Visibility Laboratory
University of California
Scripps Institution of Oceanography
San Diego 52, California

A COMPRESSED-SCALE SYSTEM OF PORTABLE VISIBILITY LIGHTS

March 1960
Index Number NS 714-100

Bureau of Ships
Contract NObs-72092

SIO REFERENCE 60-16

Approved:

S. Q. Duntley

S. Q. Duntley, Director
Visibility Laboratory

Approved for Distribution:

Roger Revelle

Roger Revelle, Director
Scripps Institution of Oceanography

A COMPRESSED-SCALE SYSTEM OF PORTABLE VISIBILITY LIGHTS

Visibility Laboratory
Scripps Institution of Oceanography, University of California
La Jolla, California

SUMMARY

This report describes a compressed-scale, battery operated, portable system of visibility lights intended primarily for use at dispersal and other tactical bases where adequate night visibility check points are not available.

1. INTRODUCTION

1.1 Origin and Solution of the Problem

The Visibility Laboratory was asked by the Air Force Cambridge Research Center to investigate "......portable visibility lights on the basis of information gained in earlier discussions on the subject and on information contained in the enclosed copy of Section I-A-3, Problem 2, of the document Air Weather Service Requirements for Research and Development." The investigation culminated in the construction of breadboard models of two alternative systems, either of which fulfilled the numerous verbal and written Air Force requirements, and a field trial of these breadboards at the Headquarters of the Air Weather Service, Scott Air Force Base, Illinois. As a result of that trial the Air Weather Service expressed its preference for the type of system described in this report. Development was immediately stopped on the discarded system (which involved flashing lamps) and concentrated on improving the components of the preferred system. The resulting prototype, which is soon to be tested by personnel of the Air Force Cambridge Research Center, constitutes the subject of this report.

1.2 Technical Background and Requirements

The subject of meteorological observations of visibility at night has a long history and more technical complexity than is usually appreciated. A concise but comprehensive and authoritative account is given by W.E.K. Middleton in his book "Vision through the Atmosphere"

(Toronto Press, 1952). In the interest of brevity in this report it will be assumed that the reader has carefully read pages 218 through 224 of of that book.

The desires of the Air Force were explored by conversations with representatives of the Headquarters of the Air Weather Service at Scott Air Force Base, Illinois, with officers at the Headquarters of the Air Research and Development Command, and with personnel at the Air Force Cambridge Research Center. The portable visibility lights must be a battery operated system for use at dispersal and other tactical bases where adequate night visibility check-points are not available. A key requirement is that the system must be "foreshortened" or "compressed" in such a manner that all of the components can be mounted within the easily accessible confines of the base, preferably near the runway or some easily traveled road or path. Specifically, it must not be necessary to mount a light five miles from the observer in order to ascertain that the visibility is five miles; in the words of Section I-A-3, Problem 2, of the document Air Weather Service Requirements for Research and Development, "lights should be visible at a distance of at least three miles when the visibility is ten miles." A compressed system similar to the one described in this report can be made to fulfill this dimension exactly, but it was found that a more practical compromise for Air Force use is produced if a unit 2.5 miles from the observer is just visible when the visibility is ten miles; a similar unit 2.0 miles from the observer will then be just visible when "the visibility" is 5 miles, etc. This slightly revised scale of compression was acceptable to the Air Weather Service.

Other requirements. Other stated requirements for the system include:

(1) that the distant lights operate unattended for at least two days;

(2) that the system operate under all weather conditions including rain, snow and temperature from -50° to $+120^{\circ}$F;

(3) that the units be small, light, and completely portable;

(4) that the color of the lights be white, amber, or red in that order of preference;

(5) that the batteries be readily obtainable through normal supply channels;

(6) that rechargeable batteries be considered;

(7) that accurate alignment of the distant units should be unnecessary;

(8) that a nomogram for converting detection distance of the lights to visibility should be provided.

The system described in this report fulfills all of these requirements.

1.3 Brief Description of the System

The system of portable visibility lights preferred by the Air Weather Service and described in this report consists of three parts:

(1) a battery operated searchlight, shown in Figure 5;

(2) a series of reflectors of the retro-directive type shown in Figures 8 and 9 located at selected distances from the searchlight;

(3) a human observer, equipped with a battery operated viewbox to control his visual adaptation, stationed near the searchlight. Figures 1, 2 and 3 show the viewbox.

Figure 13 is a nomograph which shows the distance of the reflector from the searchlight which will cause it to appear at threshold for any specified degree of atmospheric clarity, i.e., visibility. Thus, each user of the system is free to select the particular values of visibility of importance to his own operation and to place his reflectors at the appropriate distances. There is almost no fundamental upper limit to the number of reflectors which can be employed if a searchlight of sufficient beam spread is used; thus visibility can be measured in finely divided steps if desired, or in gross intervals when this is preferable. Rows of reflectors can, if desired, be mounted in any available direction toward which the searchlight can be directed. Figure 14 illustrates a recommended reflector arrangement.

Once the reflectors have been placed at the selected distances it is only necessary for the observer to count the number of reflectors he can see through the viewbox in order to determine the prevailing visibility; no calculations, tables, or graphs are required. Thus, if five reflectors are put at distances corresponding to visibilities of ¼, ½, 1, 3, and 5 miles, respectively, and if the observer can see only three of them, the visibility is more than 1 mile and less than 3. If the third reflector appears to be at threshold the visibility is 1 mile.

The searchlight shown in Figure 5 has been carefully designed to produce a narrow, uniform beam in order to conserve battery power and to insure that its light is confined to the direction of the reflectors, and, thereby, does not interfere with the vision of pilots. A major advantage of the searchlight system is that all lighting is under the instantaneous control of the searchlight operator, so that the entire system is dark except when a visibility reading is taken.

