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THE RETINAL IMAGE OF THE FRESNEL LENS OPTICAL LANDING SYSTEM

Leonard A. Temme and William A. Monaco

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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
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The theory and geometry by which the Fresnel Lens Optical Landing System (FLOLS) provides glideslope information to the pilot attempting a carrier landing is described. From the theory, geometry, and the linear spatial dimensions of the FLOLS, the image it generates on the retina of the pilot is calculated. Since the dimensions of the retinal image are a function of the distance of the eye from the FLOLS, dimensions are calculated for distances of 1.0, 0.5, 0.25, and 0.125 nautical miles from the carrier ramp and at the ramp itself. These dimensions are also considered as a function of time in seconds to the ramp, assuming an aircraft airspeed of 125 knots. The dimensions of the retinal image of the FLOLS vary with the FLOLS position on the carrier. Calculations are reported for the USS LEXINGTON (AVT-16) and the USS KITTY HAWK (CV-63). The retinal image of the FLOLS is discussed as a visual stimulus for acuity discriminations and compared to acuity measured in the laboratory. The impact of the addition of the rate descent arrows, AVCARS, on FLOLS visibility is discussed in terms of the calculated dimensions of the retinal image and known neurophysiology. A modification of

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19. ABSTRACT:

the current FLOLS display is suggested, which would increase its visibility, gain, and usable range.

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Leonard A. Temme and William A. Monaco

Naval Medical Research and Development Command
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Reviewed by:

F. E. Guedry, Jr., Ph.D.
Chief Scientist

Approved and Released by:

Captain J. O. Houghton, MC, USN
Commanding Officer

19 September 1986

NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
NAVAL AIR STATION
PENSACOLA, FLORIDA 32508-5700

SUMMARY PAGE

THE PROBLEM

The Fresnel Lens Optical Landing System (FLOLS) is the primary source of glideslope information to a pilot during the last mile of a night carrier-landing. The purpose of the present report is to define and quantify the spatial dimensions of the FLOLS image on the retina of the pilot and to determine how the dimensions change with distance during the last mile of approach. These dimensions are needed to design a stimulus in a laboratory setting to study the response of the visual system to this stimulus display.

This report describes the theory and geometry by which the FLOLS encodes glideslope information and the spatial dimensions of the stimulus configuration on the retina of the pilot. Since the position of the FLOLS on the carrier is a factor that affects these dimensions, the FLOLS image is separately calculated and reported for the USS LEXINGTON and the USS KITTY HAWK. The retinal image of the FLOLS is discussed as a visual acuity stimulus and compared to acuities reported in the literature.

FINDINGS

We conclude:

1. The retinal image a pilot uses to evaluate and control approach early on glideslope is at the minimal limits of visual resolution at distances beyond about 0.50 n mi.

2. The largest and most rapid changes in stimulus size occur within the last quarter of a mile from the carrier ramp, about 7 s from the ramp. Up to that point, stimulus size changes little, even with appreciable deviations from glideslope.

3. Because differences in carrier size affect FLOLS position relative to the ramp, the image presented to the pilot during the last mile of the approach is smaller on the USS KITTY HAWK than on the USS LEXINGTON.

4. When the pilot is from 0.25 to 0.5 n mi from the carrier ramp, the range of distance between the retinal images of the meatball and the datum lines is from about 2.6 to 7.0 min of arc. Based upon known retinal neurophysiology, the image of the datum lines may be expected to interfere with the visibility of the meatball image over the range of distances.

5. Retinal neurophysiology also suggests that the proposed rate descent arrows, AVCARS, may affect the visibility of the meatball if the AVCARS array is installed such that the distance between its image and the meatball image is in the range from 2.6 to 7.0 min of arc.

RECOMMENDATIONS

1. The effects of the meatball datum line distance upon meatball visibility and the ability to align meatball with the datum lines should be evaluated. In this way, a distance which optimizes visibility may be identified.

2. The effects of the position of the rate descent arrows, AVCARS, upon meatballs datum line alignments and meatball visibility should be evaluated. An optimal location in the FLOLS may then be identified.

3. The useful range of the FLOLS can be increased by a design alteration that positions the virtual image through the Fresnel lens further from the datum arms than the 150 ft now used. The feasibility and consequences of this modification should be explored.

INTRODUCTION

The Fresnel Lens Optical Landing System (FLOLS) is a visual landing aid which provides the primary glideslope information to pilots attempting carrier landings. During the day, the pilot's evaluation of glideslope is aided by many stimuli, which are absent at night. Often, at night, the only information available about glideslope is from the FLOLS. Night carrier-landing is often considered to be the most dangerous routi e aviation task (3,4). From 1977 to 1982, for every major carrier mishap occurring during the day, eight occurred at night (6). The greater mishap rate at night probably reflects a number of factors, including limitations in the FLOLS itself (12). Among the limitations of the FLOLS are a lack of range and sensitivity; beyond a certain distance it does not provide a well defined visual stimulus (4,6,12). The distance at which the FLOLS is a usable indicator of glideslope error in the final analysis depends upon the vision of the pilot using the FLOLS to perform the carrier landing (12).

This study was undertaken to determine the spatial dimensions of the visual stimulus which the FLOLS provides to the pilot. This information is necessary to design vision tests relevant to the demands of night carrier landings. A review of the literature from 1951 to the present leads to four conclusions: (1) the FLOLS provides the pilot a visual stimulus with which to monitor his deviation from glideslope but the stimulus requires excellent visual resolution (12); (2) the dimensions of the visual stimulus generated by the FLOLS were not available from the open literature although occasional approximations appeared in print; (3) through the 1960's and early 1970's, a great deal of research in visual landing aids was published; subsequently, interest in this field has declined, as reflected by the small number of later reports; (4) the technical literature contains no recent discussion of the physiological optics or the psychophysical demands of the visual stimulus to which the pilot attends.

The present report defines the spatial dimensions of the relevant aspects of the FLOLS-generated stimulus on the retina of the pilot performing a night carrier-landing. Different carriers present the pilot with different stimulus configurations depending upon the position of the FLOLS relative to the ramp and center line. Two carriers are discussed in the text, the USS LEXINGTON (AVT-16) and the USS KITTY HAWK (CV-63).

FLOLS GEOMETRY

For the purposes of the present analysis, the FLOLS is composed of three parts: the Fresnel lens assemblies, which are a bank of five indicator lights mounted one above the other; and two horizontal arms of lights, one on either side of the bank of the Fresnel assemblies. This configuration and its spatial dimensions are shown in Figure 1. The two horizontal arms of lights produce the datum lines. The bank of five Fresnel lens assemblies produces a narrow horizontal bar of light commonly called the meatball. The optics of the Fresnel system causes the meatball to act as if projected from a source 150 ft behind the assembly. Since the FLOLS faces the rear of the carrier, the virtual image appears to be 150 ft forward of the assembly. To the pilot of the approaching aircraft, the meatball on the face of the Fresnel indicator lamp assemblies appears to move smoothly up or down the face of the lamp assembly as the aircraft deviates from glideslope. When the aircraft is on glideslope, the meatball appears to be on the same line as the horizontal datum lines on either side of it. When the aircraft is above glideslope, the meatball appears on the face of the indicator assemblies to be above the horizontal of the datum lines. When the aircraft is below glidescope, the meatball appears on the face of the indicator assemblies to be below the horizontal of the datum lines. The FLOLS, therefore, encodes deviations of the aircraft from glideslope as deviations of the meatball from the horizontal of the datum lines. The geometry of this relationship is diagrammed in Figure 2.

For purposes of the present discussion, the standard 3.5° glideslope is assumed; however, for ease of illustration, the glideslope is exaggerated in Figure 2. The virtual image of the meatball is at the intersection of the 3.5° glideslope with the vertical plane 15Ø ft forward of the datum lines. The virtual image is below the horizontal plane of the datum lines. The case of the aircraft above glideslope is demonstrated in Figure 2. Angle "e," which is made by the meatball, the pilot's eye, and the datum lines, is the aspect of the visual display that the pilot uses to judge the approach relative to glideslope.

The size of angle "e" depends upon the magnitude of the deviation from glideslope, the distance of the pilot's eye from the FLOLS, and the distance of the virtual image from the datum arms. This last parameter is a constant for all FLOLS now in use.

