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THE COMPUTATION OF EFFECTIVE DISPLAY SENSITIVITY IN AIRCRAFT LANDING

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This report is a reprint of an Appendix which appeared in an earlier NRL classified report which received a limited distribution.

ABSTRACT

In analyzing the altitude control loop in carrier landing, it is necessary to examine the geometry involved in the calculation of effective display sensitivity. This report describes the method of determining this gain for a deck-mounted display of glide path error. Of particular utility in comparing existing systems with one another or with proposed new systems is the concept of "relative display sensitivity," which is the ratio of the effective display sensitivity of one display to that of another.

PROBLEM STATUS

This is a report on only one phase of the problem; work on the general problem is continuing.

AUTHORIZATION

NRL Problem Y02-21
BuWep Task No. RS-1170-011/6521/F002-09-02

Appendix A

THE COMPUTATION OF EFFECTIVE DISPLAY SENSITIVITY IN AIRCRAFT LANDING

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INTRODUCTION

Analytical work is presently underway at the Naval Research Laboratory on the problem of reducing the accident rate of aircraft landings aboard carriers. This work is based upon a systems analysis of the closed loop control configuration represented by the pilot-aircraft-geometry combination.

An analysis such as this involves, among other things, the determination of the amplification factors, or gains, existing in various parts of the system. A point of particular interest in the study of this man-machine system concerns the relationship between the instantaneous error of the aircraft from the glide path and the corresponding angle generated at the pilot's eye by the displayed error indication.

The pilot receives the error signal, in the systems of interest, as a visual input. The error display in these cases consists of a reference line, or point, and a marker which is displaced from this reference as a function of the error. The signal amplitude, then, is an angle — the angle subtended at the pilot's eye by the distance between the reference and the marker. An analysis of the geometry of the problem makes it a straightforward matter to determine the gain at this point in the control loop for various types of error indicators. Attention is here centered on the characteristics of the Fresnel Lens Optical Landing System (FLOLS) and the Mirror Optical Landing System (MOLS).

ANALYSIS

FLOLS (and/or MOLS) Display Sensitivity

In landing his aircraft aboard a carrier, the pilot turns on "final" about one mile astern of the carrier and intercepts a prescribed glide path. From this point, he uses the FLOLS (or MOLS) beam from aboard the carrier as an indication of his position with respect to the prescribed glide path. In other words, a displacement of the light beam from alignment with the datum lights provides him with an indication of his instantaneous altitude error.

Figure A1 illustrates the configuration for altitude control by means of the FLOLS.

The simplified diagram of Fig. A2 represents the control loop for the instantaneous situation at a given range as the aircraft approaches the carrier. The glide-path-directed altitude is, of course, decreasing at a rate proportional to the aircraft's rate of approach to the carrier. In Fig. A2, Ⓖ represents the relationship between the actual altitude error and the resulting error signal to the pilot. This gain, also termed "display

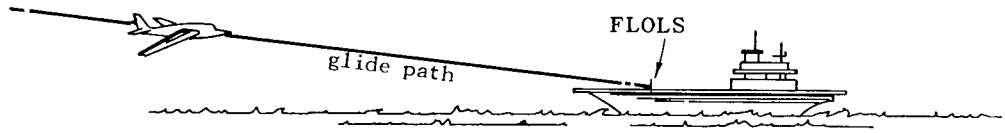

Fig. A1 - Aircraft on glide path approach to carrier

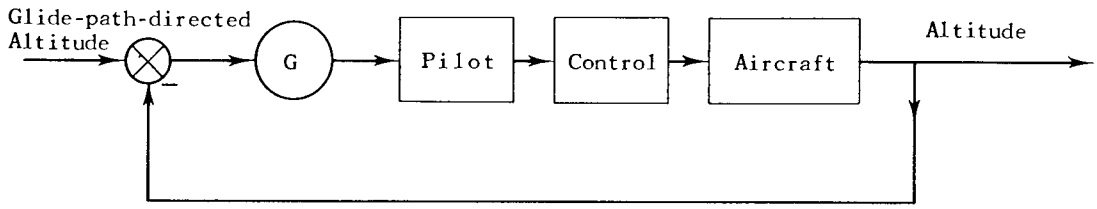

Fig. A2 - Altitude control loop for approach to carrier

sensitivity," is defined more explicitly as the ratio of the indicated error to the actual error. The indicated error is defined to be the angle subtended at the pilot's eye by the error indication.