2. PRINCIPLES OF THE COMPRESSED SYSTEM

2.1 Introduction

So far as is known by the authors of this report, successful operation of a compressed system of lights for measuring visibility at night has never heretofor been achieved. The reason for this is quite plain: Compression amplifies the effects of several already-serious difficulties inherent in the conventional use of lights at full scale. Several writers on the subject of night visibility measurements have pointed out that conventional (full scale) practice is subject to gross error arising from uncertainties in the effective intensities (candlepower) of available lights and uncertainty about the adaptive state of the observer's eyes. Middleton,* for example, in commenting on a suggestion attributed to C. A. Douglas that a searchlight and retrodirective reflectors be used to minimize the uncertainties in the intensity of separate lamps observes that this ".... does nothing to remedy the most serious defect of such observations, namely the uncertainty about the threshold illuminance necessary for the observer to be able to see the distant light." Middleton's Figure 10.4,** lifted from H. W. Rose, shows that the nighttime outdoor adaptation luminance at military airports varies by more than 3000:1 and that the total range of luminance levels

---

* W.E.K. Middleton, "Vision through the Atmosphere," (Toronto Press, 1952) Page 218, bottom paragraph.

** IBID. Page 223. Note: 1 apostilb = 1 meter lambert = $1/\pi$ candles per sq. meter; thus, 1 foot-lambert = 10.76 apostilbs.

which confronts the observer when he leaves his brightly lighted office to estimate the prevailing visibility exceeds 300,000:1, corresponding to an uncertainty of more than 500:1 in the threshold illuminance necessary for him to detect distant lights. This dilemma makes conventional (full scale) procedure for estimating visibility at night, at best, a highly imprecise determination. The existing practice is ordinarily condoned, however, because of the necessity for averaging over various directions of view, allowing for the patchiness of fog and haze, and layering effects. In reporting climatalogical visibility at night, i.e., equivalent daylight visibility, it has become the common instrumental practice to specify that horizontal distance (V_5) through an optically homogeneous atmosphere for which the transmittance of a beam of light is 5 per cent.* This corresponds in practice to the detection range of lamps ranging from 2 to 100 candles, depending upon the state of adaptation of the observer's eyes.

Disturbing though the adaptation dilemma may be in the case of conventional (full scale) practice, the uncertainty grows to exceed acceptance when the system is compressed, i.e., when lamps of lesser intensity are used at short distances, for the effect of the atmosphere is drastically reduced. For example, in an atmosphere in which a horizontal path five miles long has a transmittance of 5 per cent, a path two miles long has a transmittance of 30 per cent. Thus, the effect of the atmosphere in reducing the apparent intensity of the light is decreased from a factor of 20 in the case of a full scale system

---

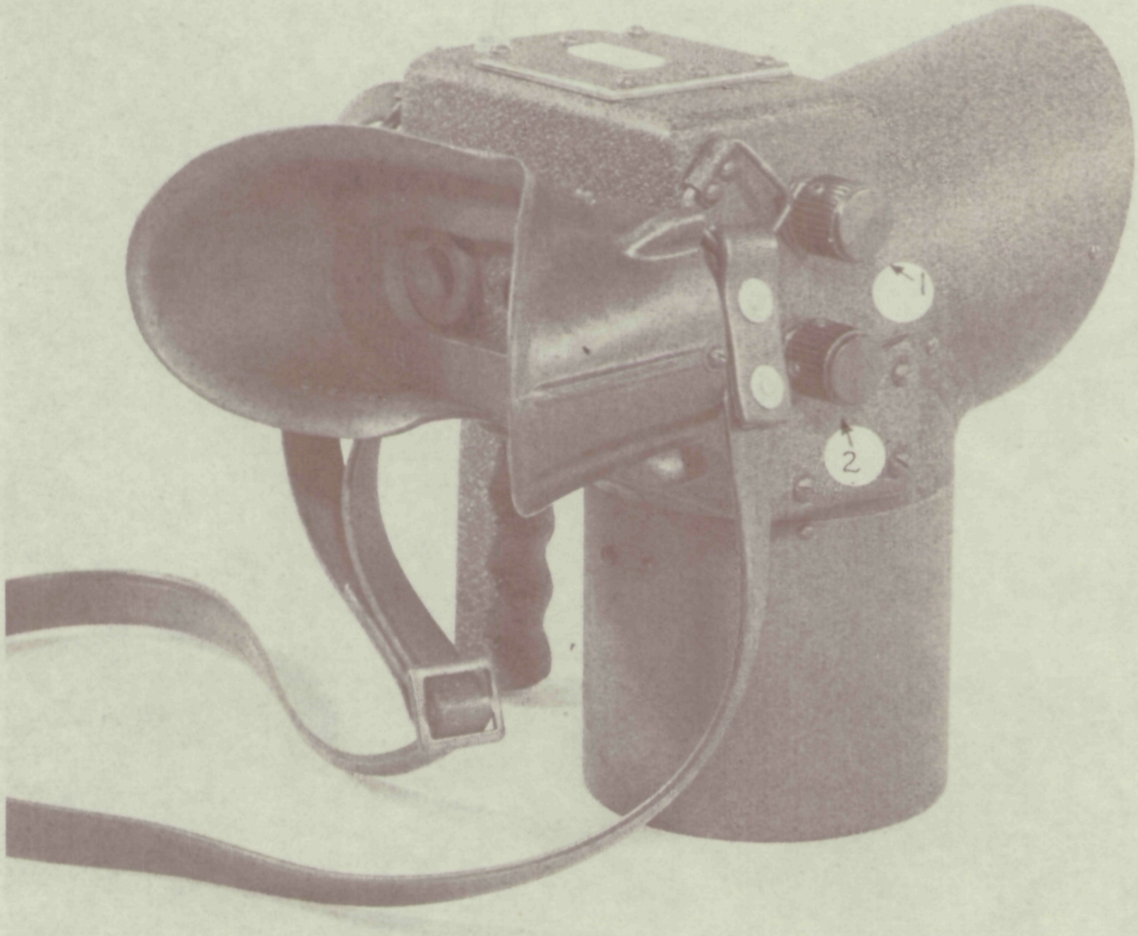
* C.A. Douglas, "Development of a Transmissometer for Determining Visual Range," U.S. Department of Commerce, Tech. Development Rpt. No. 47, February 1945.

to a factor of 3.3 for the compressed system. It is not surprising, therefore, that compressed systems of night visibility lights have not previously been adopted.

