

ABSTRACT

Measurements and calculations for the Navy 36 inch and the Army 60 inch searchlights led to the following results. x is the maximum visual range of an object illuminated by a searchlight at night viewed by an observer alongside the searchlight and at a distance d from it. A homogeneous atmosphere and a small target are assumed. It was found that

- (a) The range x of the object illuminated by the "near" side of the beam (the portion of the beam near the observer) is about 20 percent greater than when the object is illuminated by the "far" side of the beam, for a clear atmosphere. With increase of haze the difference decreases.
- (b) For a clear atmosphere the range x increases about 25, 50 and 75 percent when the observer moves from $d = 30$ feet to 100, 200 and 500 feet, respectively. The percentage increases in x remain approximately constant with increasing haze.
- (c) The range x increases with the fourth root of the area and reflectivity of the illuminated object and with the eighth root of the candle power of the searchlight, for a clear atmosphere. With increase of haze the increases of x are even less rapid.

The general conclusion was reached that by means of the present detailed manner of calculation the effectiveness of a searchlight in revealing small objects can be calculated completely from the distribution curve of light in the searchlight beam.

TABLE OF CONTENTS

	Page
Abstract	b
Chapter 1. Introduction	1
Chapter 2. Brightness of Searchlight Beam	3
Chapter 3. Ranges of Objects in Searchlight Illumination	8
Range of Object in Various Parts of the Beam	10
Range of Object for the Observer in Various Positions	10
Ranges for Searchlights of Various Candle Powers ..	11

TABLES

Table 1. Atmospheric Attenuation and Transmission	4
Table 2. Searchlight Data	5

PLATES

Plate 1. Geometry of Searchlight Beam	
Plate 2. Distribution of Light Scattered by Haze	
Plate 3. Distribution of Light in Searchlight Beam	
Plate 4. Photograph of Searchlight Beam at 5 Feet	
Plate 5. Photograph of Searchlight Beam at 40 Feet	
Plate 6. Brightness of Various Parts of Beam	
Plate 7. Brightness of Beam at Various Distances	
Plate 8. Observed and Calculated Brightness of Beam	
Plate 9. Range of Target in Various Parts of the Beam	
Plate 10. Range of Target for Observer in Various Positions	
Plate 11. Range of Target for Various Candle Powers of Search- light	

CHAPTER 1

INTRODUCTION

Authorization. The Director, Naval Research Laboratory

In this report the optical features of searchlight illumination are analyzed in considerable detail. Experimental measurements and calculations are given which led to quantitative answers to the questions, how does the range at which an object can be seen in the searchlight illumination vary with, (a) the portion of the searchlight beam used to illuminate the object, (b) the distance of the observer from the searchlight, (c) the candle power of the searchlight, and (d) the haze in the atmosphere.

The results given here depend entirely on experimental facts. Pertinent numerical facts of vision, attenuation and scattering of light by haze, geometry of a searchlight beam, and the distribution of light in the beam were brought together and from these the answers to the above questions were worked by calculation for the Navy 36 inch searchlight and the Army 60 inch searchlight. In addition, a few direct observations were made of the brightness of searchlight beams which were found to be in fair agreement with the calculations.

Since the searchlight is a visible light apparatus designed to be employed by observers using their eyes, the range at which an object can be seen in the searchlight illumination is essentially a problem in vision. The optical properties of searchlights and of atmospheric haze have been known for some years, but the necessary facts of vision have not been known, and have become available only recently. These facts, however, are for small objects which subtend less than 5 minutes of arc at the observer. Therefore the present conclusions refer only to such small objects. Larger objects can be considered when suitable vision data concerning them are forthcoming.

SUMMARY OF RESULTS

The general results of the present report are summarized below, although there is some risk of over-simplification in such brief statements. The results apply to the Navy 36 inch and the Army 60 inch searchlights.

x is the maximum visual range of an object illuminated by a searchlight at night viewed by an observer alongside the searchlight and at a distance d from it. A homogeneous atmosphere and a small object are assumed. It was found that,

- (a) The range x of the object illuminated by the "near" side of the beam (the portion of the beam near the observer) is about 20 percent greater than when the object is illuminated by the "far" side of the beam, for a clear atmosphere. With increase of haze the difference decreases. (See Plate 9.)
- (b) For a clear atmosphere the range x increases about 25 percent as the observer moves from $d = 30$ feet to 100 feet from the searchlight, and about 50 and 75 percent when he moves to $d = 200$ and 500 feet, respectively. The percentage increases in x remain approximately constant with increasing haze. (See Plate 10.)

- (c) The range x increases with the fourth root of the area and reflectivity of the illuminated object and with the eighth root of the candle power of the searchlight, for a clear atmosphere. With increase of haze the increases of x are even less rapid. (See Plate 11.)

The general conclusion was reached that by means of the present detailed manner of calculation the effectiveness of a searchlight in revealing small objects can be calculated completely from the distribution curve of light in the searchlight beam.

CHAPTER 2

BRIGHTNESS OF SEARCHLIGHT BEAM

Referring to Plate 1(a), let AB be the axis of the beam of the searchlight A. At point P in the beam let α be the angle between AP and AB. Assume the beam to be a circular cone with light distribution η across the beam given by Plate 1(b); η is symmetrical with α and is 1 for $\alpha = 0$. Let AP be x_1 , and assume x_1 so great (more than, say, 100 times the diameter of the searchlight mirror) that the α, η curve is independent of x_1 . Let c be the maximum beam candlepower, and i the illumination at P.

Then

$$i = c \eta x_1^{-2} e^{-\beta x_1} \quad (1)$$

where β is the attenuation coefficient of the atmosphere for collimated light. Eq. (1) is the definition of β .

Let the line of sight DB of an observer at D pass through P. Let DE be parallel to AB; AD = d ; DP = x_2 ; and angle PDE be ϕ . Let the conventions of the signs of α and ϕ be those shown in Plate 1(a). Let all lines be in the same plane BAD.

η is a function of α and hence of x_2 . To determine the relation we note from the geometry of Plate 1(a) that

$$\gamma = \alpha + \phi,$$

$$\text{and } \frac{\sin \gamma}{d} = \frac{\sin (90^\circ - \alpha)}{x_2}$$

Whence, eliminating γ ,

$$\tan \alpha = (d/x_2) \sec \phi - \tan \phi \quad (2)$$

The brightness Δb of an element of the beam at P as seen by the observer at D is

$$\Delta b = \sigma_b i e^{-\beta x_2} dx \quad (3)$$

where σ_b is the coefficient of scattering by the atmosphere backward toward D.

Assuming that β and σ_b are constant throughout the region of the atmosphere under consideration, the brightness b of the beam seen by the observer in the direction of P is

$$b = \int_0^\infty \sigma_b i e^{-\beta x_2} dx \quad (4)$$

Substituting (1) into (4) gives

$$b = \sigma_b c \int_0^\infty \eta x_1^{-2} e^{-\beta(x_1+x_2)} dx \quad (5)$$

Since in all cases considered here α and ϕ are small, i.e. not greater than 3° and usually less than 1° , we have to a close approximation $x_1 = x_2 = x$.

(2) and (5) reduce, respectively, to

$$a = d/x - \phi, \quad (6)$$

$$b = \sigma_b c \int_0^x \eta x^{-2} e^{-2\beta x} dx. \quad (7)$$

The brightness b was determined from (6) and (7) by graphical integration for stated values of β , d , ϕ , η and c . No examples of the graphical integrations are given in this report; they are elementary and tedious.

