NATIONAL BUREAU OF STANDARDS REPORT

8167

Photometric Characteristics of a Lens Cell
of the Fresnel-Lens Optical Landing System

by
A. C. Wall

U. S. DEPARTMENT OF COMMERCE
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NBS

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Photometric Characteristics of a Lens Cell Of the Fresnel-Lens Optical Landing System

ABSTRACT

The photometry of a diverging beam light system such as is used in the Fresnel-Lens Optical Landing System requires that correction factors be applied to (1) the apparent luminous intensity and to (2) measured photometric angles. The factor includes the distance from the cell to the virtual image; it occurs in the numerator for (1) and in the denominator for (2). The measured brightness of the cell decreases gradually with angle with no bright spots.

1. INTRODUCTION

1.0 This report gives the results of a study of one cell of a Source-Light Indicator Assembly of the Mark 6 Fresnel-Lens Optical Landing System. The areas investigated were, namely, (1) the intensity distribution of the unit, (2) the effect of test distance on intensity distribution measurements, and (3) the brightness of a cell when it is viewed by an observer not on the glide path indicated by the cell.

1.1 The Optical Landing System

1.1.1 Purpose. The purpose of the lens systems is to provide the pilot with a visual indication of his relative position with respect to a prescribed glide slope. This glide slope, as determined by the lens settings, is designed to bring the aircraft down to the deck with a safe arresting hook clearance above the stern ramp of the carrier.

1.1.2 Physical Description. The lens unit consists of five cells stacked to form a unit approximately one foot wide and four feet high. Twelve green datum lights, six on each side, are mounted in line with the horizontal centerline of the lens box. A yellow bar of light is displayed over the full width of the light unit. The unit may be considered a window through which the pilot views the bar of light. The bar of light appears as though it were located approximately 150 feet beyond the window. When viewed from anywhere on the prescribed glide slope, this bar of light will appear in line with the green datum lights. This bar will rise above the datum lights as the pilot rises above the glide slope, eventually sliding off the top of the lens box when the pilot is more than 3/4 of a degree above the glide slope. Similarly, as the pilot drops below the glide slope, the bar will drop below the datum lights and finally slide off the bottom of the lens box.

1.2 Photometric Considerations. In the photometry of projected parallel light, there is a critical photometric distance beyond which the inverse square law is valid and

$$I = E\,d^2 \tag{1}$$

where I is the luminous intensity
E is the measured illuminance at a point
d is the distance from the point to the light
and d is greater than the critical distance.

At the critical point (and beyond) the whole lens appears flashed (macroscopically) to an observer on or near the beam axis; with typical projectors and sources, at shorter distances only a smaller central area of the lens appears flashed. This condition may or may not exist if the source is not at the focus of the lens. See figure 1.