2.2 CONTROL OF OBSERVER ADAPTATION

When the Air Weather Service requirement for a contracted system of portable visibility lights was discussed at the Visibility Laboratory, Dr. John H. Taylor proposed the introduction of adaptation control as a solution to the precision problem. This concept, applicable to full-scale and contracted systems alike but essential to the practical success of the latter, has been embodied in the viewbox depicted in Figures 1, 2, 3, 4. It superimposes upon the outdoor scene a uniformly bright field of sufficient luminance to produce an adaptation of 1 foot-lambert, a luminance level to which the eye achieves a stable state of adaptation very quickly even under extreme circumstances.

Structure of the Viewbox. Figures 1, 2, and 3 are photographs of the viewbox from various angles and Figure 4 is a schematic representation of its internal structure. The viewbox consists of a sealed housing containing an inclined glass plate (beam splitter) which superimposes upon the field of view light from a uniformly bright translucent diffuser illuminated by a lamp in the lower, whitened cavity of the instrument. This added luminance fixes the adaptation of the observer at 1 foot-lambert after the necessary photometric adjustments have been made in the manner described below. Binocular viewing virtually without parallax on nearby

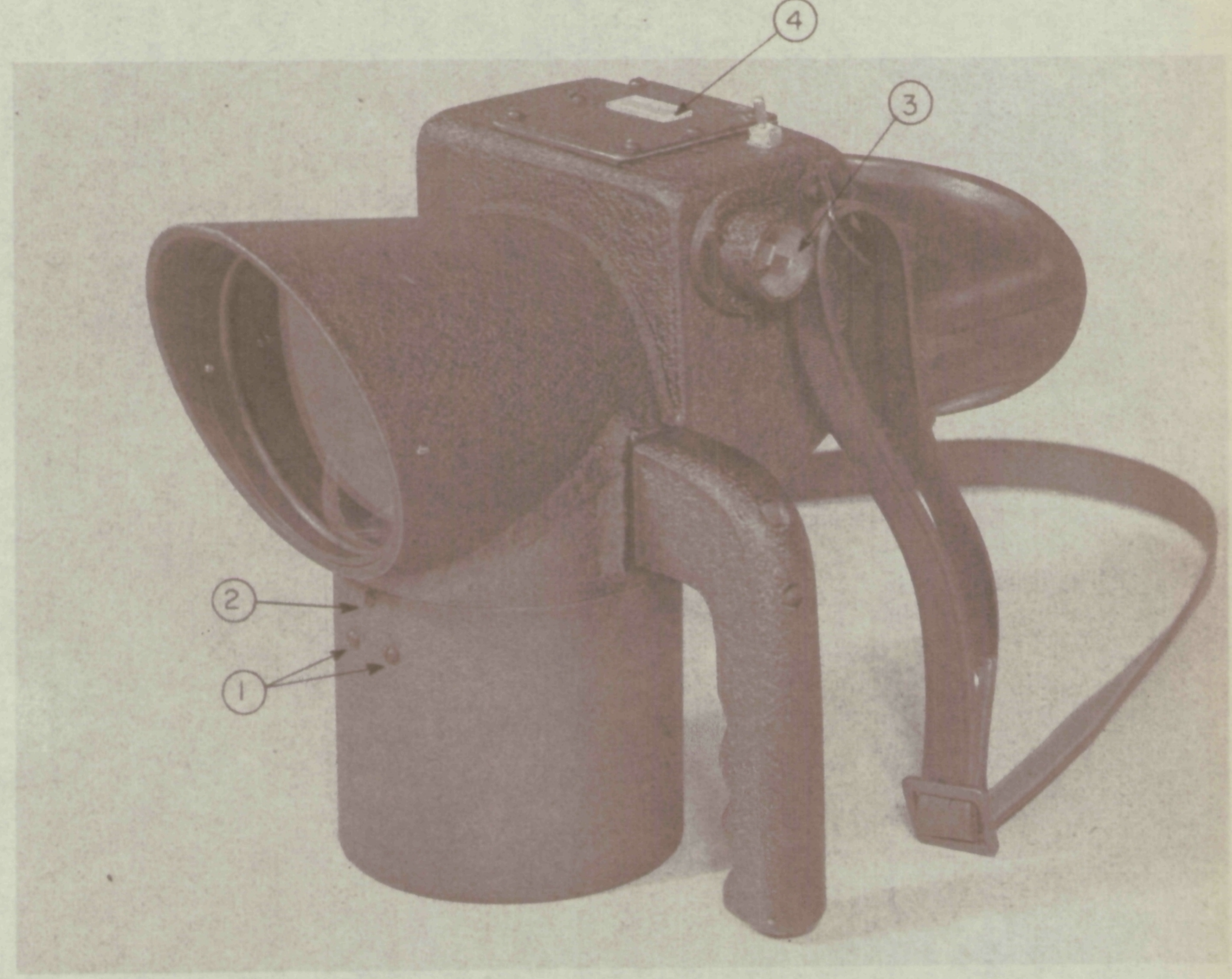


PORTABLE VISIBILITY LIGHTS VIEW BOX

(Right Side View)

1. Control rheostat for the comparison photometric field
2. Control rheostat for the uniform light source

Figure No. 1



PORTABLE VISIBILITY LIGHTS VIEW BOX
(Left Side View)