The trigonometric relationships of the FLOLS and the approaching aviator's view are shown in Figure 3. The ramp of the carrier is indicated by A; FLOLS location on the side of the carrier deck is B. Location C is behind the carrier directly below the pilot's eye in the aircraft. The FLOLS virtual image is at D, 15Ø ft forward of the FLOLS and below the horizontal plane of the datum lines by the amount determined by glideslope angle. Distance A-B depends upon the particular carrier installation; distance A-C is the distance the perpendicular below the aircraft is behind the carrier. For the present analysis, distance A-C is assigned values of 1.Ø, Ø.5, Ø.25, Ø.125, and Ø n mi. The location of the aircraft is P; Q is the intersection of the glideslope with the perpendicular from aircraft P; R is the intersection of the perpendicular from aircraft P with the level of the ramp. Distance Q-R is the height a point on glideslope is above the level of the deck. Distance P-Q is the deviation from the 3.5° glideslope which, for each of the distances behind the carrier ramp, is assigned a value of 5, 1Ø, 15, 2Ø, 25, and 3Ø ft. Angle "e," the aspect of the visual display upon which the pilot judges the approach relative to glidepath, is the arithmetic difference between angles "a" and "b." Angle "a" is formed by BPR, and angle "b" is formed by DPC.

In addition to determining the angular subtense of the meatball-datum line disparity on the pilot's retina, a number of other stimulus parameters of the FLOLS display were calculated. The length of the datum arm, distance between datum lights, size of datum lights, distance between the meatball and the datum arm, the size of the meatball, and the distance the whole FLOLS display is from the carrier centerline are presented here in terms of visual angle.

THE RETINAL STIMULUS

The angular subtense on the pilot's retina of the deviation of the meatball above or below the horizontal datum lines is shown in Figure 4 as a function of the distance the aircraft is behind the ramp of the USS LEXINGTON (AVT-16). This angular subtense, in minutes of arc, is the aspect of the stimulus display that provides glideslope information to the pilot, angle "e." The subtense of angle "e" was calculated for six different deviations from glideslope, at 5-ft increments from 5 to 30 ft; each was plotted as a different curve. The size of the retinal image is the same for deviations above or below glideslope.

The horizontal axis at the top of Figure 4 represents the time in seconds to the ramp, from 1.0 n mi behind the ramp, assuming a closing airspeed of 125 knots. For a deviation of as much as 30 ft from glideslope, the size of the visual stimulus increases from seconds of visual angle at a distance of 1.0 n mi to less than 5 min of arc at a distance of 0.25 n mi, which is 7 s approach time to the ramp. The figure shows, therefore, that the cues to which the pilot is attending early on the glideslope are on the order of seconds of arc and that the size of the stimulus increases very little from 1.0 to 0.25 n mi. During the 3.5 s from 0.25 n mi to 0.125 n mi from the ramp, the stimulus increases more than it increases during the first three-quarters of the approach. During the last 0.125 n mi, or 3.5 s of the approach, the visual angle increases from 11 to 78.4 min of arc. Data in this figure lead to three general conclusions: Firstly, an angular deviation of the meatball from the datum line by a given amount indicates different amounts of deviations from glideslope depending upon the distance of the aircraft from the FLOLS. Secondly, the stimulus sizes with which the pilot evaluates deviations early on glideslope are of dimensions that are at the minimal limits of visual resolution. Thirdly, the greatest changes in stimulus size occur rapidly and late on glideslope where corrections generally cannot salvage a poorly begun approach.

As a function of the distance from the ramp, Figure 5 shows the length and width of the meatball and the distance between the meatball and the datum lines when they are aligned, that is with 0 error in glideslope. These functions have the same characteristics as those of the previous figure. The distance on the retina between the images of the meatball and the datum line increases from about 2.25 min of arc at 1.0 n mi to about 13 min of arc at 0.125 n mi. Figure 6 depicts the thickness and the length of the retinal image of the datum line as a function of the distance from the ramp up to 1.0 n mi.

The FLOLS is laterally displaced from the carrier landing deck center line by an amount characteristic of the carrier. The angle subtended by the distance between the center line and the FLOLS is plotted in Figure 7 as a function of the distance behind the ramp. At 1.0 n mi, the FLOLS is almost 1° from the center line; at 0.5 n mi it is 1.8°; at 0.25 n mi it is 3.25°; and at 0.125 n mi it is about 5.5° from center; while at the ramp it is about 16° from center.

Figures 8 through 11 depict the results of comparable calculations for the USS KITTY HAWK (CV-63). Differences between the USS KITTY HAWK and the USS LEXINGTON are because the FLOLS is placed on the USS KITTY HAWK 127 ft further from the ramp than on the USS LEXINGTON. Consequently, the stimulus display generated by the FLOLS is smaller on the USS KITTY HAWK than on the USS LEXINGTON. Figure 8 shows the angular deviations of the meatball from the datum line as a function of the distance in nautical miles the aircraft is behind the ramp. These have been calculated for glideslope deviations of from 5 to 30 ft in 5-ft increments. Note that the scale of the ordinate in this figure is the same as that of Figure 4 in which comparable results from the USS LEXINGTON are shown. The relationship between aircraft-ramp distance and the size of the visual angle is, in general, the same as shown in Figure 4 except that the visual stimulus is smaller. The visual angles subtended on the pilot's retina of meatball width, length, and its distance from the datum lines in the absence of glideslope error are shown in Figure 9. Figure 10 shows datum line thickness and length. Figure 11 shows the angular subtense on the retina of FLOLS displacement from the carrier center line.

DISCUSSION

These stimulus dimensions are needed to generate a comparable stimulus display in the laboratory to study the role of such visual factors as acuity, accommodation, night vision, etc., for night carrier landings. Several points should be made about visual acuity and the calculated dimensions of the FLOLS-generated visual stimulus. Normal best-corrected central acuity under daylight conditions is nominally described as the ability to resolve one minute of arc on the retina or 20/20 (2). The angular deviation in minutes arc of the meatball image from the horizontal datum line is presented in Table I. These deviations are shown for a range of

TABLE I

Minutes of ARC deviation of the meatball from the horizontal of the datum lines for the USS LEXINGTON.

DISTANCE BEHIND RAMP (nautical miles)	DEVIATION FROM GLIDESLOPE (FEET) 5	10	15	20	25	30
1.0	0.055	0.115	0.175	0.235	0.295	0.356
0.5	0.200	0.411	0.622	0.833	1.043	1.253
0.25	0.644	1.306	1.986	2.629	3.289	3.949
0.125	1.730	3.488	5.243	6.995	8.745	10.492
0	12.939	25.900	38.800	51.621	64.368	77.025

distances up to 1 n mi from the ramp of the USS LEXINGTON for glideslope errors of 5 to 30 ft (also, see Fig. 4). Table I is divided by a line above which are the viewing conditions requiring an acuity greater than 20/20 to resolve the vertical deviations of the meatball from the datum line horizontal. This line could be considered to reflect the limits of the average useful range of the FLOLS for normal daytime central vision.

The standard 1 min of arc visual resolution is a generalization from a particular type of acuity measurement with a stimulus designed for clinical purposes. Spatial resolution is determined by a number of stimulus parameters including spatial configuration, luminance, and the retinal locus stimulated (5). Each of these is an important determinant of the visibility of the FLOLS image.

The stimulus configurations used to study acuity in the laboratory differ from those generated by the FLOLS. The alignment of the meatball between the two datum lines requires a visual judgment different from a discrimination of letters on a standard acuity chart or the identification of the location of the gap in the standard Landolt C stimulus. Meatball alignment may be more closely related to a test of vernier acuity, which in the laboratory results in much finer acuities then the letter-type acuities (15). Studies of vernier acuity in the laboratory have used stimuli requiring the alignment of two points or two adjacent line segments, but the FLOLS requires the alignment of a point between two horizontal lines. The horizontal orientation of the FLOLS is likely to be a significant determinant of spatial vision since central visual acuity is greater for vertical than for horizontal targets (1). Furthermore, the separation distance between the meatball and the two datum lines on either side of it is likely to be a significant factor limiting acuity. This hypothesis is derived from a number of studies in which retinal sensitivity as well as acuity were altered by the proximity of elements in the visual display (14,16). For example, a study of vernier acuity with vertical bar stimuli showed that the presence of flanking lines degraded acuity when the flanking lines were from 2.5 to 7.5 min of arc away from the acuity stimuli. Closer than 2.5 and further than 7.5 min of arc, the flanking bars had no effect upon acuity (15). Inspection of Table I shows that the range from 2.5 to 7.5 min of arc covers a large part of the most important range of the FLOLS. This effect upon vernier acuity is most likely a consequence of the neurophysiological characteristics of retinal neuronal processing and not simply some effect that could be overcome by a change in observer attitude or attention. This last point suggests that the distance between the datum line and the meatball is a factor determining how well the alignment of the meatball with the datum lines can be seen and that there is an ideal separation that could optimize visibility over the most critical range of the approach. If the measurements of vernier acuity cited above are used as a guide, then the distance between meatball and datum lines should be no less than 7.5 min of arc. This is an extrapolation from data obtained with stimulus conditions vastly different from those of the operational environment and needs a thorough empirical validation.

The hypothesized dependence of meatball alignment upon meatball-datum line separation is relevant to the current plans of the Navy to modify the FLOLS by adding AVCARS. These are two sets of additional lights to be placed above and below the horizontal of the datum line. The AVCARS system is designed to supply the pilot with information about the speed at which the aircraft is moving toward or away from glideslope. It does not provide information already directly available from meatball-datum line displacement, but it does add information to the FLOLS display about the rate at which the aircraft is moving perpendicular to glideslope. At the present time, AVCARS has not been implemented.