Figure A3 represents the geometry associated with the FLOLS. From this diagram, the FLOLS display sensitivity can be derived.

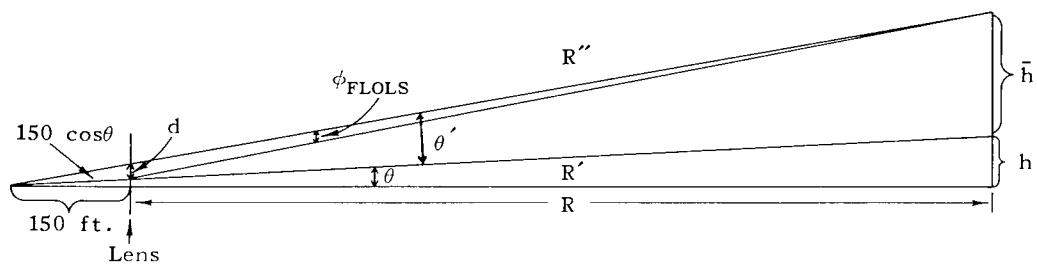

Fig. A3 - FLOLS geometry

In Fig. A3,

θ is the prescribed glide path angle;

R is the range (in feet) to the lens;

h is the altitude (in feet) prescribed by the glide path angle θ;

θ' is the angular error of the aircraft in the beam;

$\bar{h}$ is the altitude error in feet which corresponds to θ';

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d is the displacement on the lens which represents an altitude error $\bar{h}$;

ϕ_{FLOLS} is the angle subtended at the pilot's eye by the error indication d; and

150 feet is the image distance of the lens.

The angles θ and θ' are both very small (θ is generally about 4 degrees; the maximum θ' such that the light is still seen in the lens is 0.7 degrees). For this reason $150 \cos \theta \approx 150$ and $R \approx R' \approx R''$. Then by similar triangles,

$$\frac{d}{150 \cos \theta} = \frac{\bar{h}}{R' + 150 \cos \theta}$$

or

$$\frac{d}{150} \approx \frac{\bar{h}}{R + 150} .$$

For $R >> 150$, $d \approx 150\, \bar{h}/R$. In other words, the displacement on the lens is directly proportional to the altitude error and inversely proportional to the range. The angle subtended at the pilot's eye by this displacement is

$$\tan \phi_{FLOLS} = \frac{d}{R''} \approx \frac{d}{R} .$$

For ϕ_{FLOLS} small and in radians,

$$\phi_{FLOLS} \approx \frac{d}{R} \text{ (rad)}.$$

By substitution, then,

$$\phi_{FLOLS} \approx \frac{150\, \bar{h}}{R^2} \text{ (rad)}.$$

The indicated error ϕ_{FLOLS} as displayed by the FLOLS, then, is directly proportional to the image distance of the lens and to the altitude error in feet and inversely proportional to the square of the range.

By definition, the display sensitivity DS_{FL} of the FLOLS is the ratio of the indicated error ϕ_{FLOLS} to the actual error $\bar{h}$. Therefore,

$$DS_{FL} = \frac{\phi_{FLOLS}}{\bar{h}} = \frac{150\, \bar{h}/R^2}{\bar{h}} = \frac{150}{R^2} \text{ (rad/ft)}.$$

This relationship points out that the display sensitivity varies inversely as the square of the range.