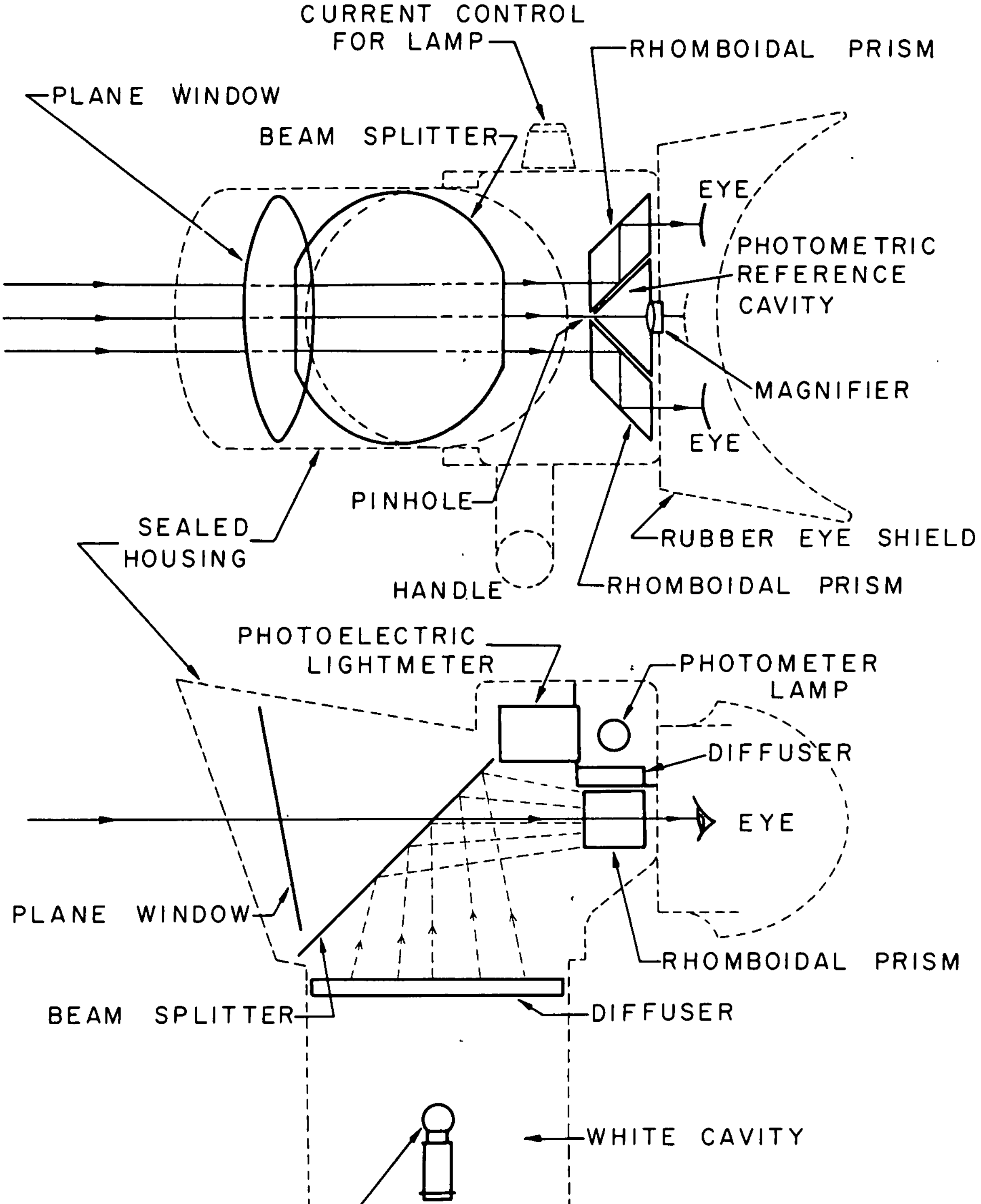
1. Do not remove these screws
2. One of three screws to be removed for replacing lower lamp
3. Power receptical
4. Light meter window

Figure No. 2

PORTABLE VISIBILITY LIGHTS VIEW BOX

1. Power switch
2. Remove screws for access to light meter and reference lamp

Figure No. 3



SCHEMATIC OF VIEW BOX

FIGURE 4

SIO - 60 - 16

objects is achieved by means of a pair of rhomboidal prisms; this feature will be appreciated by observers who wish to use some nearby mark (a flashlight, for example) to indicate the precise direction of the reflector nearest threshold.

Power for the lamp in the lower cavity is provided by the same storage battery used for the searchlight.* The power cord from this battery plugs into the receptacle in the upper left corner of the viewbox, as shown in Figures 2 and 3. Control of the lamp in the lower cavity is by means of the lower of two rheostat knobs located on the right side of the instrument. The proper setting of this control is made possible by means of the built-in photometer described in the following paragraph.

Between the rhomboidal prisms is a whitened, hollow, triangular prismatic cavity having a pin-hole at the center of its apex edge and a magnifier (lens) in the middle of its rear face. If the observer looks at the pinhole through the magnifier he sees the combined luminance of the external scene and the adapting field provided by the lower illuminated diffuser. The cavity surface which surrounds the pinhole provides a photometric field, the brightness of which is determined by the output of a small lamp at the top of the instrument. This lamp, also powered from the searchlight battery, is controlled by the upper rheostat knob on the right side of the viewbox.

---

* A separate battery pack could, of course, be used if desired. The total power required by the viewbox is 0.42 amperes at 12 volts or 5 watts.

A miniature photoelectric light meter is used to monitor this lamp and its scale may be read through a window in the top of the viewbox.

Operation of the Viewbox. The viewbox is intended to be carried by the observer when he goes out doors to make the visibility observations; both a neckstrap and a carrying handle have been provided with this in mind.* After turning on the searchlight the observer will plug the power cord into the receptacle on the left side of the viewbox and station himself on or beside a nearby marker established by the ground layout, as described in section 3.9 of this report. The power switch on the viewbox is then turned on and the upper rheostat knob adjusted until the needle on the meter of the photoelectric monitor, visible through the window in the top of the viewbox, is between the two dots. The observer then directs the viewbox toward the scene illuminated by the searchlight and looks through the central (lens) aperture of the box at the pinhole. He adjusts the lower rheostat knob on the right side of the viewbox until the luminance of the pinhole matches that of the surrounding comparison field. This completes the photometric setting of the adapting field at a luminance of 1.0 foot-lamberts, and the viewbox is ready for use.

A test was made to determine the precision with which this 1 foot-lambert value of adapting field could be set into the instrument by using the internal calibration procedure described above. Three operators

---

* A standard tripod-mounting socket has also been provided for use if desired, but it is recommended that the viewbox be kept indoors except during observations.

each made a series of calibrations and the value of the luminance obtained by each calibration was measured with a Macbeth Illuminometer. The coefficient of variation of the luminance determinations was ± 12 per cent. An error of 12 per cent in the setting of the luminance would produce an error of about 3 per cent in the estimation of V_5 in the worst situation ($V_5 = 5$ miles).