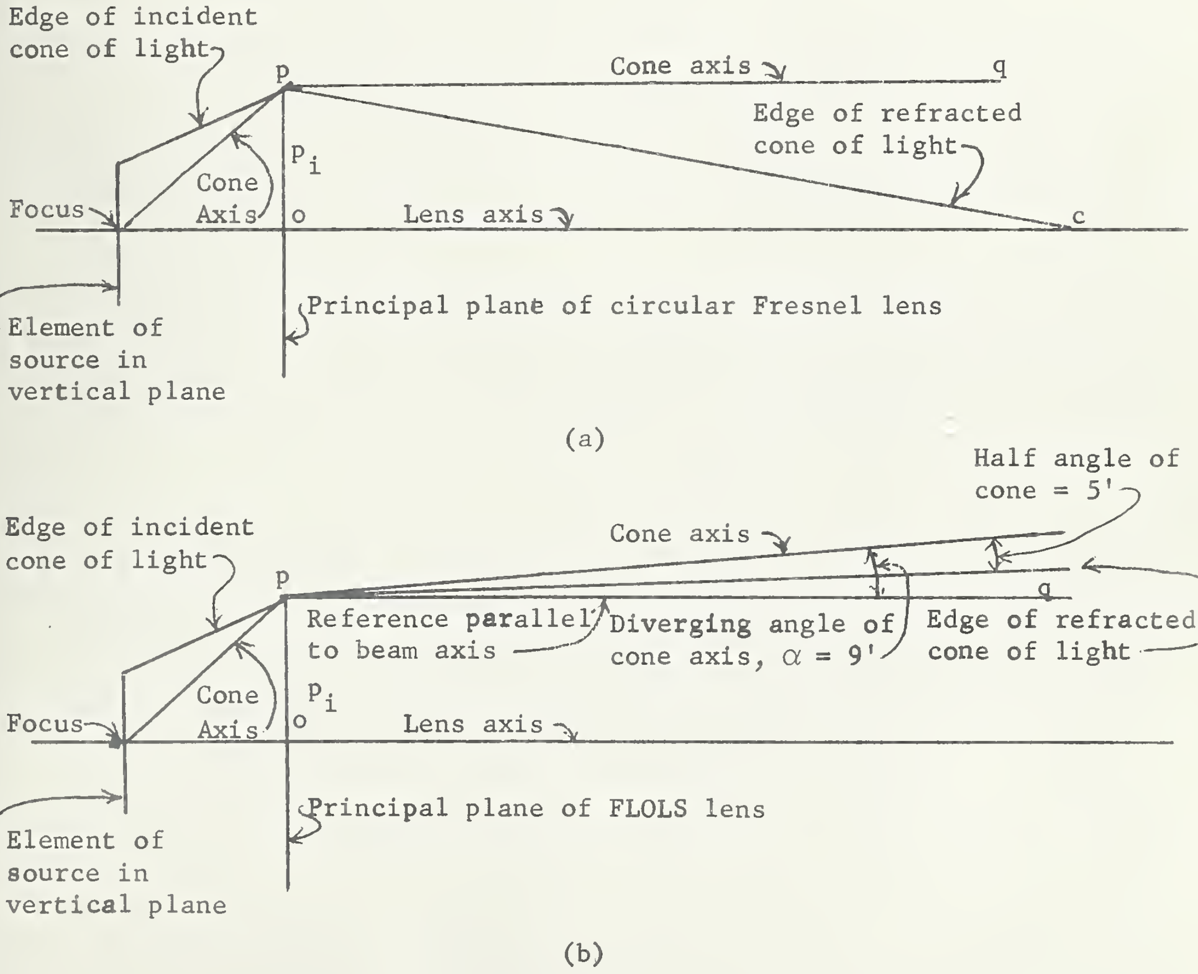

Figure 1. Simplified section in vertical plane of a collimated-beam lens system (a) and a FLOLS (b). (Angles are exaggerated.)

Figure 1a shows the axis and one edge of each of two cones of light incident on and refracted by a circular Fresnel lens at point p on the edge of the lens. The light to the right is collimated (source at focus), which means that the axis pq of the cone of refracted light is parallel to the beam axis. The angles between each cone axis and cone edge are equal. There is then a point c on the lens axis where the edge of the cone of refracted light crosses the axis. To a two-dimensional observer at point c, the point p would appear bright, as would all other points p_i closer to the axis. Since this reasoning applies equally well to all planes through the lens axis, it follows that, to a three-dimensional observer at (and beyond) point c, a circular lens of radius op (assuming it to be a perfect lens) would appear bright all over, or flashed. Point c is therefore the critical point beyond which equation (1) is valid and oc is referred to as the critical distance.

Consider now figure 1b, wherein the source of the FLOLS is closer to the lens than the focus and the axis of the refracted cone of light through point p at the upper edge of the Fresnel lens diverges at an angle (α) equal to arctan 4.75/1800, or 9 minutes. The half angle between the lower edge of the refracted cone of light and the cone axis is approximately arctan 0.033/24, or only 5 minutes. Therefore the lower edge of the cone never intersects the axis.

Because of the dimensions of the source of the FLOLS (1/16 inch by 3/4 inch) the lens will flash in a horizontal plane through the beam axis. There is then no critical distance at or beyond which the FLOLS cell appears totally flashed to an observer and beyond which the inverse square law can be applied conventionally to photometric measurements.[1]

2. TEST PROCEDURES

2.1 Effects of Test Distance. To evaluate the effects of test distance on intensity distribution measurements, both the indoor range (30 meters maximum) and the outdoor range (279.4 meters) described in Section 2.1 of NBS Technical Note 198 (NBS Report 7610) were used. The associated photometric instrumentation is described in Section 2.3a of that Note. The indoor range permitted shorter test distances than maximum; the outdoor range did not. For comparison purposes, measurements were made at photometric distances of 15, 30 and 279.4 meters.