The attenuation β and the back scattering σ_b were known from earlier work on atmospheric haze^{1,2}. The attenuation β is listed in the third column of Table I for various visual ranges and weather given in the first two columns which were taken from the International Daylight Visibility Table.

Table I. Atmospheric attenuation and transmission.

Weather, amount of haze	Visual range v , sea miles	Attenuation β sea mi ⁻¹	Transmission a per sea mi.
except'n'ly clear	37.3	0.105	0.9
	14.4	.273	0.8
clear	11.0	.356	0.7
	7.67	.511	0.6
	5.65	.693	0.5
light haze	4.28	.916	0.4
	3.25	1.204	0.3
	2.44	1.608	0.2
thin fog	1.70	2.303	0.1
	1.31	2.997	0.05

The visual range v is the maximum distance that a large black object can be seen against the horizon sky in daylight. It has been shown¹ that $\beta v = 3.92$. It is convenient here to use the transmission per sea mile a , where

$$a = e^{-\beta} \quad (8)$$

The values of a are in the fourth column of Table I.

It is known that the attenuation of visible light in the lower atmosphere is almost entirely due to scattering. Therefore the scattering and attenuation are proportioned. Hence

$$\sigma_b = K\beta \quad (9)$$

From observations¹ of the brightness of a searchlight beam at night for two types of atmosphere, very clear $a=0.8$ and light haze $a=0.3$, K was found to be the same value 3.72×10^{-2} in each case. Then

$$\sigma_b = 3.72 \times 10^{-2} \beta \quad . \quad (10)$$

We assume that (10) is true for all the values of β of Table I. This can only be an approximate assumption, for it seems very probable that K changes as the weather changes from very clear to thick fog. However, there are no measurements in this connection other than those already referred to.

It may be clarifying to give the details of the determination of $K = 3.72 \times 10^{-2}$. Referring to Plate 2 a beam of incident light in the direction shown is scattered by an element of the atmosphere at P . σ_θ is the fraction of the incident light scattered per unit solid angle at angle θ with the direction of the incident light. The curve is a plot of the values of σ_θ , Ref. 1, Fig. 4. derived from the measurements of the brightness of a searchlight beam for θ from 20° to 160° . The strong forward scattering is clearly shown in Plate 2. σ_b is the back scattered light. Since the lower atmosphere reduces the beam by scattering only, with no absorption.

$$\begin{aligned} \beta &= \int_0^\pi \sigma_\theta 2\pi \sin \theta d\theta \\ &= 2\pi \sigma_b \int_0^\pi (\sigma_\theta / \sigma_b) \sin \theta d\theta \quad . \quad (11) \end{aligned}$$

From a graphical integration of (11), with σ_θ given by the curve of Plate 2, one found $\beta = 26.9 \sigma_b$, or $K = 1/26.9 = 3.72 \times 10^{-2}$.

Light distribution curves, in the present notation the η , α curves, are given in Plate 3 for the Army 60 inch and the Navy 36 inch searchlights. Data of these searchlights are in Table II. The values of the maximum beam

Table II. Searchlight data.

	Amperes	Volts	Kilo-watts	Max. beam candle power without shutter	Lumens per watt
Army-60 inch	150	78	11.7	400,000,000	6.2
Navy-36 inch	195	90	17.5	340,000,000	7.2

candle power are lower than values sometimes stated, but are probably fairly representative of the searchlights in actual use.

Plates 4 and 5 are photographs of the beam of the Army 60 inch searchlight. The beam was directed at the sky about 5° above the horizon, the camera being 5 feet from the searchlight in the case of Plate 4 and 40 feet in the case of Plate 5. The night was normally clear; α was estimated to be about 0.7. The times of exposure were 30 seconds; the light streaks in the beam were caused by insects and moths fluttering in the light. A scale of ϕ

is marked in each picture. It will be realized that the most useful part of the searchlight beam is the small circular area at the end of the beam of radius about 1° or less, for this is the place where distant objects are illuminated by the searchlight.

From the foregoing equations and data the brightness b of the searchlight beam was calculated for a number of cases and is plotted in Plates 6 and 7. All values of b were for the axial plane of the searchlight which passes through the eyes of the observer, i.e. plane BAD. Plate 1. Each value of b was calculated from Eqs. (6) and (7) by graphical integration. Plate 6 gives the variation of b with ϕ for $d=7.5$ feet and for the atmospheric transmission $a = 0.3$ and 0.7 . Plate 7 gives the variation of b with d , for $\phi = 0$, for several values of a . The circumstance that the b, ϕ curves of Plate 6 fall rather sharply to zero at a certain value of ϕ provides the explanation of the familiar observation that the beam comes to a definite end when viewed by an observer near the searchlight. The finite end of the beam is clearly shown in the photographs of Plates 4 and 5. As the observer moves away from the searchlight the end of the beam becomes less distinct, and when he is several miles away the beam fades out imperceptibly in the distance, if the atmosphere is homogeneous.

In general the b curves of Plates 6 and 7 were of no great interest in themselves, for their trends are about what one would expect from simple consideration. Their importance was in their use in the calculation of ranges of objects in Chapter 3. A point of minor interest was the approximate constancy of b with ϕ for ϕ greater than about 1° , shown in Plate 6. The relation can be stated as a theorem in physical optics; the theorem can be proved and the conditions under which it is exact and under which it becomes inexact can be laid down. It appears to be a new theorem. However, it is not used here, and we leave its elucidation to the student.

Two sets of experimental observations of the brightness of a searchlight beam were made in which b was measured for $\phi = 0^\circ$ for several values of d . One set was made with a 60 inch Army searchlight and the other with a 24 inch Navy searchlight. The observations are plotted as crosses in Plate 8, the upper four referring to the 60 inch and the lower three to the 24 inch searchlight. b was measured with a calibrated Macbeth Illuminometer with a blue filter over the illuminometer lamp to obtain a color match with the beam. The illuminometer had an objective lens of 12 inches focal length which made the central field about 1° in diameter. The instrument was used to measure the brightness b of the beam at the point $\phi = 0^\circ$, as shown in the photographs of Plates 4 and 5. The use of the illuminometer of 1° field to measure b at the end of the beam where b fell from a maximum value to zero in about 1° could only be expected to give an average value of b .

In the case of the 24 inch Navy searchlight the maximum beam candle power c and the atmospheric transmission were measured at the same time that b was observed, c was 50.3×10^6 candles and a was 0.70 . a was measured by means of a telephotometer and a known light at a known distance ². The η, a curve of the distribution of light in the beam was not known for the 24 inch searchlight. However, since the searchlight was well designed, its η, a curve was assumed to be approximately that of the Navy 36 inch searchlight of Plate 3. On this assumption the b, d curves for $\phi = 0^\circ$ and $+1^\circ$ were calculated and are plotted in the dotted curves of Plate 8. One would expect the observed points, the crosses, to lie on the $\phi = 0^\circ$ curve or perhaps between

the two ϕ curves. They do this tolerably well, indicating fair agreement between the direct measurement of b and the values obtained by calculations from measurements of haze and data of the searchlight.

In the case of the 60 inch Army searchlight the atmospheric transmission was not measured. However, the night seemed normal (it was the same evening that the photographs of Plates 4 and 5 were taken) and a was estimated to be 0.7. On this basis with $c = 4 \times 10^8$ and the γ_1 , a curve of Plate 3, the calculated b, d curves of Plate 8 were determined for $\phi = 0^\circ$ and 1° . They agree about as expected with the four observed points shown by the crosses.