The observer then looks through the viewbox at the scene and counts the number of reflectors which he can see. This count yields the visibility directly. If the reflectors are spaced as recommended by Figure 14, the reflectors represent visibilities of $\frac{1}{4}$, $\frac{1}{2}$, 1, 3, and 5 statute miles respectively.

Primary Calibration of the Viewbox. The primary photometric calibration of the viewbox is not done in the field. At the factory, however, or at an Air Force repair facility it can be accomplished in a completely darkened room with the aid of a Macbeth Illuminometer as a luminance reference. The illuminometer is adjusted to have an internal luminance of one (1) foot-lambert. The adaptation field luminance in the viewbox is then adjusted by means of the lower rheostat until a photometric match is obtained between it and the illuminometer with the latter looking into the viewbox through either of the two eye-ports. This procedure establishes the luminance of the adaptating field at one foot-lambert.

It is next necessary to match the luminance of the photometric reference cavity to that of the adapting field. This is accomplished by looking through the central eye-port and adjusting the luminance of the portion of the reference cavity surrounding the small (1 mm) pinhole at the apex of the cavity by means of the upper rheostat.

If the color temperatures of the two illuminated fields are not sufficiently close it may not be possible to obtain a valid luminance match between them. This usually indicates that the lamp illuminating the reference cavity is being operated at the wrong temperature. To compensate for this, neutral density gelatin filters are placed on top of the diffusing plastic between the lamp and the reference cavity. The effect of changing these filters is to require the lamp to be operated at a higher or lower intensity in order to compensate for the change in attenuation of the filter. The concomitant change in color temperature of the lamp may permit the necessary match. In the event that this procedure fails to produce the desired match, the introduction of one of the Wratten photometric filters at the same position in the instrument should produce this result. In performing the primary calibration at the Visibility Laboratory it was necessary to introduce a Wratten CC 20 G filter between the lamp in the lower cavity and the diffuser in order to correct for selective reflectance of the beam splitter. With the aid of this color correcting filter it was possible to obtain a good photometric match between the Macbeth Illuminometer and the adaptation field. It was also necessary to insert a CC 10 G between the photometer lamp and the diffuser at the top of the reference cavity in order to obtain the required color balance between the reference and adaptation fields.

When the proper combination of filters is obtained they should be cemented in place by a small amount of adhesive such as household cement (e.g., Duco, Glyptal, etc.) at the corners of the filter.

The next step is the adjustment of the sensitivity of the small light meter located at the top of the viewbox. This must be carefully done without disturbing the adjustment of the upper rheostat, for this meter is the "memory" device that provides calibration for the previously described routine field adjustments.

First it is necessary to note how far the needle deflection is from the midpoint of the two dots on the meter scale. The cover plate and gasket at the top of the instrument may then be removed by removing the six retaining screws. The light meter can then be carefully lifted out with the fingers and the "zero set" (small screw on the rear side of meter) adjusted. Next, replace the meter in the viewbox making certain that it is properly seated in the recess and, holding the cover in place, note if the "zero set" was adjusted sufficiently to bring the needle within two dots on the meter scale. If not, it will be necessary to repeat the above process until the needle falls midway between the two dots. After adjustment the cover plate and gasket are secured with the six screws and the calibration is completed.

2.3 ILLUMINATION OF THE REFLECTORS

A battery-operated, narrow-beam, portable searchlight is used to illuminate all of the reflectors simultaneously. A Crouse-Hinds model DCE 12 (Serial No. 44253) Incandescant Searchlight has been slightly modified, as described below, to produce a two-degree beam of nearly a million candle power when powered by three 12-volt automobile-type storage batteries connected in series.

Four modifications of the factory model were made:

(a) A GE No. 1238 miniature lamp with a double contact bayonet base was installed;

(b) a switch and current control for the lamp was mounted externally on the searchlight;

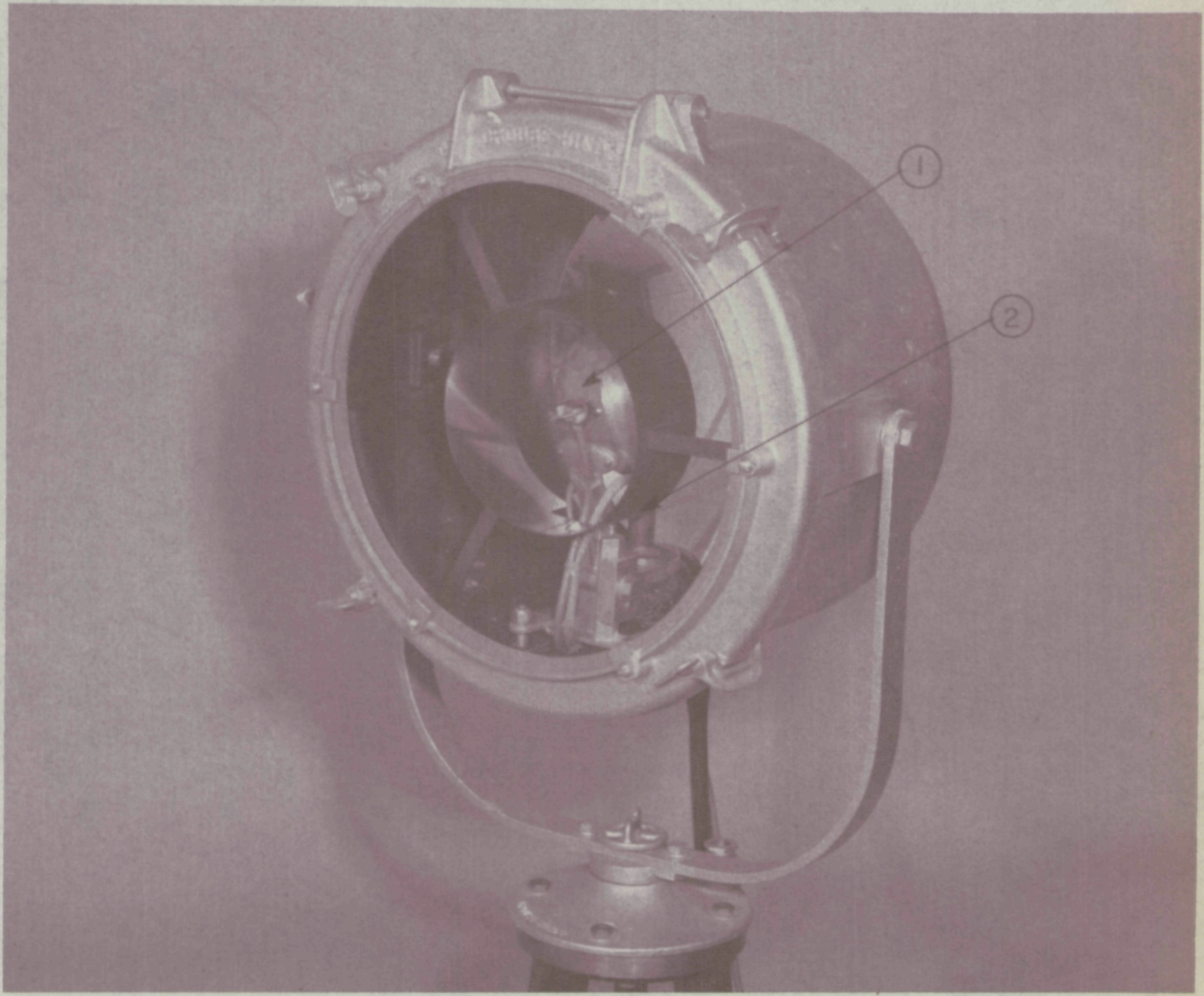
(c) a small hole was made in the secondary mirror and an International Rectifier DP2 photocell was mounted to receive the light passing through this pinhole; and