ILS Display Sensitivity

From Fig. A4 it is possible to derive the display sensitivity of the Indicator Landing System (ILS). In Fig. A4, as in Fig. A3, θ is the prescribed glide path angle (in degrees), θ' is the angular error of the aircraft in the beam, h is the altitude (in feet) when the

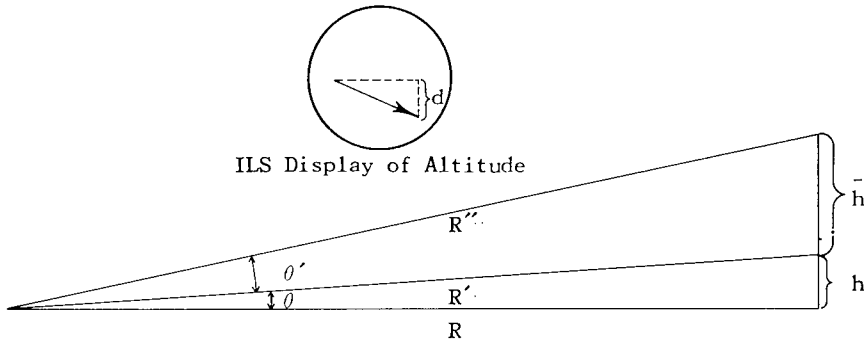

Fig. A4 - ILS geometry

aircraft is on the proper glide path, $\bar{h}$ is the altitude error (in feet) corresponding to θ', and R is the range (in feet). Again, because θ and θ' remain very small, $R \approx R' \approx R''$.

The ILS is designed to provide an indicator displacement proportional to the angular error of the aircraft in the ILS beam. Therefore,

$$d \propto \theta' \quad \text{or} \quad d = k\,\theta'.$$

But

$$\tan\theta' = \bar{h}/R' \quad \text{or} \quad \theta' \approx \bar{h}/R \text{ (rad) for small } \theta'.$$

Therefore,

$$\theta' \approx 57.3\,\frac{\bar{h}}{R}\,(\text{deg})$$

and

$$d = k\left(57.3\,\frac{\bar{h}}{R}\right)(\text{deg}).$$

Since the ILS indicator exhibits a 3/4-in. deflection for a 0.7-degree angular error,

$$k = 0.75/0.7 = 1.07 \text{ (in./deg)}.$$

Therefore,

$$d = (1.07)(57.3)\,\bar{h}/R = 61.31\,\bar{h}/R \text{ (in.)}.$$

The indicated error was defined to be the angle subtended at the pilot's eye by the error indication. Therefore, this angle ϕ_{ILS} is a function of the error indication d and the distance from the indicator to the pilot's eye D (see Fig. A5). From Fig. A5, then,

$$\phi_{ILS} \approx d/D \text{ (rad)}.$$

But $d = 61.31\,\bar{h}/R$ (inches), and D is measured to be 15 inches. Therefore,

$$\phi_{ILS} \approx \frac{61.31\,\bar{h}/R}{15} = 4.09\,\bar{h}/R \text{ (rad)}.$$

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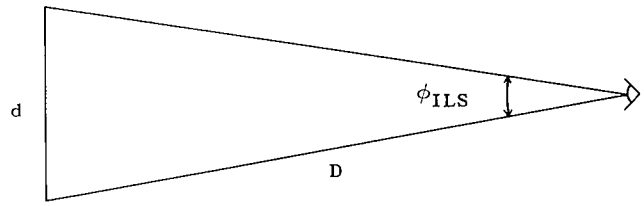

Fig. A5 - ILS-pilot geometry

By definition, the display sensitivity DS_{ILS} of the ILS is the ratio of the indicated error to the actual error, or

$$DS_{ILS} = \phi_{ILS}/\bar{h} = (4.09\ \bar{h}/R)/\bar{h} = 4.09/R\ (\text{rad/ft}).$$

Relative Display Sensitivity

Comparison of the display sensitivity of two systems leads to the concept of "relative display sensitivity." This term is defined to be the ratio of the display sensitivity of one system to that of the other.