The effectiveness of AVCARS was established in a set of studies of night carrier-landings conducted with a simulator (7,10). For these tests, the two sets of AVCARS vertical rate lights were positioned on either side of the meatball, between it and the datum lines. Based on the vision science literature (16), the placement of the AVCARS in this position may decrease the visibility of the meatball-datum line alignment. Consequently, other positions for the AVCARS rate lights should be considered. This issue needs further clarification, preferably before the installation of AVCARS.

Meatball-datum line visibility during night carrier-landings is likely to be affected by "dark focus" (8,11). As the visual environment becomes poorer (provides fewer or degraded visual stimuli), the accommodative mechanism(s) of the eye tend toward some intermediate resting level. The literature reports an average dark focus value of about 1.5 diopters of myopia for U. S. Air Force recruits and college students (9,13). Approximate expected Snellen acuity can be calculated for various amounts of myopia, and for 1.0 diopters of myopia, an acuity of from 2.5 to 4.0 min of arc can be expected in the normal population. Dark focus may therefore be an important factor affecting an individual's ability to land an aircraft at night.

The above discussion has focused upon a number of visual factors that could affect the spatial resolution of the pilot. Glideslope information in the FLOLS derives from the fact that the virtual image of the indicator light is at a point 150 ft behind the datum arms. If the virtual image is designed to be further than 150 ft forward of the datum arms, then the FLOLS display would generate a larger signal to the pilot for a given error in glideslope. In effect, positioning the virtual image more than 150 ft forward of the datum arms increases the gain of the error signal of the FLOLS. The visual angle between the meatball and the datum lines was recalculated with the virtual image of the meatball at 200 ft from the datum lines. With this change in the stimulus display, there is an increased error signal generated on the pilot's retina for a given glideslope deviation. For example, at 1.0 n mi from the ramp of the USS KITTY HAWK, the signal generated for a given amount of glideslope error is 25% larger than the signal as it is now generated. At the ramp, the proposed modification will result in a 20% larger signal. This modification might then result in improved boarding rates and pilot safety during night carrier-landings. The feasibility and consequences of this modification should be explored.

CONCLUSIONS

1. The retinal image a pilot uses to evaluate and control approach early on glideslope is at the minimal limits of visual resolution at distances beyond about 0.50 n mi.

2. The largest and most rapid changes in stimulus size occur within the last quarter of a mile from the carrier ramp, about 7 s from the ramp. Up to that point, stimulus size changes little, even with appreciable deviations from glideslope.

3. Because differences in carrier size affect FLOLS position relative to the ramp, the image presented to the pilot during the last mile of the approach is smaller on the USS KITTY HAWK than on the USS LEXINGTON.

4. When the pilot is from 0.25 to 0.5 n mi from the carrier ramp, the range of distance between the retinal images of the meatball and the datum lines is from about 2.6 to 7.0 min of arc. Based upon known retinal neurophysiology, the image of the datum lines may be expected to interfere with the visibility of the meatball image over the range of distances.

5. Retinal neurophysiology also suggests that the proposed rate descent arrows, AVCARS, may affect the visibility of the meatball if the AVCARS array is installed such that the distance between its image and the meatball image is in the range from 2.6 to 7.0 min of arc.

RECOMMENDATIONS

1. The effects of the meatball datum line distance upon meatball visibility and the ability to align meatball with the datum lines should be evaluated. In this way, a distance which optimizes visibility may be identified.

2. The effects of the position of the rate descent arrows, AVCARS, upon meatballs datum line alignments and meatball visibility should be evaluated. An optimal location in the FLOLS may then be identified.

3. The useful range of the FLOLS can be increased by a design alteration that positions the virtual image through the Fresnel lens further from the datum arms than the 150 ft now used. The feasibility and consequences of this modification should be explored.

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Figure 1

Schematic of the FLOLS with linear dimensions.

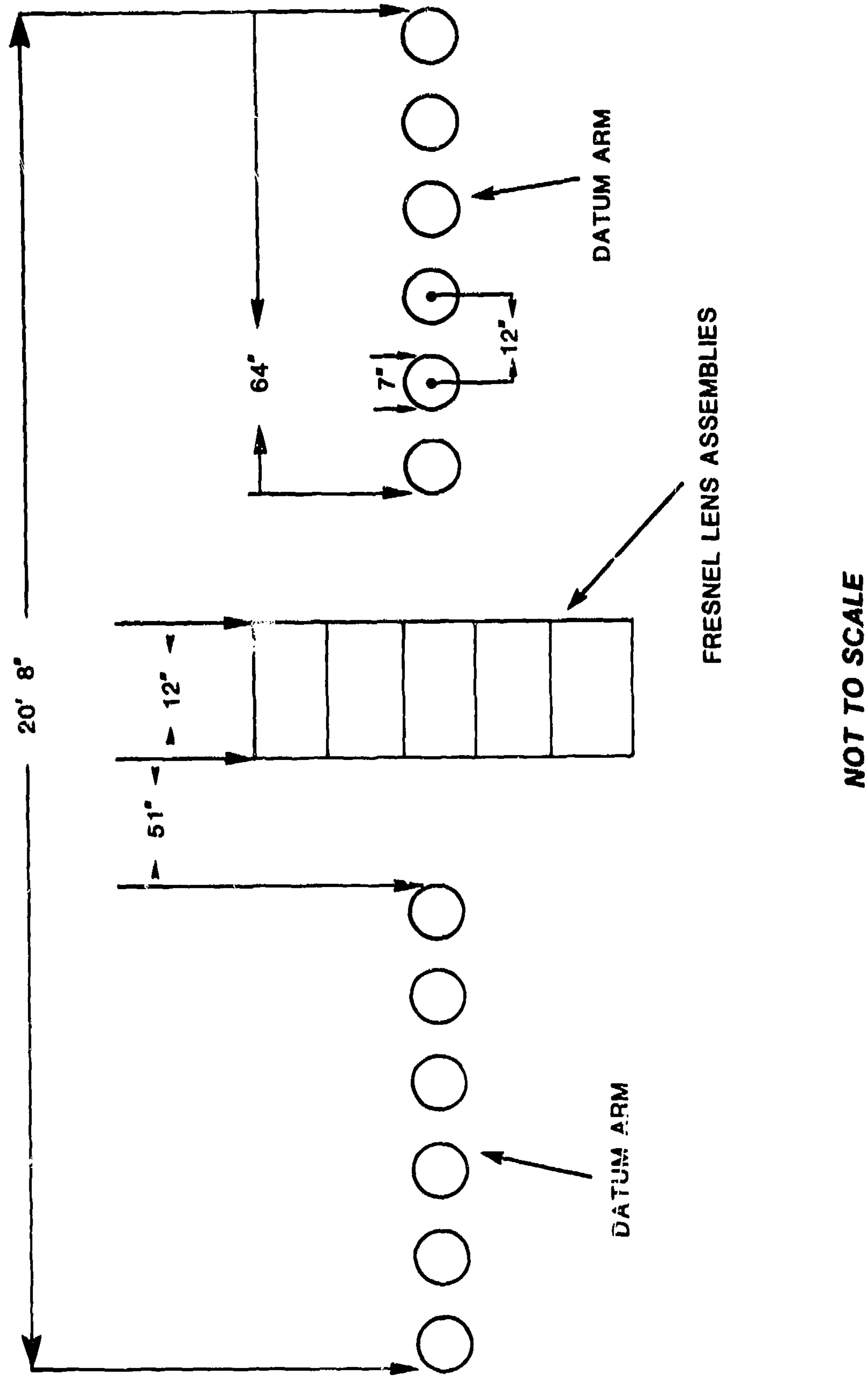

DATUM ARM
64"
7"
12"
FRESNEL LENS ASSEMBLIES
20' 8"
12"
51"
DATUM ARM
NOT TO SCALE

Figure 2

Schematic of the geometry of the FLOLS and glideslope. The angular dimensions of the glideslope are exaggerated for ease of illustration. The pilot's view of the FLOLS display is shown in the insert.