(d) A sealed microammeter was mounted externally on the searchlight and connected to the DP2 photocell; this meter reads 10 microamperes when the lamp is operating at the light output for which the system is designed.

Figure 5 is a photograph of the searchlight.

Optical and Photometric Characteristics of Incandescent Searchlights

The incandescent searchlight utilizes a parabolic mirror to image the lamp filament at an infinite distance. The emitted ray bundle from a point of the filament on the optical axis is rendered parallel (collimated) to the optical axis upon reflection. The lamp filament, however, is of a finite size and ray bundles emitted from off-axis points of the filament will leave the parabolic mirror at an angle



INCANDESCENT SEARCHLIGHT

1. DP2 Monitor Photocell
2. Modified Lamp Base

Figure No. 5

with the optical axis. The beam will therefore exhibit a divergence or spread. The distribution of the light flux within this beam will not be uniform, however, due to several factors, including: (1) the basic optical aberrations of parabolic reflectors; (2) the variation of the actual mirror surface from a true parabolic surface; (3) the fact that the filament is not spherical in all directions, and (4) the variation of flux output over the length and width of the lamp filament. When all these factors combine, a distribution of light flux can be seen to have a general bell-shaped appearance. If the intensity of the beam is plotted against the angular position from the optical axis a curve known as the beam characteristic of the searchlight is generated. This characteristic may be improved and smoothed by the addition of a concave spherical secondary mirror in front of the lamp so as to reflect the light flux eminating from the front of the filament back to the parabolic mirror and hence to an infinite distance. The secondary mirror ordinarily images the filament on itself, i.e., the filament is at the radius of curvature of the concave mirror. Figure 6 is a plot of the beam characteristic measured in a horizontal direction of the searchlight used in this system. The characteristic width depends largely on the shape of the filament. The characteristic (in the above case) is smaller in width in the vertical direction by a factor of 2/3. The searchlight beam must be properly directed if the reflector array occupies the maximum permissible spread. This will be discussed again in Section 3.8.