The relative display sensitivity S_r of the ILS compared with the FLOLS, then, can be expressed as the ratio of the display sensitivity of the ILS to that of the FLOLS:

$$S_r = \frac{DS_{ILS}}{DS_{FLOLS}} = \frac{4.09/R}{150/R^2}$$

or

$$S_r = 0.027\ R.$$

In other words, the relative sensitivity ratio of the two systems is directly proportional to range and can be calculated for any instant during the landing maneuver.

Figure A6 is a plot of the relative sensitivity ratio of the ILS compared to the FLOLS for values of range from 4000 feet to touchdown. From this graph it can be seen, for example, that at the range of 4000 feet, where the pilot is in the early stages of his descent, the FLOLS is 109 times less sensitive than is the ILS. By the time the range has decreased to 1000 feet, the sensitivity ratio has also decreased to about 27. In other words, at this range the ILS is 27 times more sensitive in displaying altitude error than is the FLOLS. The sensitivities of the two systems become equal only when the aircraft is 37 feet from the lens.

DISCUSSION

This computational method of determining effective display gain was developed to fulfill a requirement in the analysis of the pilot-aircraft-geometry loop for controlling altitude in carrier landing.

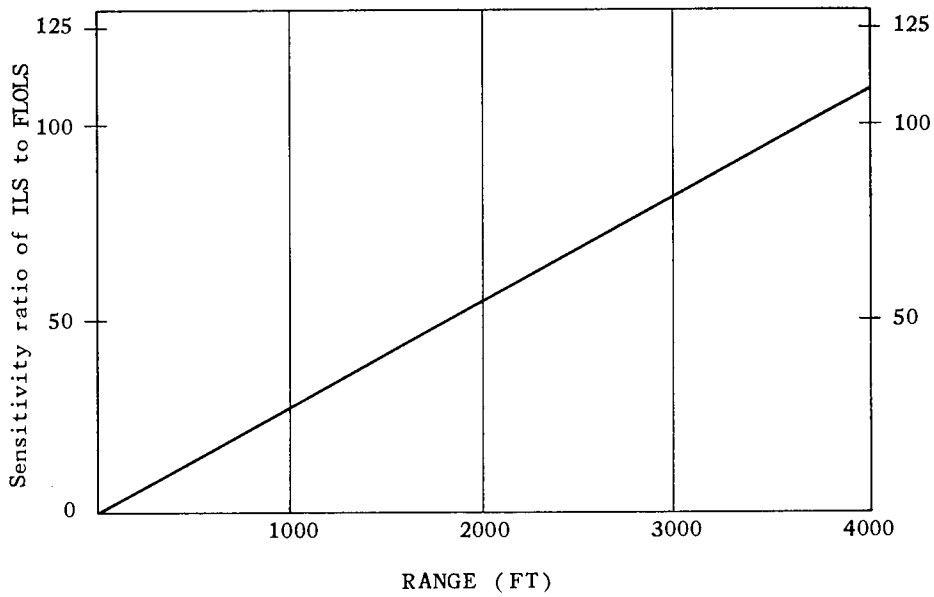

Fig. A6 - Sensitivity ratio of ILS to FLOLS vs. range

It cannot be emphasized strongly enough that the comparison of the FLOLS display with the ILS display is not intended as a recommendation of the ILS for carrier use. The ILS was introduced into this discussion merely as a standard of comparison.

The computation does underline one serious problem with the FLOLS and the MOLS, i.e., an extremely low effective display sensitivity at longer ranges. This arises from the fact that the relation between (a) displayed error at the eye and (b) vertical displacement of the aircraft from the glide path is inversely proportional to the square of the range.

The ILS system suffers from several serious defects, not the least of which are display lag, noise, and beam diffraction. It is, however, a system that has been flown by many pilots over many years.

Optical systems generally are not characterized by these difficulties. A modified version with greatly increased sensitivity should provide materially increased accuracy in carrier approach.