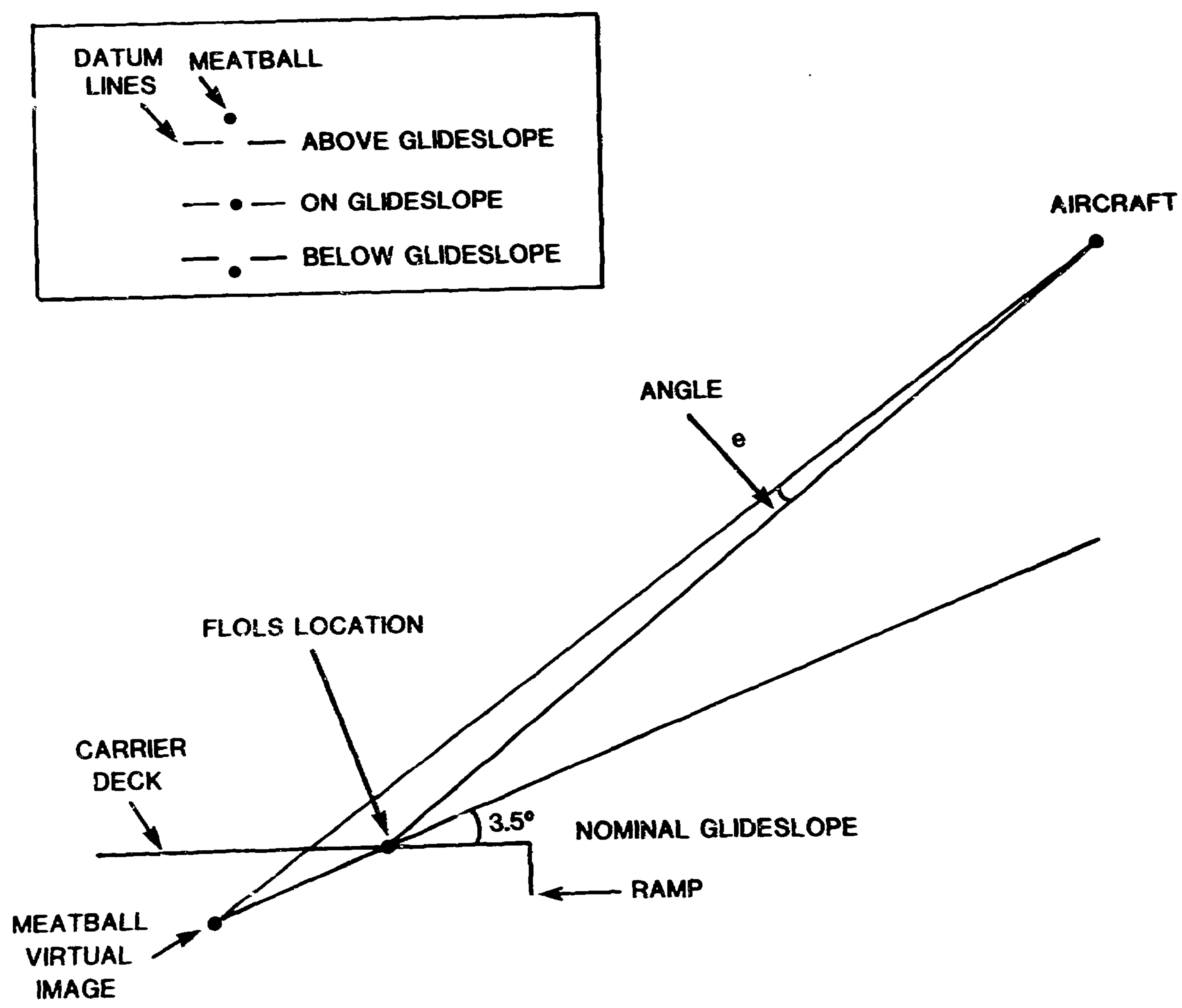

DATUM LINES
MEATBALL
ABOVE GLIDESLOPE
ON GLIDESLOPE
BELOW GLIDESLOPE
AIRCRAFT
ANGLE
e
FLOLS LOCATION
CARRIER DECK
3.5°
NOMINAL GLIDESLOPE
RAMP
MEATBALL VIRTUAL IMAGE

Figure 3

The trigonometric relationships among the FLOLS, its position on the carrier and the pilot's eye. "A" is the ramp of the carrier, "B" is the FLOLS actual position on the edge of the carrier, "C" is the location behind the carrier of the perpendicular below the pilot, "D" is the apparent origin of the light through the FLOS. The difference between Angle "a" and Angle "b" is Angle "e", the deviation of the meatball from the datum line horizontal.

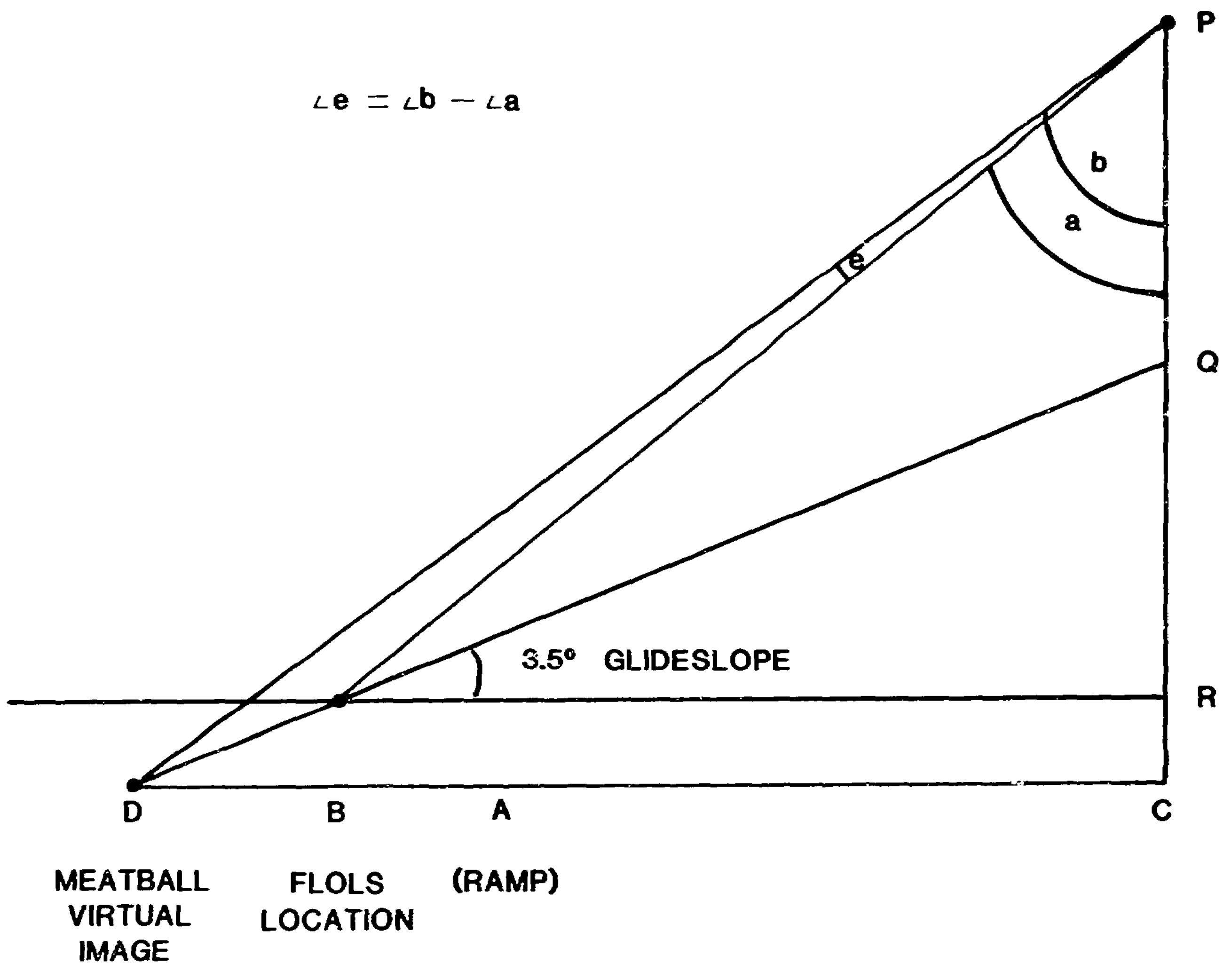

∠e = ∠b − ∠a
P
b
a
e
Q
3.5° GLIDESLOPE
R
D
B
A
C
MEATBALL
VIRTUAL
IMAGE
FLOLS
LOCATION
(RAMP)

Figure 4

The meatball datum line deviation on the retina in minutes of arc as a function of the distance of the pilot from the ramp of the carrier USS LEXINGTON. The abscissa indicated at the bottom of the figure is in nautical miles while the one indicated at the top of the figure is in seconds to the ramp if airspeed is assumed to be 125 knots. Deviation of the aircraft glidepath from the 3.5 degree glideslope is the parameter and is presented for deviations of, from 5 to 30 ft. Visual angles are the same for deviations above or below glideslope.