In comparing the observed and calculated values of the brightness of the Army searchlight it was assumed that the brightness was due to atmospheric haze and not to the insects flying around in the beam which are so noticeable in the foreground of the photograph of Plate 4. The assumption was probably correct because the region at the end of the beam where the brightness was measured was several hundred feet above the ground where there were few insects.

CHAPTER 3

RANGES OF OBJECTS IN SEARCHLIGHT ILLUMINATION

An object illuminated by a searchlight appears to an observer who is not too far from the searchlight to be surrounded or immersed in the luminous beam of the searchlight. Usually the object appears brighter than the surrounding field of light; in fact, under the supposition of this report, namely, that the beam is caused by an optically homogeneous atmosphere throughout the length of the beam, an object, even if painted with ordinary black paint, is always brighter than the searchlight beam surrounding it. It is assumed that the object is so small and so far away that its longest linear dimension subtends an angle less than about 5 minutes of arc at the observer. Thus the illuminated target is approximately a point source of light surrounded by a luminous field. In this case the threshold illumination of the point source at the eye is known from an earlier investigation³, and the maximum ranges at which the object can be seen can be calculated.

A plane object is assumed of area A square feet and of diffuse reflectivity R . It is assumed that the plane of the object is normal to the axis of the searchlight beam, and that the observer is so near the searchlight and the object so far from the searchlight that the line of sight of the observer is also approximately normal to the plane of the object. It is assumed that the illumination i on the object is mainly due to the searchlight and that the illumination on the object from other sources, as night sky light, stars, aurorae, moon, etc., are relatively weak. Then, if x is the distance from the searchlight to the object, i is given by (1), or

$$i = c \eta x^{-2} e^{-\beta x} \quad (12)$$

The illuminated object is a source of light of candle power iAR/π in the direction of the observer, i being in foot candles. Since the object is assumed to appear to the observer approximately as a point source, the illumination j which it produces at the observer is

$$j = iAR/\pi x^{-2} e^{-\beta x} \quad (13)$$

The earlier experiments³ showed that the illumination j at the visual threshold, for young observers with good vision, from a point source in a field of brightness b_f was given approximately (within a factor of 3) by

$$j = 10^{-10} (1 + 3.38 \times 10^6 b_f)^{1/2}, \quad (14)$$

where j is in foot candles and b_f is in candles per square foot. In other words, the point source was just visible, or at the threshold of visibility, in the field of brightness b_f when (14) was satisfied. We shall use (14) in the present searchlight case. There is a possible error in doing this. (14) referred to the case of a uniform field of diameter about 25 minutes of arc or greater surrounding the point source. The field of the searchlight beam around the illuminated object is in general not uniform, as shown by the b, ϕ curves of Plate 6. It was considered that the error due to the non-uniformity was not serious.

Substituting (12) and (13) into (14) leads to

$$(x^{-2} e^{-\beta x})^2 = 10^{-10} (1 + 3.38 \times 10^6 b_f)^{1/2} (\pi/ARc \eta) \quad (15)$$

where x is the maximum visual range of the object, or simply the "range" of the object. In the case of the searchlight the field brightness b_f is the sum of the brightness b of the beam and the brightness b_s of the night sky. Then (15) is

$$(x^{-2} e^{-\beta x})^2 = 10^{-10} \left[1 + 3.38 \times 10^6 (b + b_s) \right]^{1/2} (\pi/ARc \eta) \quad (16)$$

From (16) the range x was calculated for various conditions of haze, positions of target and observer and types of searchlight, using the values of the beam brightness b from Plates 6 and 7.

(16) is of the form $x^2 e^{mx} = n$ which can not be solved explicitly for x . A nomograph of this function was prepared to facilitate numerical solution.

The brightness of the horizon sky on clear, moonless, nights is about 3×10^{-5} c. ft.⁻², and is less than this if there is much haze, fog or clouds. It is seen from Plates 6 and 7 that the values of b are usually much greater than 3×10^{-5} unless there is considerable haze ($a < 0.3$) and the observer is at a considerable distance from the searchlight ($d > 200$ feet). Therefore b_s is usually less than b .

For an object on the axis of the searchlight $\eta = 1$. Approximately b_s and the number 1 on the right hand side of (16) are usually negligible. Therefore (16) may be written approximately

$$(x^{-2} e^{-\beta x})^2 \propto b^{1/2} (ARc)^{-1} \quad (17)$$

From (7) approximately for β small $b \propto c$. Then (17) becomes

$$(x^{-2} e^{-\beta x})^2 \propto (AR)^{-1} c^{-1/2}$$

or

$$xe^{\beta x/2} \propto (AR)^{1/4} c^{1/8} \quad (18)$$

From (18) it is seen that for β small the range x increases approximately with the fourth root of the size and reflectivity of the object and with the eighth root of the candle power of the searchlight; with increasing haze, i.e. increase of β , the increase of x is even less. This explains why great increases in the candle power of the searchlight yield only moderate increases in the visual ranges of illuminated objects.

In the following numerical calculations we shall assume throughout an object for which $AR = 100$ and whose angular diameter at the observer is not greater than about 5 minutes of arc. Since we shall be concerned with ranges greater than 1 sea mile such a target is, for example,

Length	Width	Reflectivity
10 feet	10 feet	1.00
20	5	1.00
25	20	0.20

It is also assumed throughout that $b_s = 3 \times 10^{-5}$ candles per square foot.

RANGE OF OBJECT IN VARIOUS PARTS OF THE BEAM

We take $d = 7.5$ feet, which means that the observer is 7.5 feet from the axis of the searchlight. The range at which he can see the target was calculated from (16) for various values of ϕ with the values of b from Plate 6. The results are given in Plate 9 for the Navy 36" searchlight for a clear ($a = 0.7$) and a hazy ($a = 0.3$) atmosphere and for the Army 60" searchlight for $a = 0.7$. It is seen from the curves of Plate 9 that when the object is illuminated by the portion of the beam on the side of the axis nearest to the observer, i.e. ϕ is negative, the ranges are greater than when the object is illuminated by the portion of the beam on the side far from the observer, i.e. ϕ is positive. The reason, of course, is that in the "near" case the portion of the beam is less bright than in the "far" case, as seen from the curves of Plate 6. The fact is familiar to operators of searchlights who know from experience that they can see objects somewhat better in the near side than in the far side of the searchlight beam. The difference, however, becomes less as the haze increases.

An important simplifying result appears from the curves of Plate 9, namely, the range is relatively constant for ϕ from about -0.1° to $+0.3^\circ$. This means that we may make subsequent range calculations for $\phi = 0^\circ$ with the realization that the ranges obtained are not sensitive to the exact positioning of the axis of the beam on the object, as long as the object is within $\phi = -0.1^\circ$ to $+0.3^\circ$.

RANGE OF OBJECT FOR THE OBSERVER IN VARIOUS POSITIONS

In this case x was calculated from (16) as a function of d for various amounts of haze, for a night sky brightness $b_s = 3 \times 10^{-5}$ c. ft.⁻², and for $\phi = 0^\circ$, using the values of b of Plate 7. The results are in Plate 10. It is seen that there is an increase in range as the observer moves away from the searchlight, the increase being, for a clear atmosphere, about 25 percent as the observer moves from 30 feet to 100 feet from the searchlight, and about 50 percent when he moves to 200 feet. The value of x given in Plate 10 for no beam were of academic interest, and were obtained by putting $b=0$ in (16).