The three 21-volt lamps were connected in series and operated at 63 volts.

[1]Douglas, C.A., Review of Elementary Theory of the Photometry of Projection Apparatus, NBS Report 8168.

2.2 Brightness. The 30-meter test distance was used for the brightness determinations. The lamps were operated at 63 volts. A vertical intensity distribution was made through 0.0° horizontal. Then, with the goniometer elevation set to the angle of maximum reading, the cell lens was covered by a mask which exposed only a 1/4-inch-high area of the cell. The mask was raised and lowered by steps to expose the whole area of the cell lens in 1/4-inch increments, and the brightness of the individual areas was read and recorded.

3. RESULTS

3.1 Intensity distribution of a cell of the FLOLS. Vertical intensity distributions, in relative values, of a single cell of the FLOLS through 0.0° horizontal are shown in figures 2 and 3. The photometric distance was 30 meters. A horizontal intensity distribution, also relative, through the vertical beam axis is shown in figure 4.

3.2 Apparent intensities and beam spreads and corrections thereto. It was noted above that computations based on the conventional applications of the inverse square law do not yield a constant intensity independent of the test distance when the test distance is considered to be that between the photometer and the lens of the FLOLS cell. However, it can be shown[1] that an intensity can be computed if the distance from the point of measurement to the position of the virtual image (150 feet) is used in the following equation:

$$I = (150 + d)\ (d)\ E \qquad (2)$$

where I is the luminous intensity of the virtual image formed by the cell
E is the measured illuminance at a point
d is the distance from the cell to the point of measurement.

Further, the geometric relations of figure 5 show that the measured angles and beam widths must also be corrected by a factor which depends upon the photometric distance used during the test.

[1] Douglas, C.A., Review of Elementary Theory of the Photometry of Projection Apparatus, NBS Report 8168.