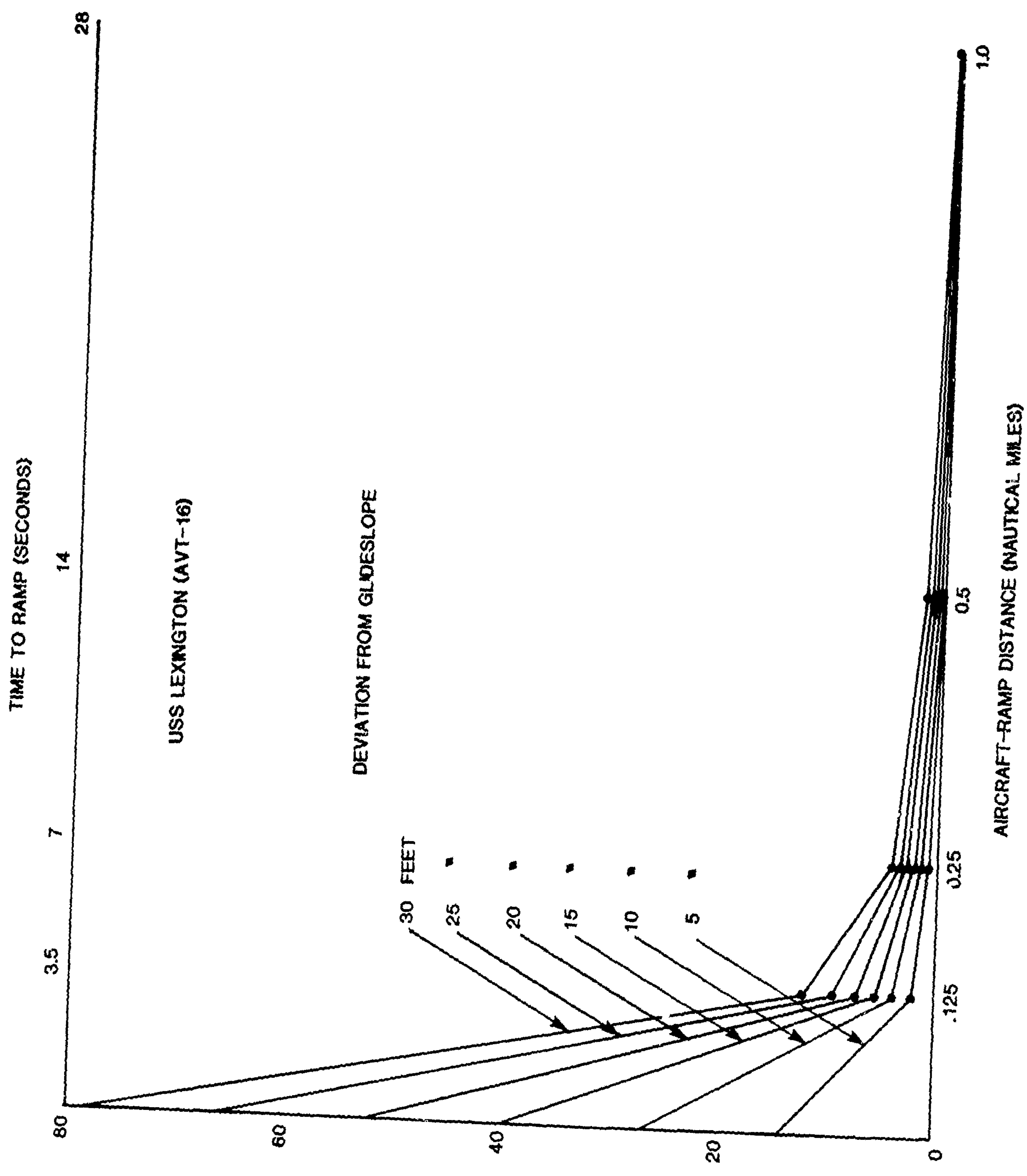

TIME TO RAMP (SECONDS)
3.5
7
14
28
USS LEXINGTON (AVT-16)
DEVIATION FROM GLIDESLOPE
30 FEET
25 "
20 "
15 "
10 "
5 "
80
60
40
20
0
.125
0.25
0.5
1.0
AIRCRAFT-RAMP DISTANCE (NAUTICAL MILES)
MEATBALL-DATUM LINE ANGLE (MINUTES OF ARC)

Figure 5

The visual angle in minutes of arc of the meatball length and width as well as the separation between the meatball and datum line as a function of the distance from the ramp of the USS LEXINGTON. Nautical miles is indicated on the lower abscissa while seconds to the ramp is indicated on the upper abscissa for a 125 knot airspeed.

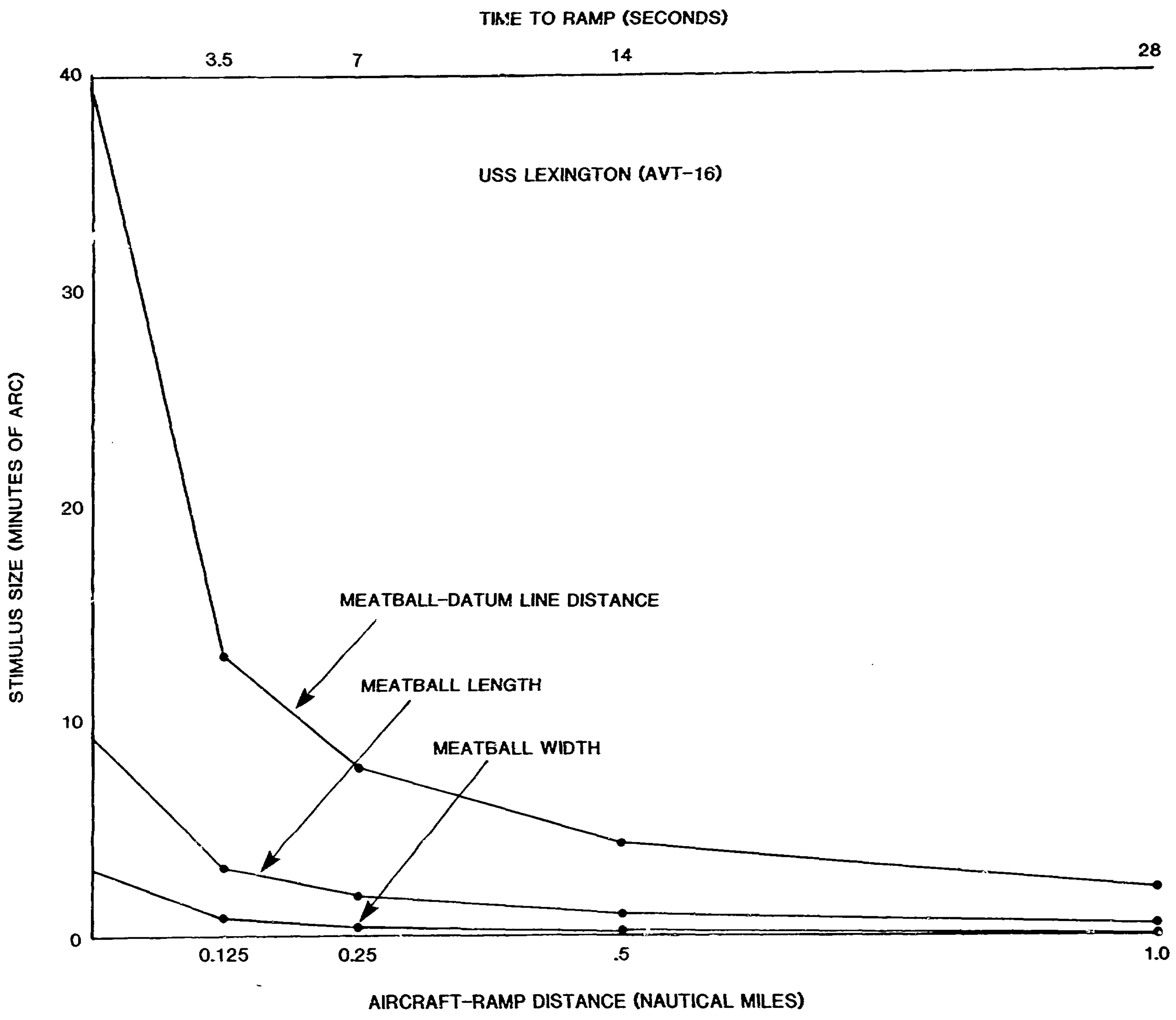

TIME TO RAMP (SECONDS)
3.5
7
14
28
USS LEXINGTON (AVT-16)
40
30
20
10
0
STIMULUS SIZE (MINUTES OF ARC)
MEATBALL-DATUM LINE DISTANCE
MEATBALL LENGTH
MEATBALL WIDTH
0.125
0.25
.5
1.0
AIRCRAFT-RAMP DISTANCE (NAUTICAL MILES)

Figure 6

The visual angle in minutes of arc of the datum line length and width as a function of distance behind the USS LEXINGTON ramp in nautical miles on the lower abscissa while the upper abscissa indicated seconds to the ramp for an airspeed of 125 knots.