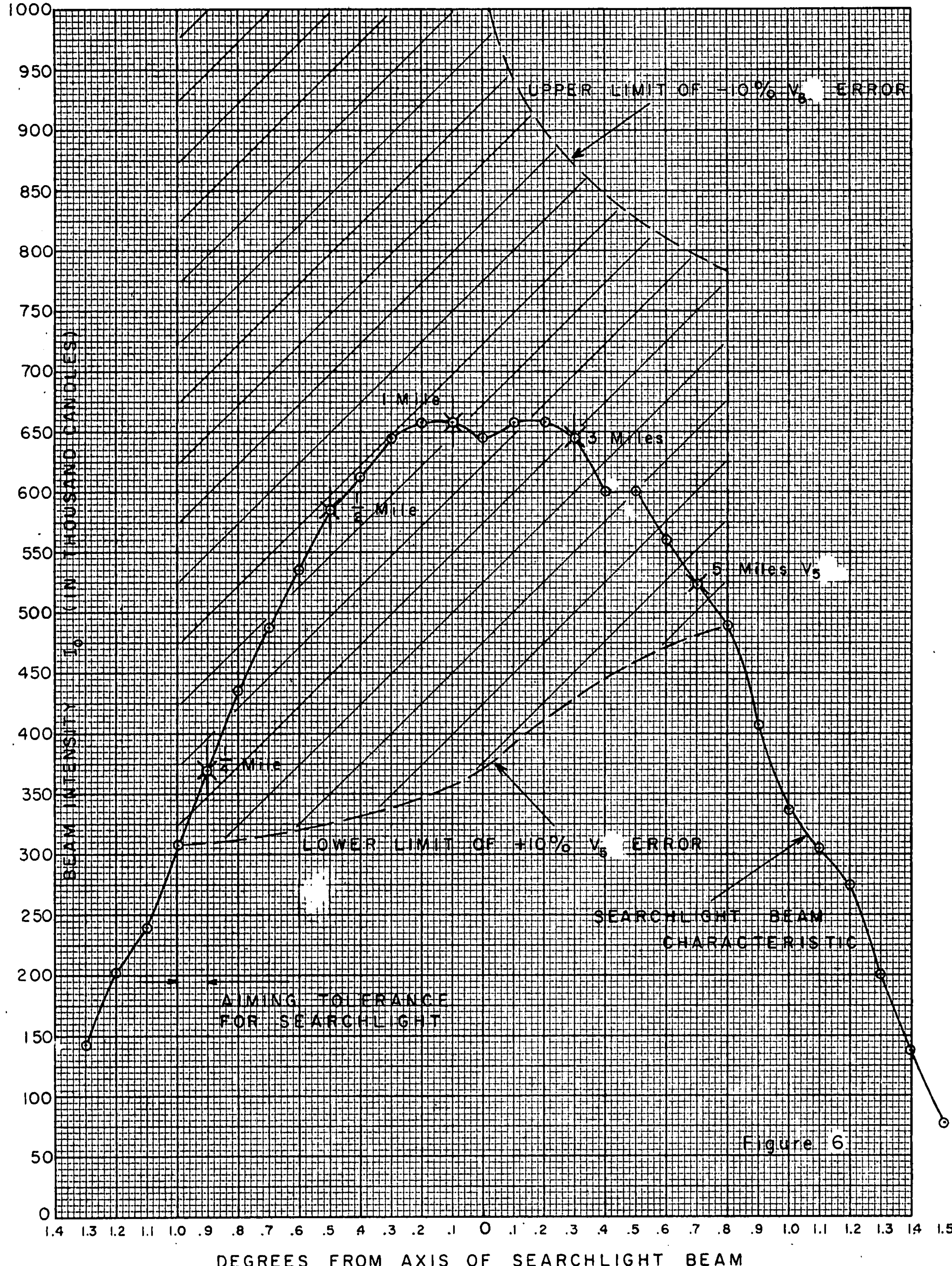
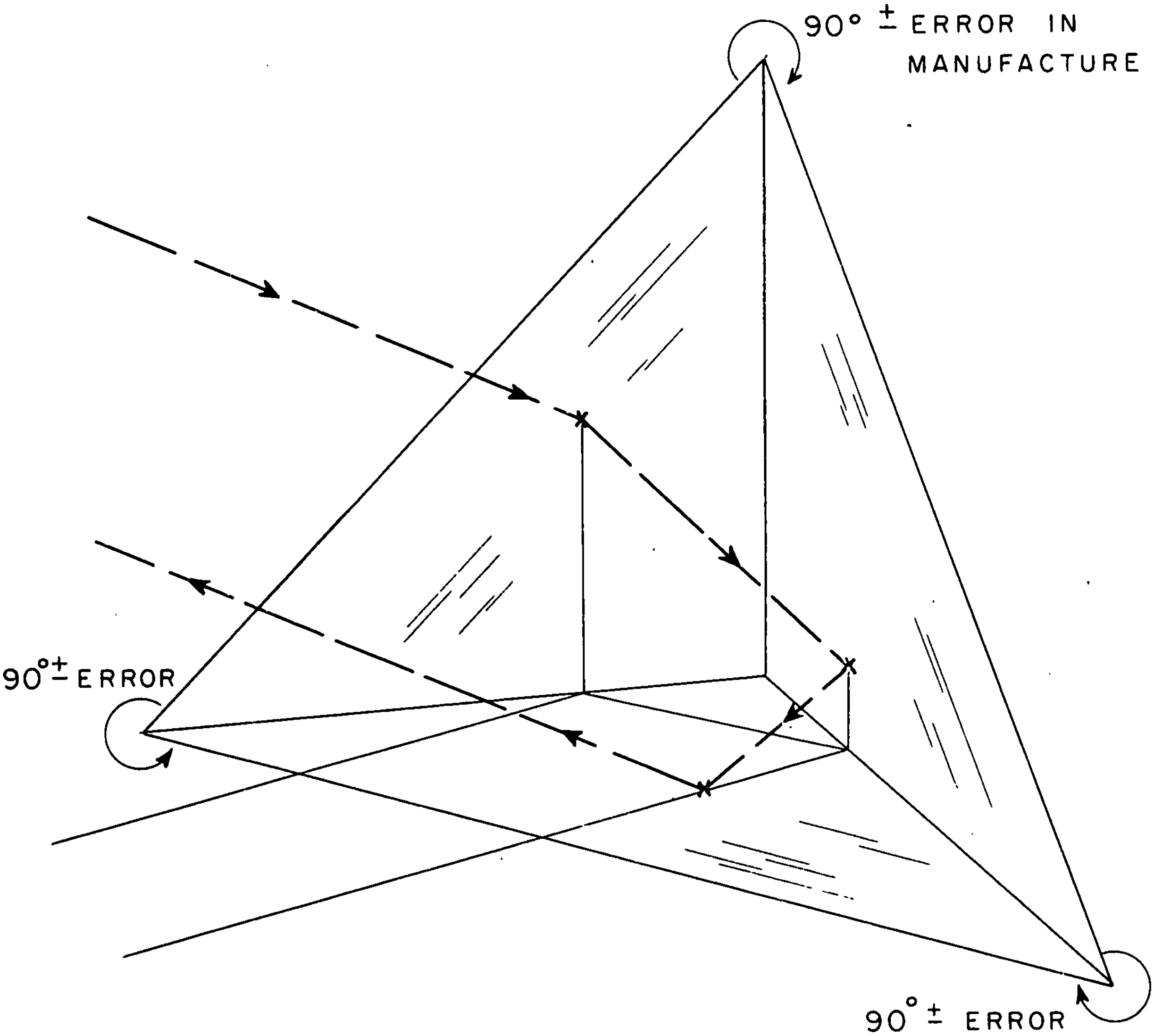

1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
BEAM INTENSITY I₀ (IN THOUSAND CANDLES)
UPPER LIMIT OF -10% V₅ ERROR
1 Mile
3 Miles
1/2 Mile
5 Miles V₅
1/4 Mile
LOWER LIMIT OF +10% V₅ ERROR
SEARCHLIGHT BEAM CHARACTERISTIC
AIMING TOLERANCE FOR SEARCHLIGHT
1.4 1.3 1.2 1.1 1.0 .9 .8 .7 .6 .5 .4 .3 .2 .1 0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4 1.5
DEGREES FROM AXIS OF SEARCHLIGHT BEAM

Figure 6

2.4 REFLECTORS

In principle it would be possible to use plane mirrors located at selected distances from the searchlight to return the light to the observer. Insurmountable difficulties preclude this, however, for the alignment and rigidity-of-mounting requirements are impracticable. The retrodirective reflector, originated by Fizeau in 1849 for use in the measurement of light velocity between distant stations, eliminates these difficulties. The best retrodirective reflector is the corner-cube type (sometimes called a triple-mirror) consisting of three mutually perpendicular plane reflecting surfaces, as illustrated by Figure 7. It possesses the property that any ray of light which is successively reflected from all three surfaces is exactly reversed in direction. Any light beam is, therefore, returned toits source regardless of whether or not the source is directly in front of the reflector. No alignment or rigidity-of-mounting problems are encountered with these reflectors.