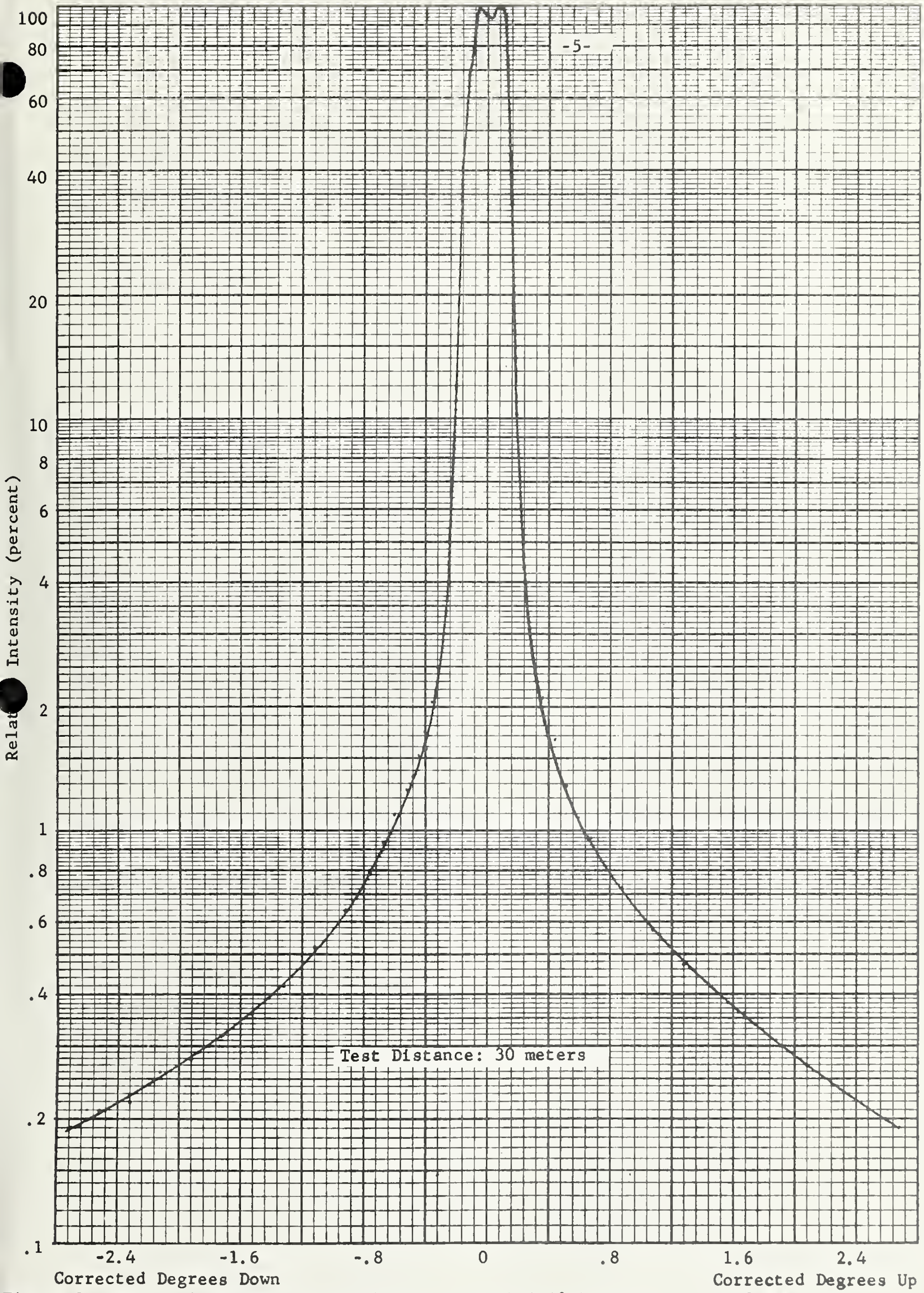

Figure 2. Vertical intensity distribution through 0.0° horizontal of one cell of a Source-Light Assembly of the Mark 6 Fresnel-Lens Optical Landing System. NBS Report 8167.