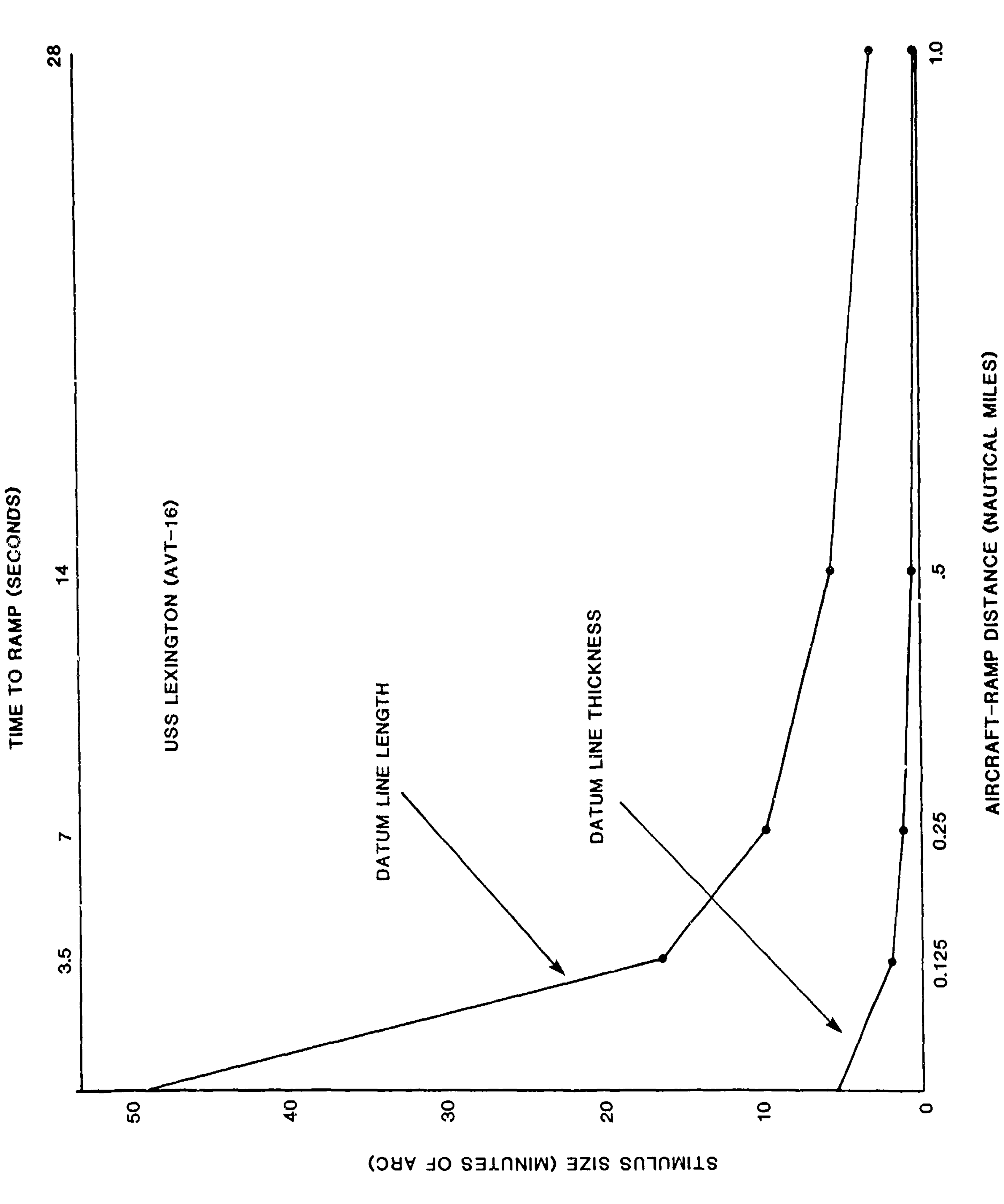
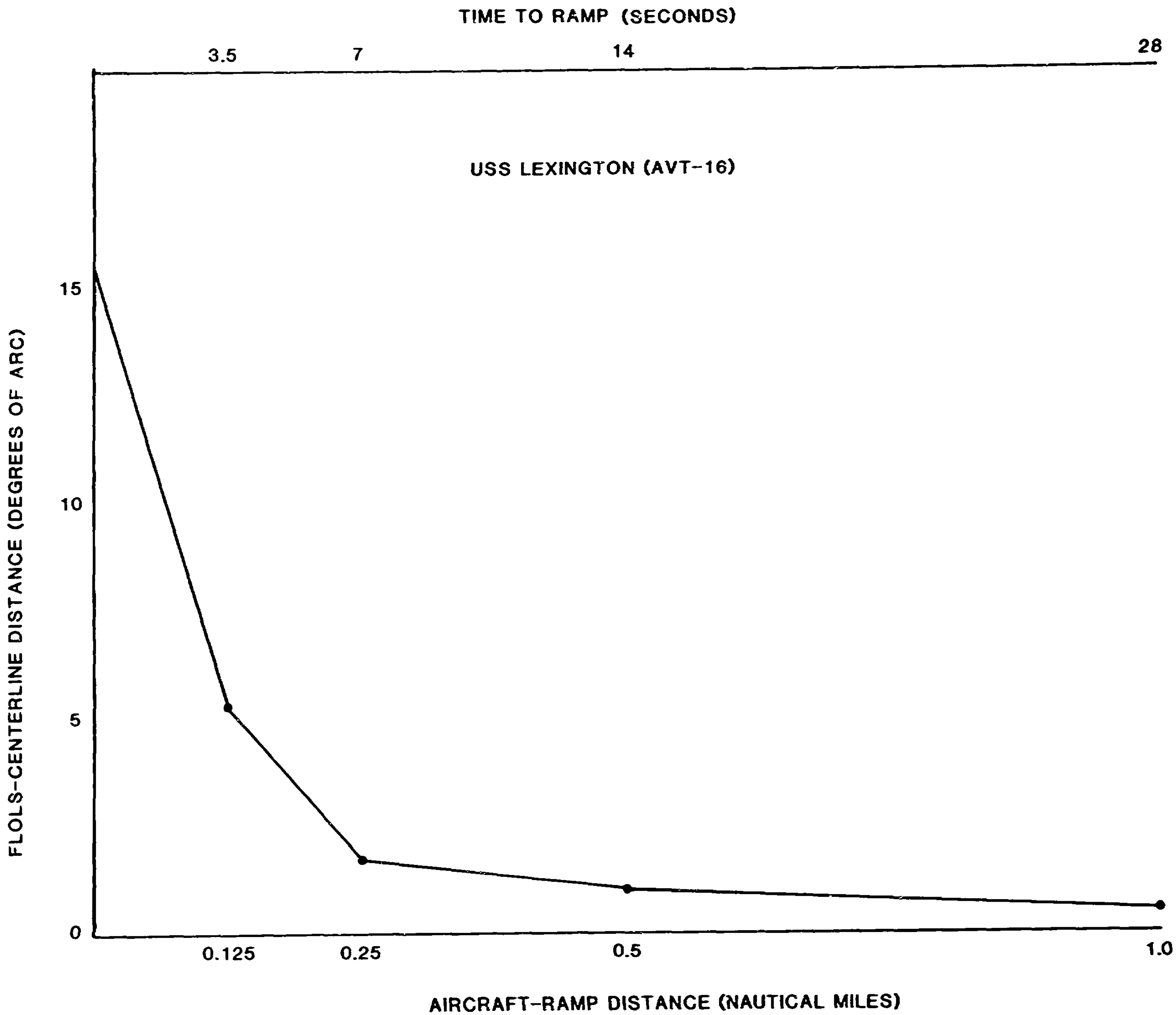

TIME TO RAMP (SECONDS)
3.5
7
14
28
USS LEXINGTON (AVT-16)
DATUM LINE LENGTH
DATUM LINE THICKNESS
STIMULUS SIZE (MINUTES OF ARC)
0
10
20
30
40
50
0.125
0.25
.5
1.0
AIRCRAFT-RAMP DISTANCE (NAUTICAL MILES)

Figure 7

The visual angular distance between the USS LEXINGTON landing deck center line and the FLOLS as a function of the distance behind the carrier ramp in nautical miles on the lower abscissa while seconds to the ramp is indicated on the upper abscissa for an airspeed of 125 knots.



TIME TO RAMP (SECONDS)
3.5
7
14
28
USS LEXINGTON (AVT-16)
FLOLS-CENTERLINE DISTANCE (DEGREES OF ARC)
15
10
5
0
0.125
0.25
0.5
1.0
AIRCRAFT-RAMP DISTANCE (NAUTICAL MILES)

Figure 8

The meatball datum line deviation on the retina in minutes of arc as a function of the distance of the pilot from the ramp of the carrier USS KITTY HAWK. The abscissa indicated at the bottom of the figure is in nautical miles while the one indicated at the top of the figure is in seconds to the ramp if airspeed is assumed to be 125 knots. Deviation of the aircraft glidepath from the 3.5 degree glideslope is the parameter and is presented for deviations of from 5 to 30 ft. Visual angles are the same for deviations above or below glideslope.