The curves of Plate 10 are true only for a homogeneous atmosphere. In the case of a searchlight turned upward to view objects in the sky the atmosphere is usually nonhomogeneous, and often the nonhomogeneity consists in relatively heavy haze in the first few thousand feet above sea level, and a relatively clear atmosphere above. In such case the b, d curve is quite different from the b, d curves of Plate 10 for a homogeneous atmosphere, and the improvement in range occasioned by the observer moving away from the searchlight follows a curve different from those of Plate 10. For example, b may be very bright due to haze in the first few thousand feet, and then with increasing distance may fall to low values; for example, see Fig. 1, reference 4.

In consequence, as the observer moves away from the searchlight he may obtain at first only a small improvement in range; then, as he continues to move away he may suddenly find the range much increased because of the fact that he has reached a position in which his line of sight to the object passes alongside of, and not through, the bright section of the beam.

RANGES FOR SEARCHLIGHTS OF VARIOUS CANDLE POWERS

In this case x was calculated from (16) as a function of c for various amounts of haze, for $\phi = 0^\circ$, and for two positions of the observer $d = 20$ and 100 feet. The η, α curve of the Navy 36 inch searchlight was used. The x, c curves are in Plate 11, and illustrate the relatively slow increase of range with increase of candle power. The slow increase is indeed obvious from (16) or (18).

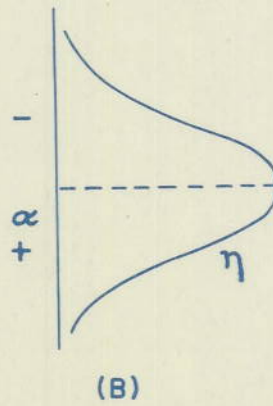
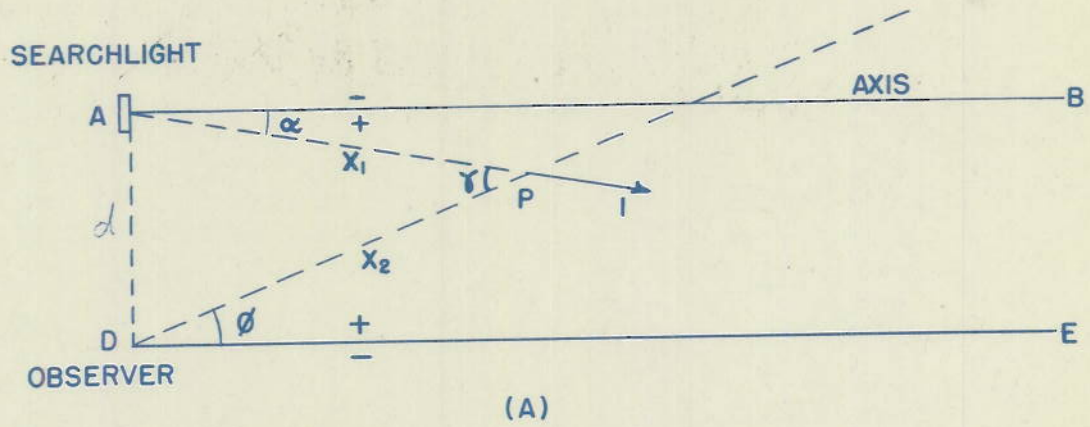
Although this report is not primarily concerned with the design of searchlights it is of interest to remark on the effect of width of beam brought out by the calculations of the Army 60 inch and the Navy 36 inch searchlights, the 60 inch having a beam width of about 7/10 of that of the 36 inch, as seen from Plate 3. We have ascribed to the Army searchlight a maximum beam candle power c of 400 million and to the Navy searchlight 340 million. Assume that c for the Navy searchlight were 400 million; the values of the ranges of the Navy searchlight of Plate 9 would be increased by about 4 percent for $\alpha = 0.7$. We see then from Plate 9 that the widths of the flat maxima of the x, ϕ curves are roughly in proportion to 7/10 and hence to the beam widths given by the η, α curves of Plate 3 for the two searchlights. In other words the angular width of the most effective portion of the searchlight beam as judged by seeing objects at maximum ranges is roughly proportional to the angular width of the beam as determined by the light distribution curve η, α . It has sometimes been surmised that narrowing the beam might give greater increase in range than might be expected from the increased light intensity occasioned by the greater concentration of light. It appears that the surmise is not correct for the two searchlights under consideration.

In concluding this chapter it is well to emphasize again that the ranges of Plates 9, 10 and 11 refer to objects that are small enough to appear approximately as point sources. The ranges of larger objects can not yet be worked out because visual thresholds of larger objects are not available. Also, it may be mentioned again that the present results are restricted to the axial plane of the searchlight BAD, Plate 1. The case of the searchlight tipped upward or downward so that it illuminates the object in a portion of the beam above or below the axial plane has not been worked out. The case may readily be calculated by the present methods, but it appeared that no important new facts were to be learned from its consideration at this time.

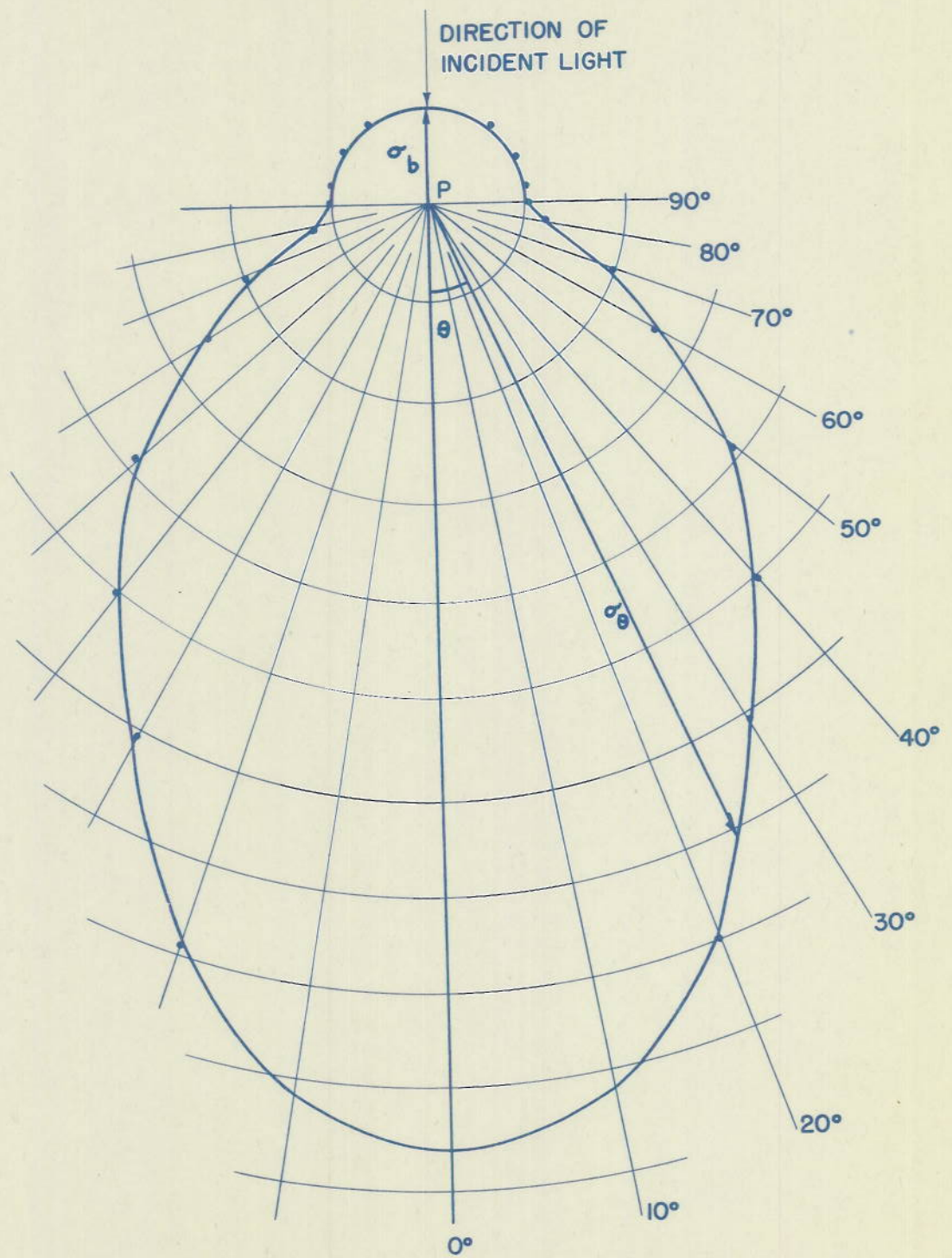
Acknowledgment. It is a pleasure to acknowledge the cooperation of the Army Engineer Board, Fort Belvoir, Virginia. The Board, through Major O. P. Cleaver, Lieutenant F. J. Millican, and Mr. C. F. Cashell, operated the 60 inch searchlight for the purpose of the photographs of Plates 4 and 5 and the measurements of Plate 8.