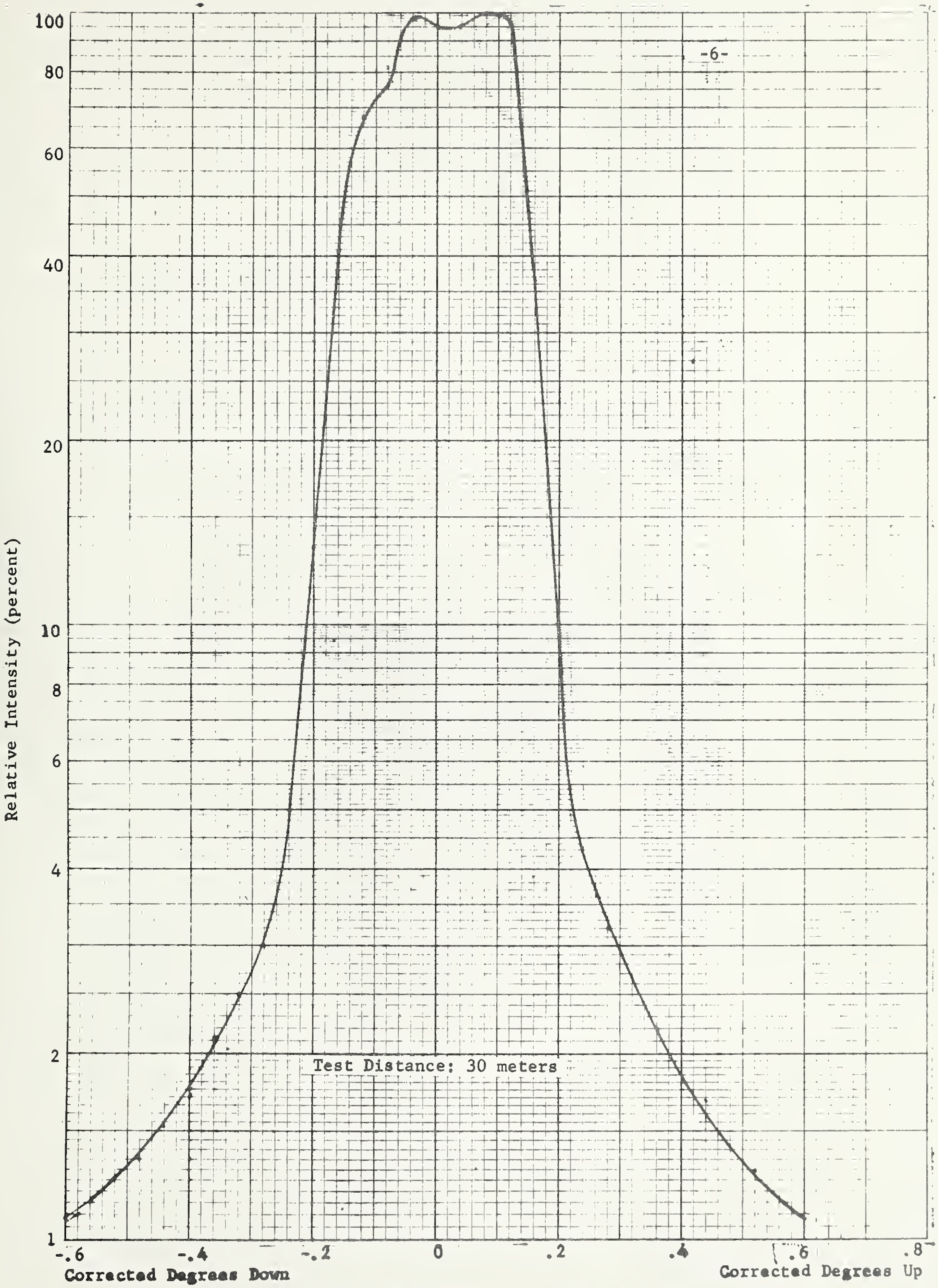

Figure 3. Vertical intensity distribution (expanded scale) through 0.0° horizontal of one cell of a Source Light Assembly of the Mark 6 Fresnel-Lens Optical Landing System.
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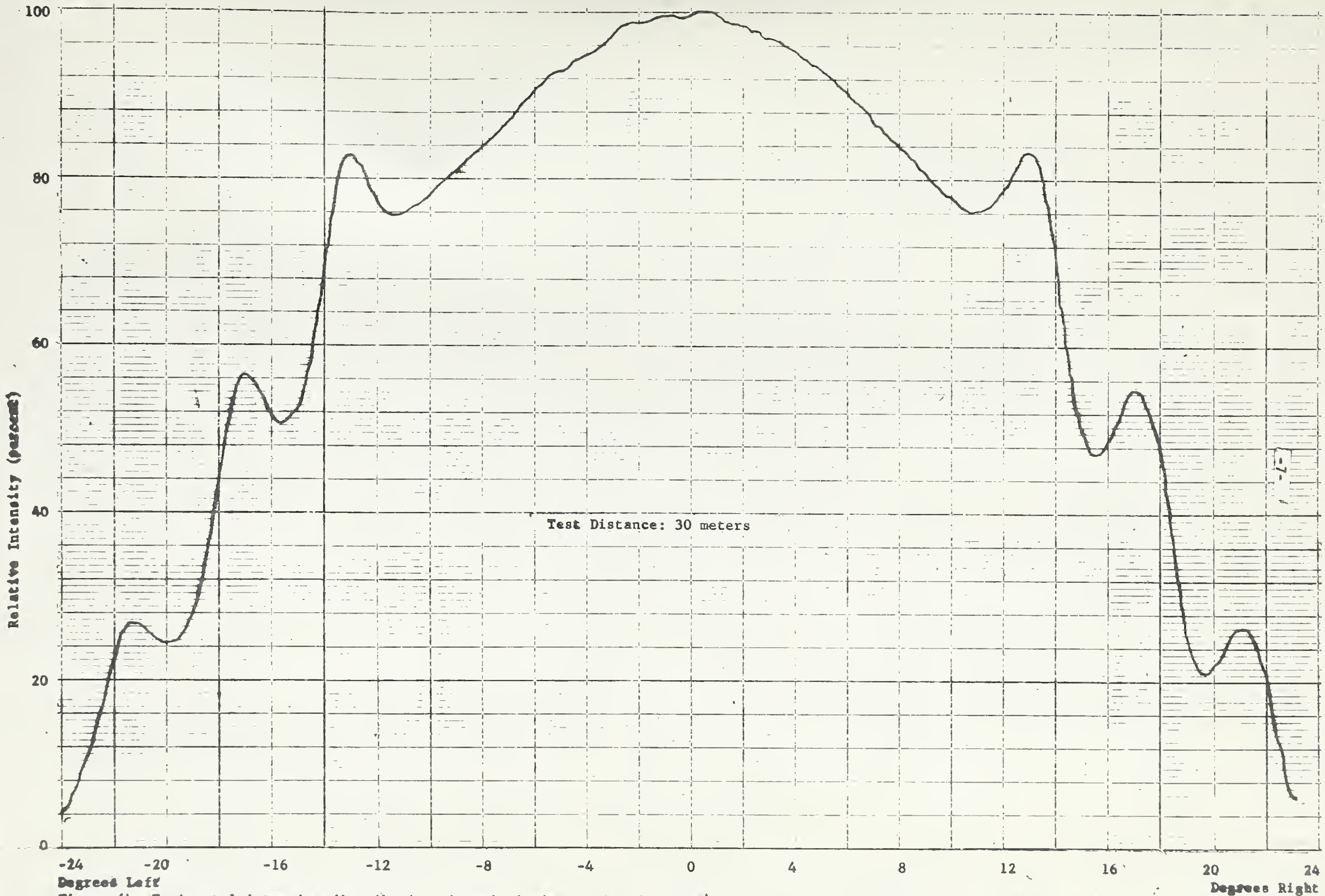

