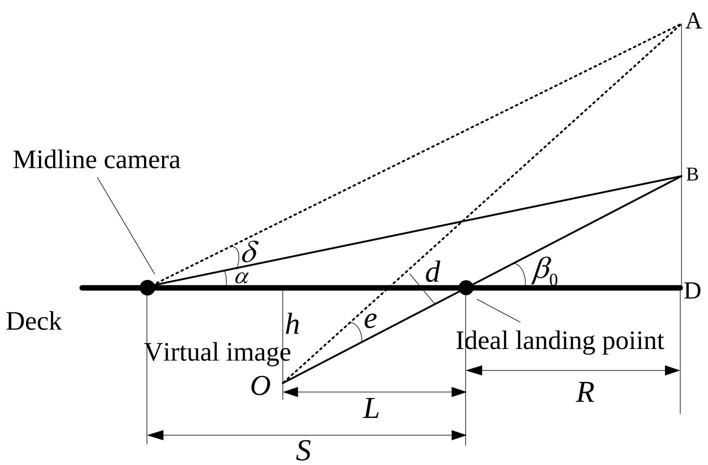

Fig.6 Schematic consistency of slide indication

B is the space point on the ideal slide path, β_0 is the ideal slide angle, α is the measuring angle along the midline camera on the ideal slide path; S is the distance between the ideal landing point and the rear midline camera, R is the horizontal distance between the space point B and the ideal landing point; D is the intersection point between the vertical plane of point B and the midline of the oblique deck. When measuring deviation angle δ exists in mid-line camera, the target position measured by mid-line camera will be deviated, that is, when point A exists error in mid-line camera, the indicator point in current distance, AB is the downslide offset caused by the indicator error of camera on the downslide of carrier-based aircraft. O is the position of the virtual image of the optical downslide in the optical landing aids, L is the distance from the virtual image to the ideal landing point, and h is the height of the virtual image downward. If the pilot operates the landing of the aircraft according to the information provided by the midline camera, d is the amount of meat ball offset the pilot can see.

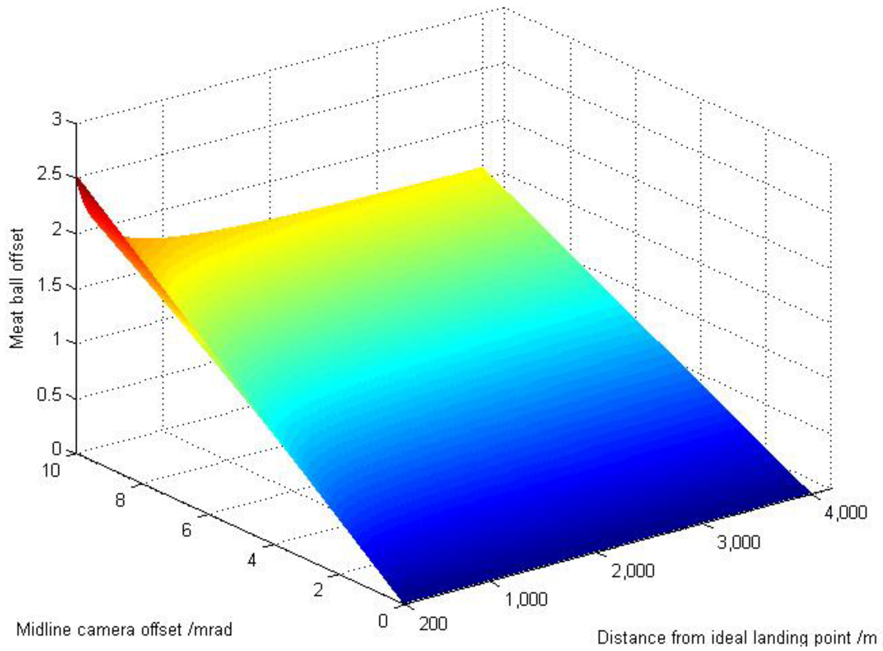

Fig.7 Meatball offset under different distances and different median camera indication errors.

When sliding down the benchmark slide, there are the following relationships

$R\tan\beta_0 = (S+R)\tan\alpha$

When there are measurement errors in the midline camera, it is obtained according to the geometric relationship in the graph.

$(R+L)\tan(\beta_0+e) = (S+R)\tan(\alpha+\delta)+h$

Therefore, the indication deviation of the optical landing aids at the current distance from the pilot can be calculated, and the meatball offset that the current pilot can see can be obtained.

Figure 7 shows the offset of the balls produced at different distances and different median camera indication errors.

6. conclusion

The safe landing of carrier-based aircraft largely depends on the precise instruction and guidance of the guidance equipment in the landing guidance system. When the guidance equipment deviates, it will affect the landing of carrier-based aircraft. This paper analyses and simulates the impact of the landing point and the slip offset of the carrier-based aircraft when the guidance deviation of the optical landing aids and the midline camera occurs. Within the allowable error range, it will not affect the safe landing of the carrier-based aircraft, so it is not necessary to calibrate the system. In this paper, an indicator of consistency is proposed, and the "meat ball" offset seen by pilots in the presence of errors in the above two types of guidance equipment is taken as the object of analysis. Through the simulation calculation, although the errors are within the allowable range, the "meat ball" offset seen by pilots is relatively large, which can easily cause great psychological pressure on pilots, affect the operation and cause safety accidents. Therefore, indication consistency can be used as an indicator of system calibration.

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