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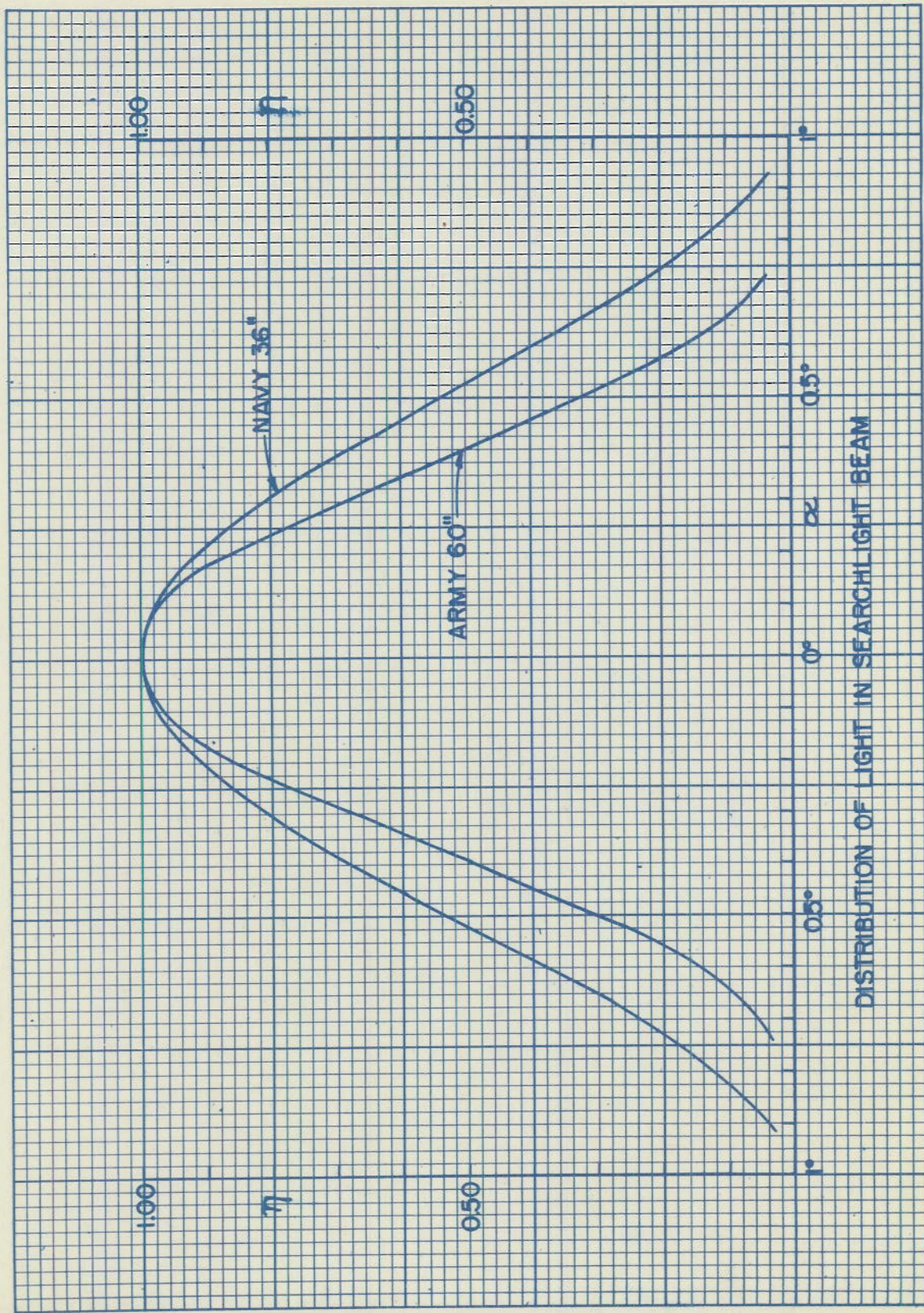
1. E. O. Hulburt, J.O.S.A. 31,467-476 (1941), "Optics of atmospheric haze".
2. NRL Report H-2303, June 6, 1944, "Some devices for measuring atmospheric attenuation of light".
3. NRL Report H-2627, October 11, 1945, "Threshold and signalling ranges of point sources of light in fields of brightness from dark to daylight".
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GEOMETRY OF SEARCHLIGHT BEAM