Figure 4. Horizontal intensity distribution through the beam axis of one cell of a Source-Light Assembly of the Mark 6 Fresnel-Lens Optical Landing System.

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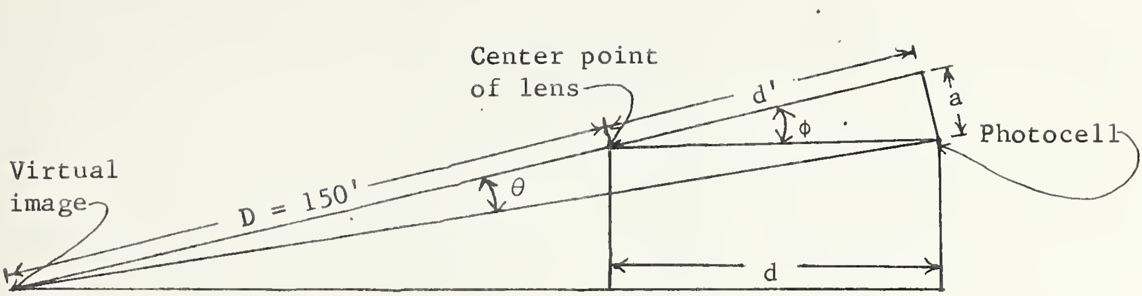

Figure 5. Measured and corrected vertical angles and their relation.

$$\tan \phi = \frac{a}{d'} = \frac{a}{d} = \phi \qquad \text{for small angles}$$

$$\tan \theta = \frac{a}{d' + D} = \frac{a}{d + D} = \theta \qquad \text{for small angles}$$

where ϕ is the goniometer angle (measured)
d is the test distance
θ is the corrected angle
D is the apparent distance of the source behind the Fresnel lens

when d = 50' $\quad \theta = \frac{50\phi}{50 + 150} = .25\phi$

when d = 100' $\quad \theta = \frac{100\phi}{100 + 150} = .40\phi$

when d = 1000' $\quad \theta = \frac{1000\phi}{1000 + 150} = .87\phi$

The results of the tests, made at different photometric distances, after the proper corrections have been made, show a surprising consistency, as shown in table I.

Table I

Test Distance (meters)	Peak "Intensity" (kilocandelas)		Vertical Beam Spread at 50% Max. (degrees)	
	from eq. (1)	from eq. (2)	measured	corrected
15	7.9	32.0	1.1	0.28
30	12.5	31.3	0.7	0.28
279.4	30.0	34.8	0.35	0.30

It follows that the corrected peak intensity values may be substituted for 100% in figures 2, 3, and 4. The angles have been corrected on the figures.

3.3 Brightness of Lens. The average relative brightness of the incremental areas 1/4 inch high and the width of the cell is shown in figure 6 as a function of the distance in inches from the center of the bar of light. This curve was extrapolated (using data taken from figure 2) to 50 inches from the center of the bar. The values shown in table II are taken from figure 2 and from the extrapolated curve. The "distance from center of bar of light" values greater than those shown in figure 6 would lie in other cells of an assembly of five cells. The values in table II are percent of the peak brightness in the center of the bar of light.

Table II

Distance from Center of Bar of Light (inches)	Relative Brightness (percent)
1	47.5
2	2.7
3	1.6
4	1.1
5	0.8
6	0.6
7	0.5
8	0.5
9	0.4
10	0.4
20	0.15
30	0.09
40	0.06
50	0.04

4. CONCLUSION

Table II measurements show that the brightness of the FLOLS cell lens decreases smoothly as the distance from the center of the bar of light increases; there are no peaks in the curve to indicate bright spots at any vertical angle other than that of the "meat ball."