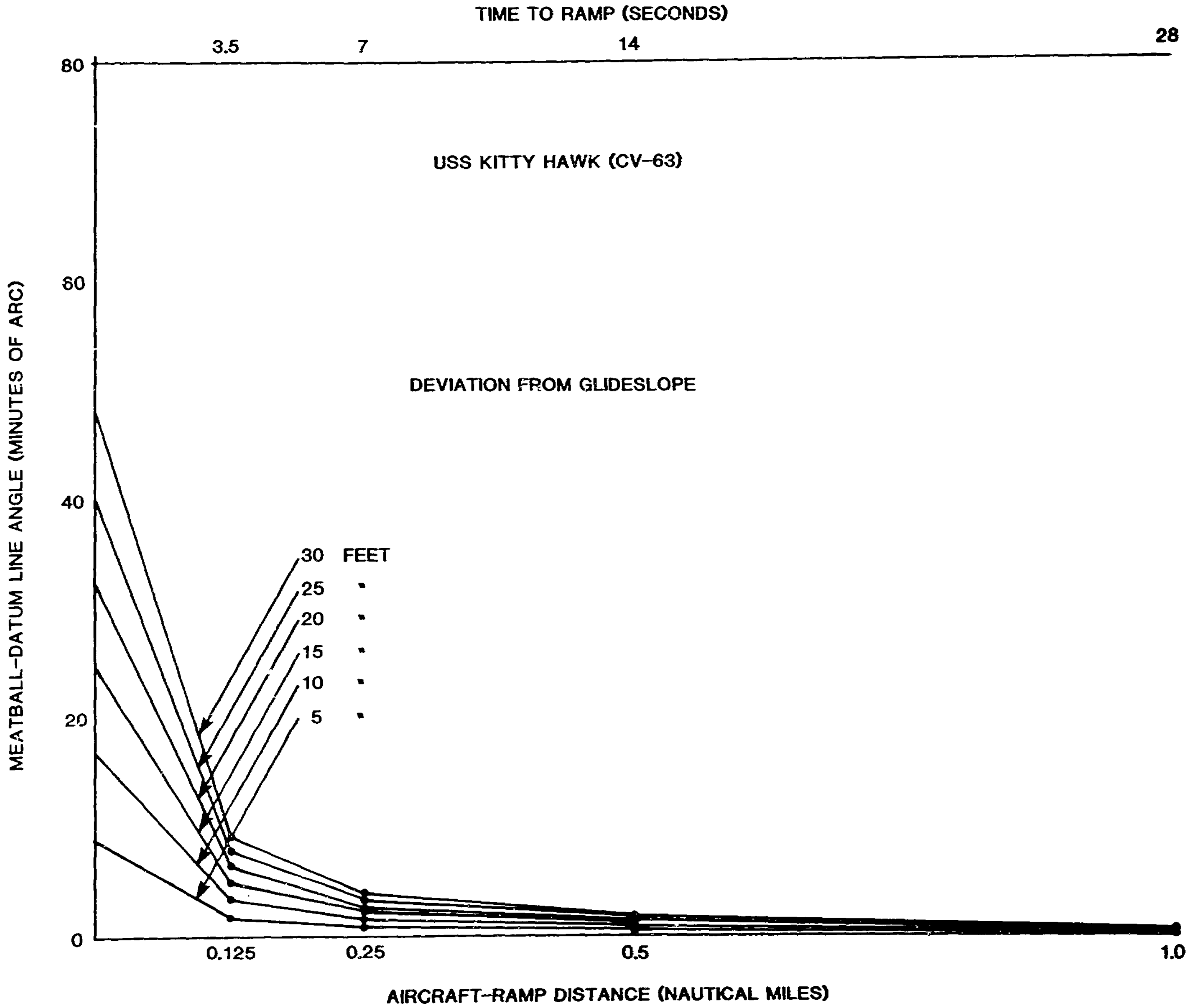

TIME TO RAMP (SECONDS)
3.5
7
14
28
USS KITTY HAWK (CV-63)
DEVIATION FROM GLIDESLOPE
30 FEET
25 "
20 "
15 "
10 "
5 "
MEATBALL-DATUM LINE ANGLE (MINUTES OF ARC)
80
60
40
20
0
0.125
0.25
0.5
1.0
AIRCRAFT-RAMP DISTANCE (NAUTICAL MILES)

Figure 9

The visual angle in minutes of arc of the meatball length and width as well as the separation between the meatball and datum line as a function of the distance from the ramp of the USS KITTY HAWK. Nautical miles is indicated on the lower abscissa while seconds to the ramp is indicated on the upper abscissa for a 125 knot airspeed.

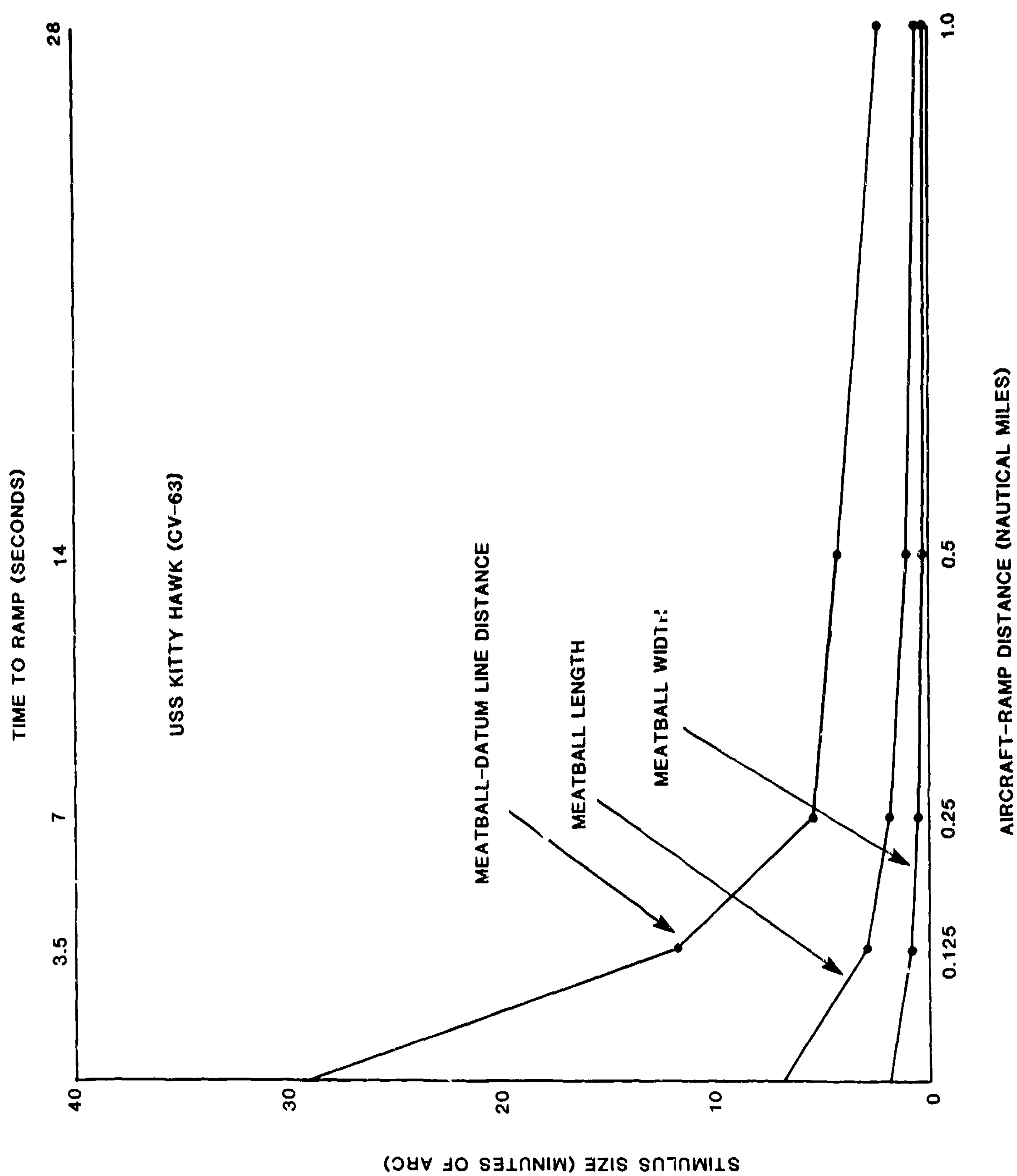

TIME TO RAMP (SECONDS)
3.5
7
14
28
USS KITTY HAWK (CV-63)
MEATBALL-DATUM LINE DISTANCE
MEATBALL LENGTH
MEATBALL WIDTH
40
30
20
10
0
STIMULUS SIZE (MINUTES OF ARC)
0.125
0.25
0.5
1.0
AIRCRAFT-RAMP DISTANCE (NAUTICAL MILES)

Figure 10

The visual angle in minutes of arc of the datum line length and width as a function of distance behind the USS KITTY HAWK ramp in nautical miles on the lower abscissa while the upper abscissa indicated seconds to the ramp for an airspeed of 125 knots.