SCATTERING OF LIGHT BY HAZE



DISTRIBUTION OF LIGHT IN SEARCHLIGHT BEAM



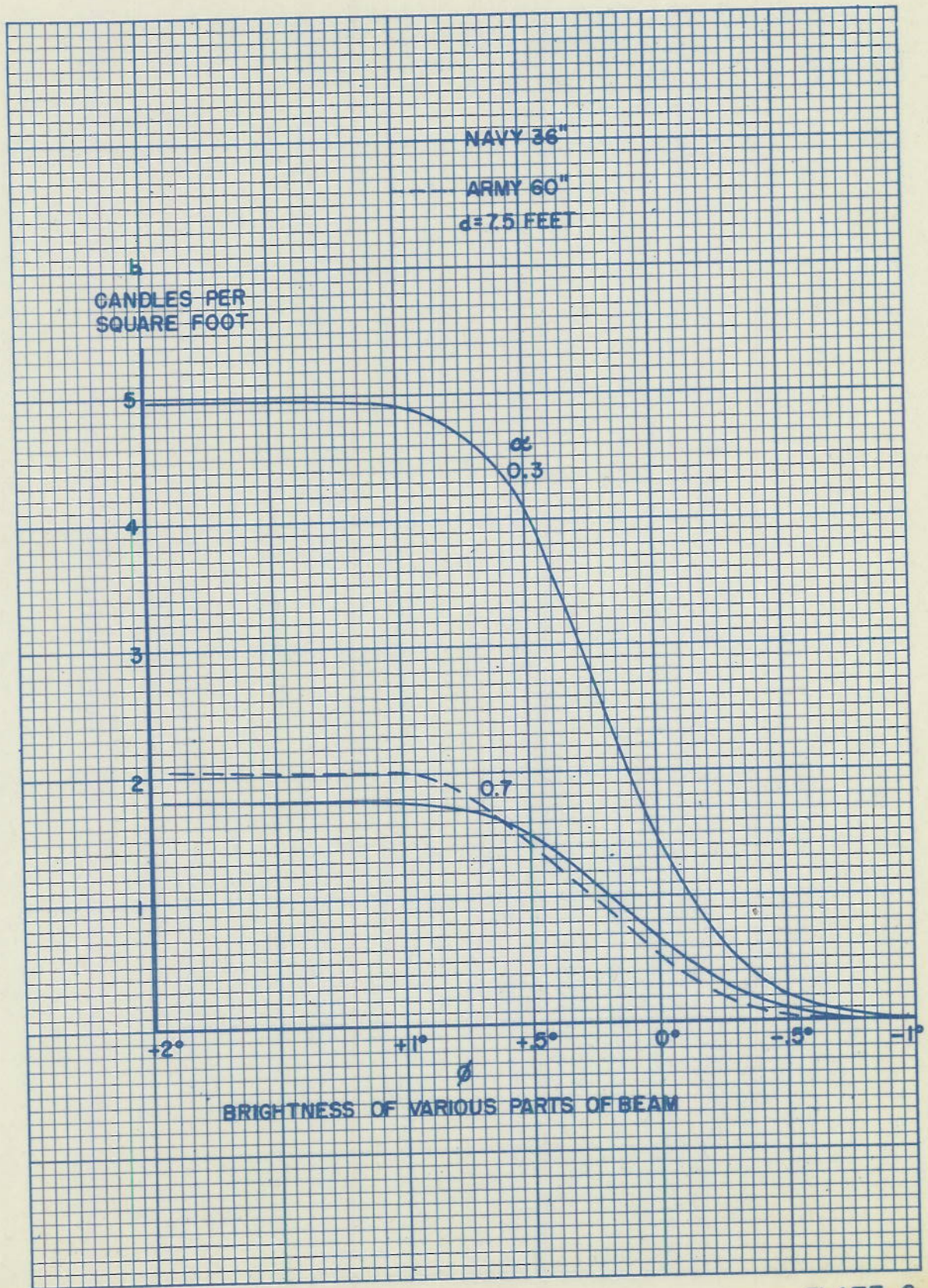
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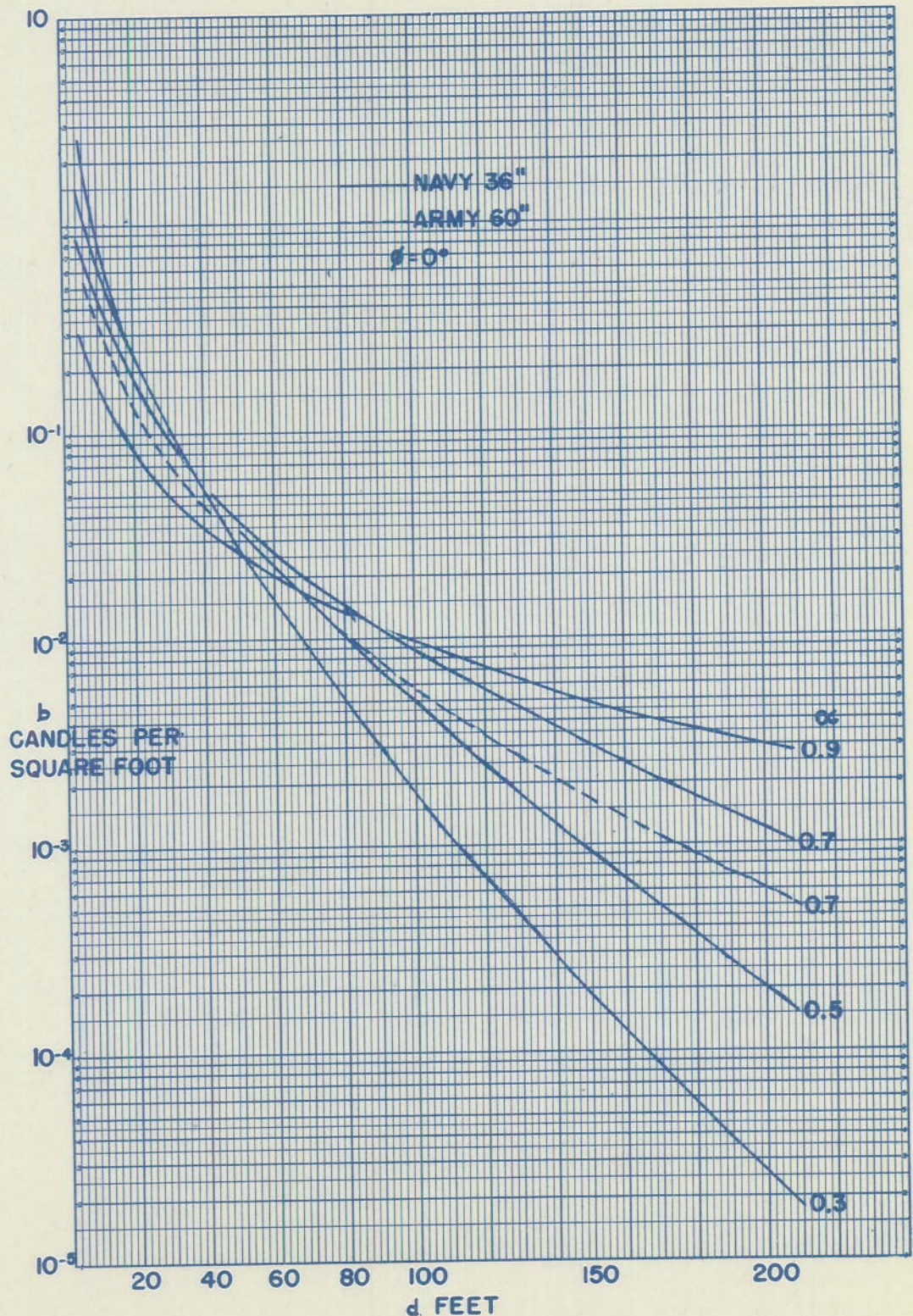
ARMY 60 INCH SEARCHLIGHT BEAM, CAMERA 5 FEET FROM SEARCHLIGHT.