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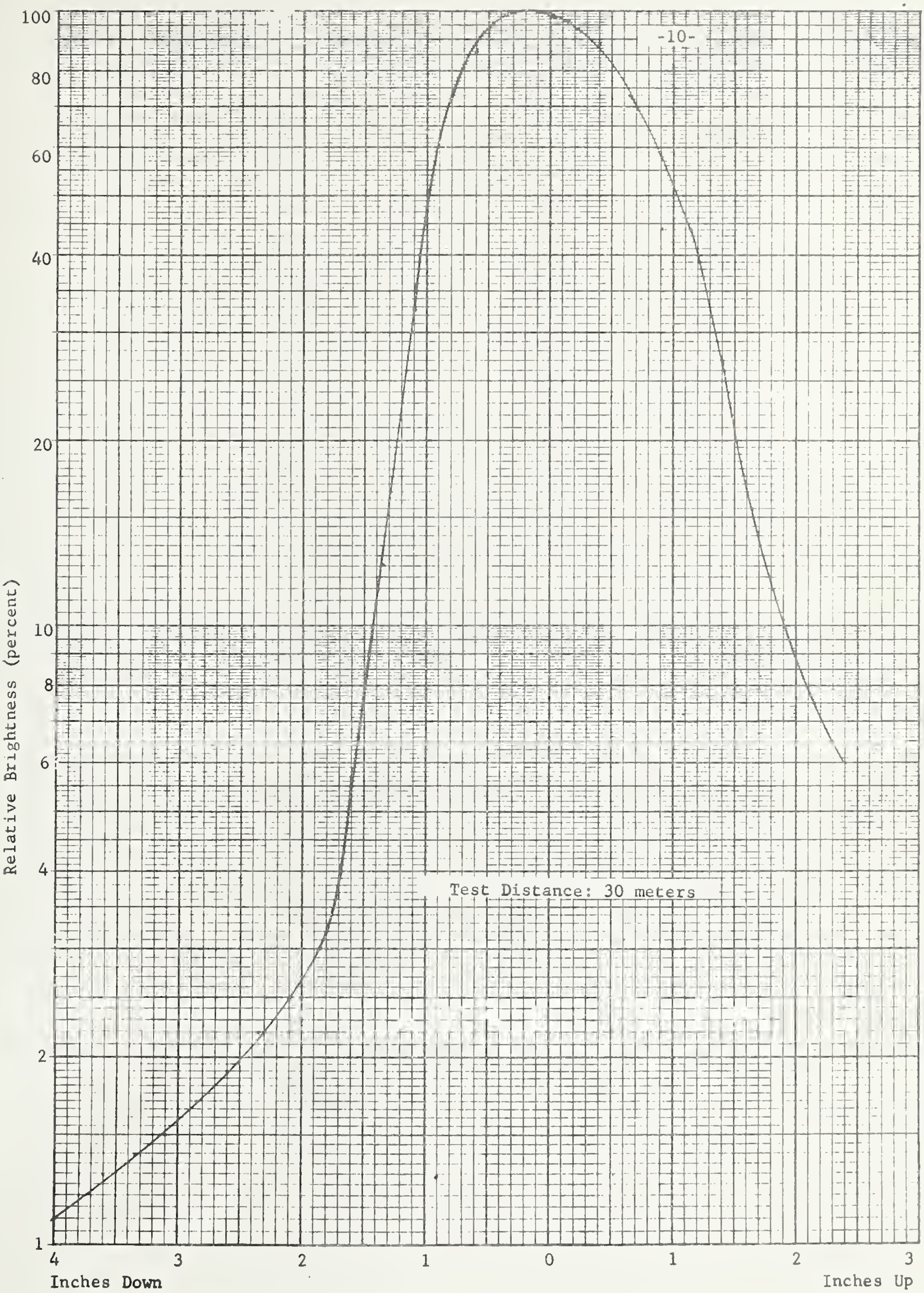

Figure 6. Average relative brightness of 1/4-inch-high areas the width of the lenticular lens of one cell of the Source-Light Assembly of the Mark 6 Fresnel-Lens Optical Landing System as a function of the vertical distance from the center of the bar of light.
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