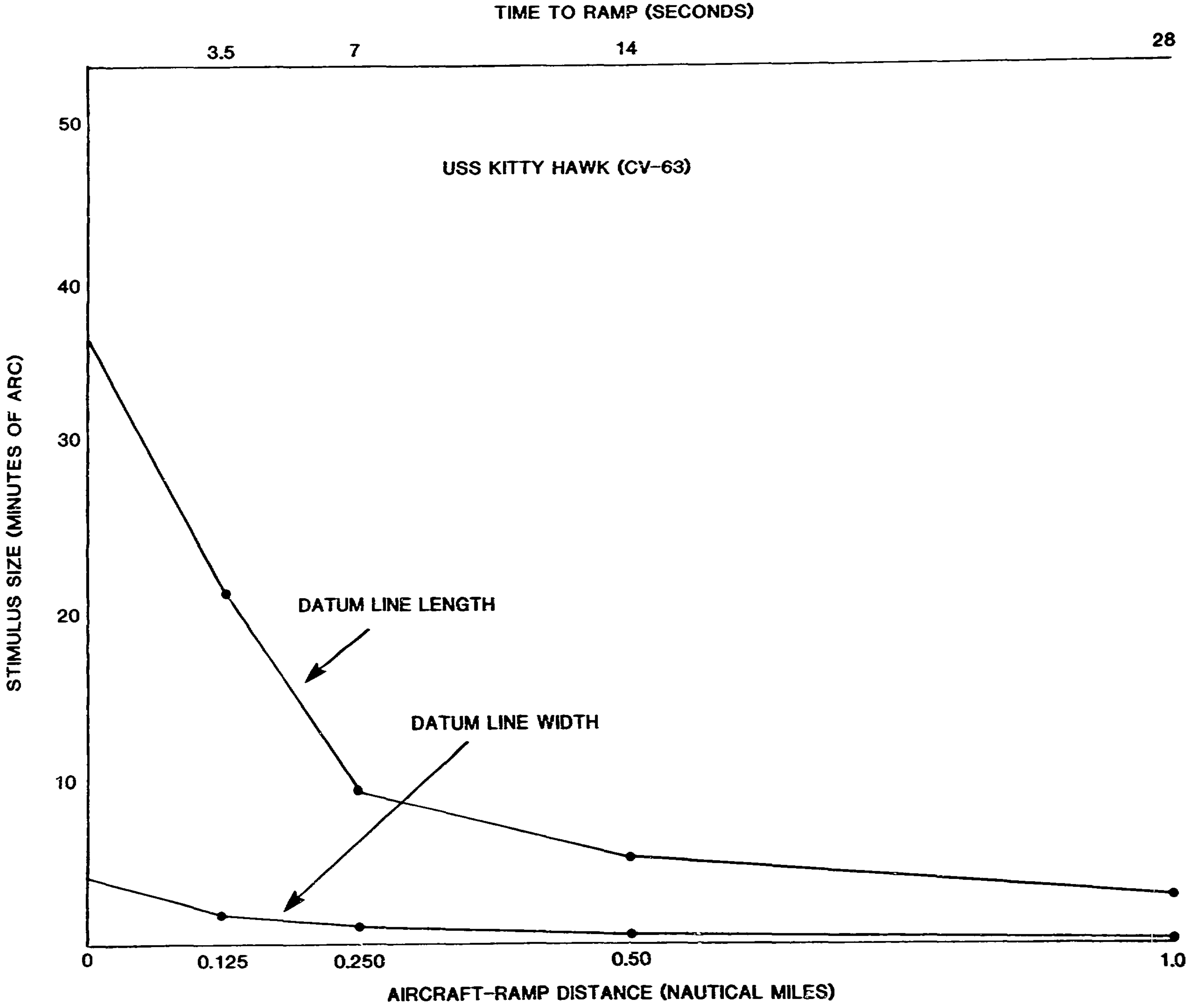
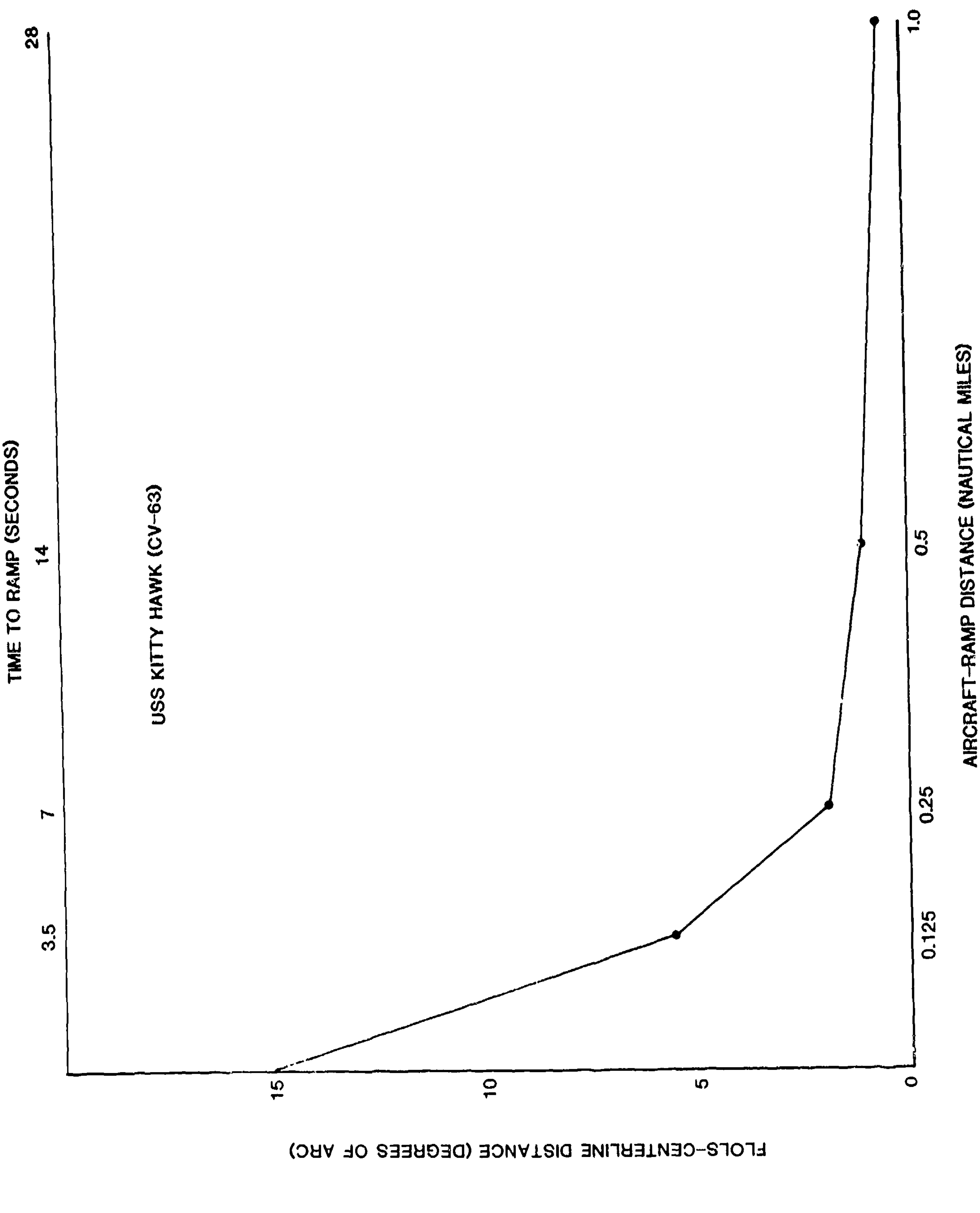

TIME TO RAMP (SECONDS)
3.5
7
14
28
USS KITTY HAWK (CV-63)
STIMULUS SIZE (MINUTES OF ARC)
50
40
30
20
10
DATUM LINE LENGTH
DATUM LINE WIDTH
0
0.125
0.250
0.50
1.0
AIRCRAFT-RAMP DISTANCE (NAUTICAL MILES)

Figure 11

The visual angular distance between the USS KITTY HAWK landing deck center line and the FLOLS as a function of the distance behind the carrier ramp in nautical miles on the lower abscissa while seconds to the ramp is indicated on the upper abscissa for an airspeed of 125 knots.


TIME TO RAMP (SECONDS)
3.5
7
14
28
USS KITTY HAWK (CV-63)
FLOLS-CENTERLINE DISTANCE (DEGREES OF ARC)
15
10
5
0
AIRCRAFT-RAMP DISTANCE (NAUTICAL MILES)
0.125
0.25
0.5
1.0