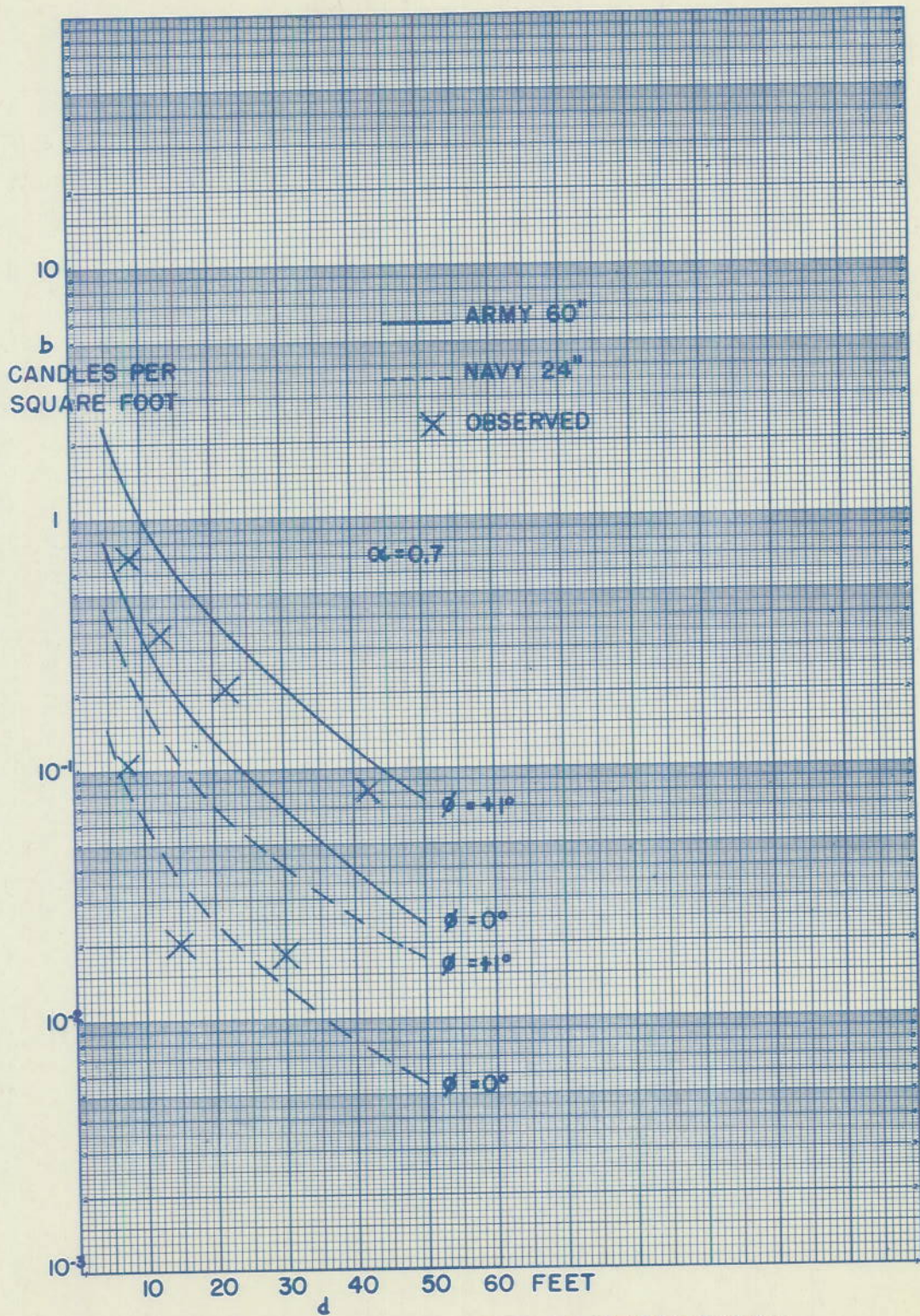
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ARMY 60 INCH SEARCHLIGHT BEAM, CAMERA 40 FEET FROM SEARCHLIGHT.

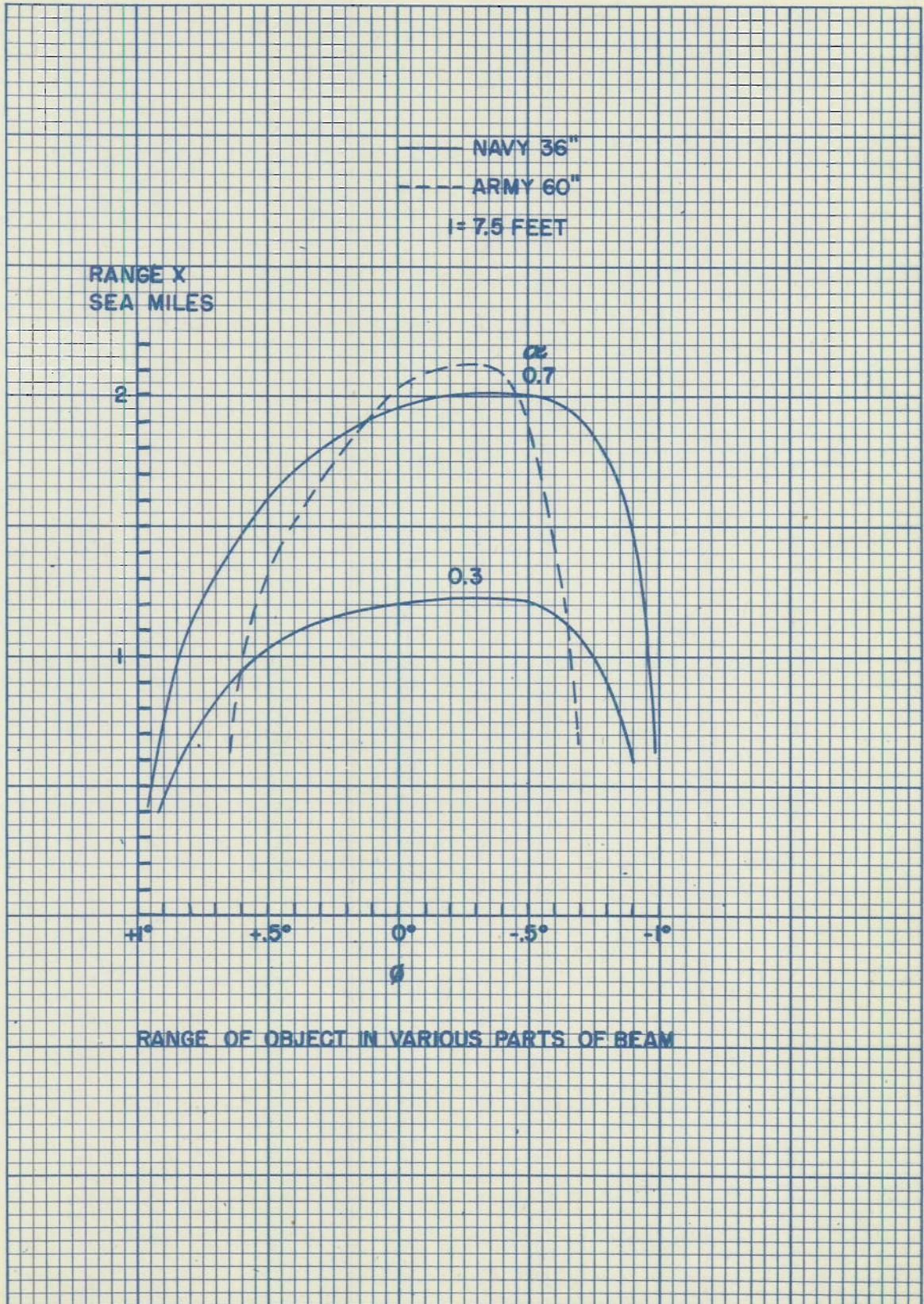


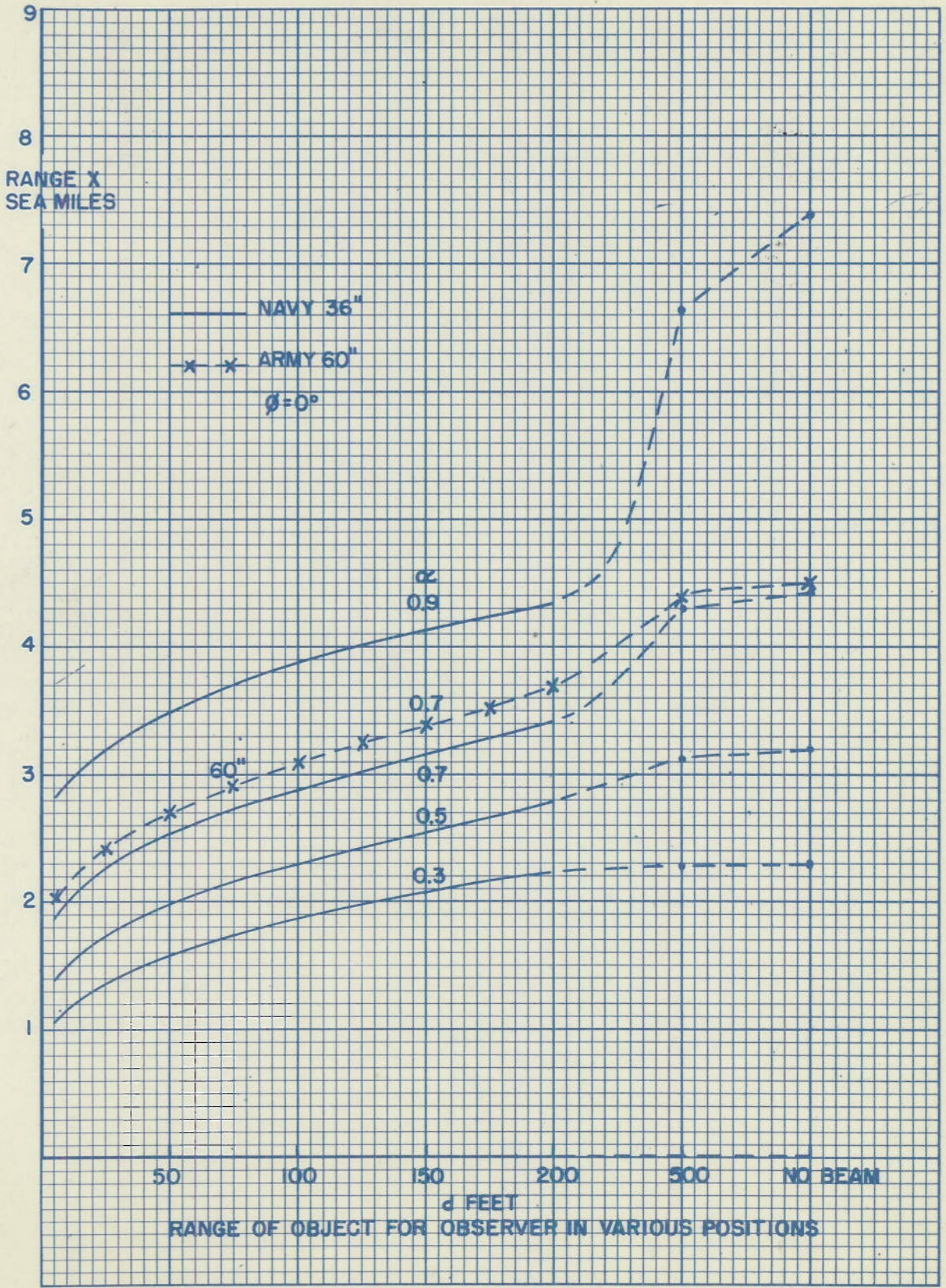


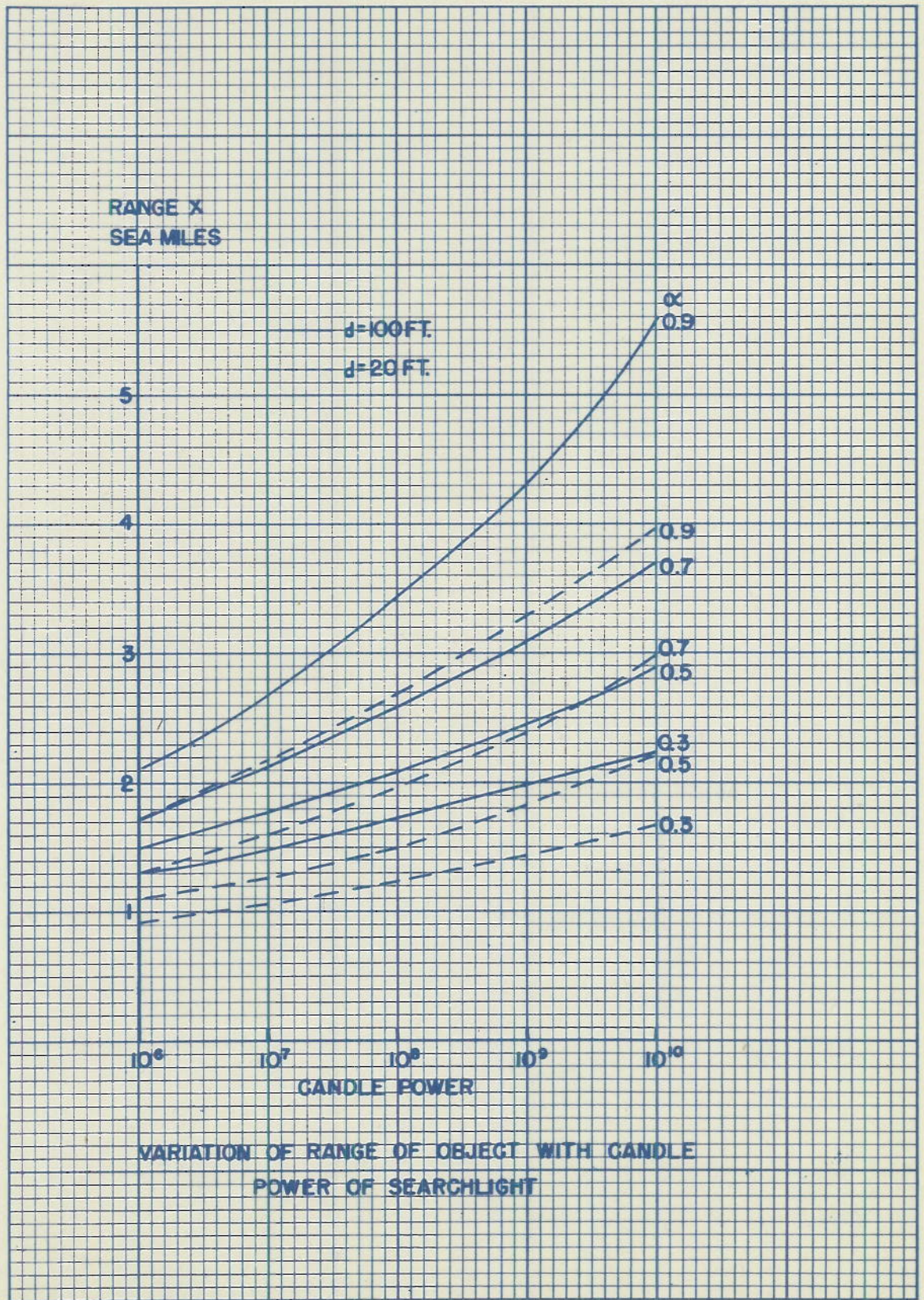
BRIGHTNESS OF BEAM AT VARIOUS DISTANCES



OBSERVED AND CALCULATED BRIGHTNESS OF BEAM







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