Retrodirective reflectors designed for use at short range are commonly employed in roadside signs, as highway obstruction markers, and for many other purposes. These units are inexpensive and readily available but they fail to redirect the light with sufficient accuracy for use at long distances. Long-range retrodirective systems have traditionally required costly precision glass prisms in order to achieve reasonable reflector efficiency. The expense of such prisms would be prohibitive for the portable visibility light application. During 1959, however, new moulded plastic retrodirective reflectors of high

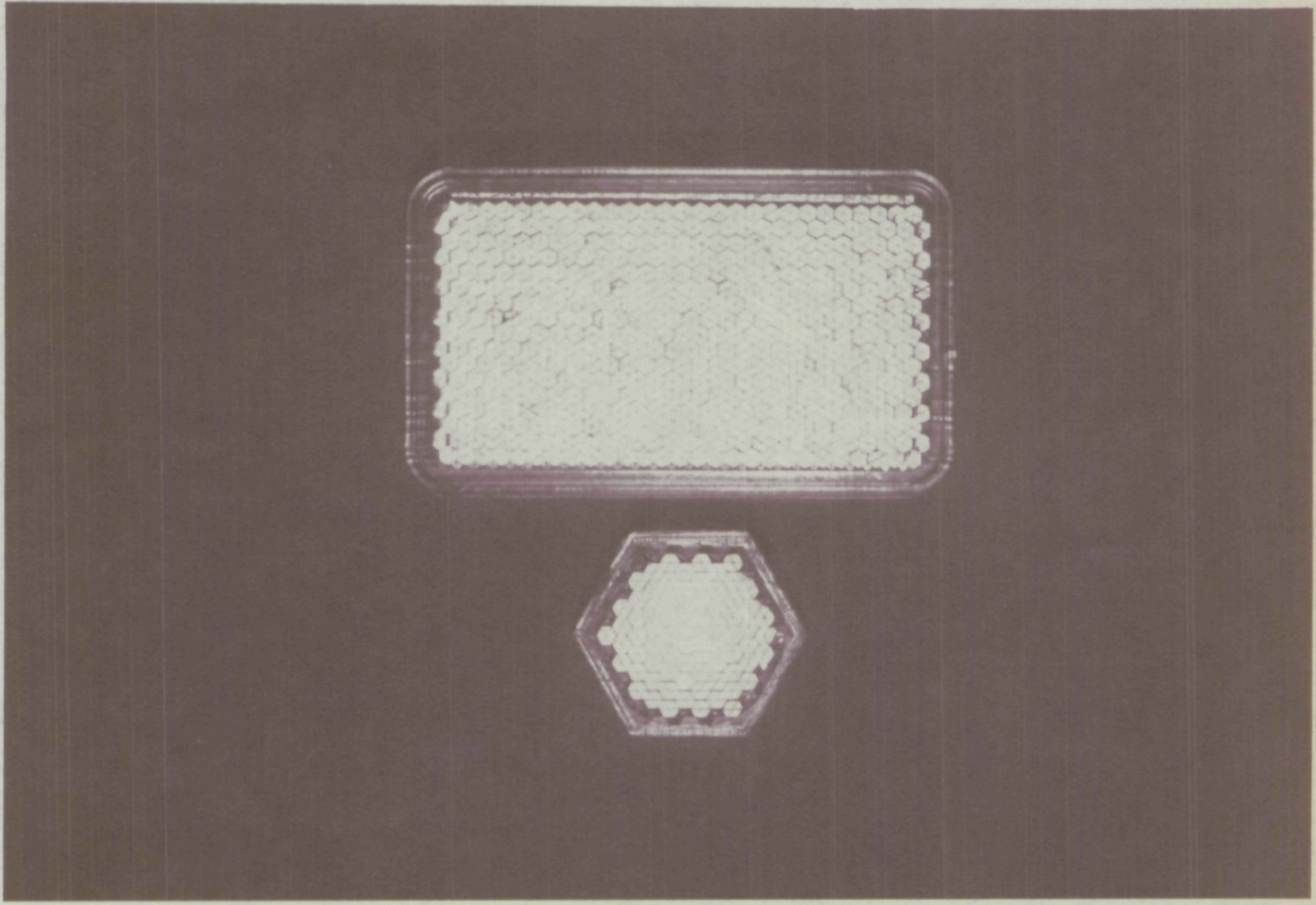


LIGHT RAY PATH THROUGH A RETRO-DIRECTIVE REFLECTOR

Figure 7

efficiency were produced on an experimental production basis by the Stimsonite Division of the Elastic Stop Nut Corporation of America. The Stimsonite No. 21 reflector, hereinafter called the "rectangular reflector," was used in the early trials of the portable visibility light system and a cluster of 19 of these units is specified for the nearest ($\frac{1}{4}$ mile) reflector in the present design. A new experimental reflector having more than five times the efficiency of the rectangular reflectors was made late in 1959 by Stimsonite and the first production lot of these new units were delivered during March 1960. Clusters of 103 of these small units are specified for use at each of the more distant locations. The new reflectors are made in hexagonal shape and bear the manufacturer's catalog number FOS-3051. They will be referred to throughout the remainder of this report as "hexagonal reflectors." Figure 8 is a photograph of the rectangular and hexagonal Stimsonite moulded plastic retrodirective reflectors. It should be emphasized that the portable visibility light system described in this report would not have been economically practicable prior to the very recent development of the new rectangular and hexagonal reflectors.

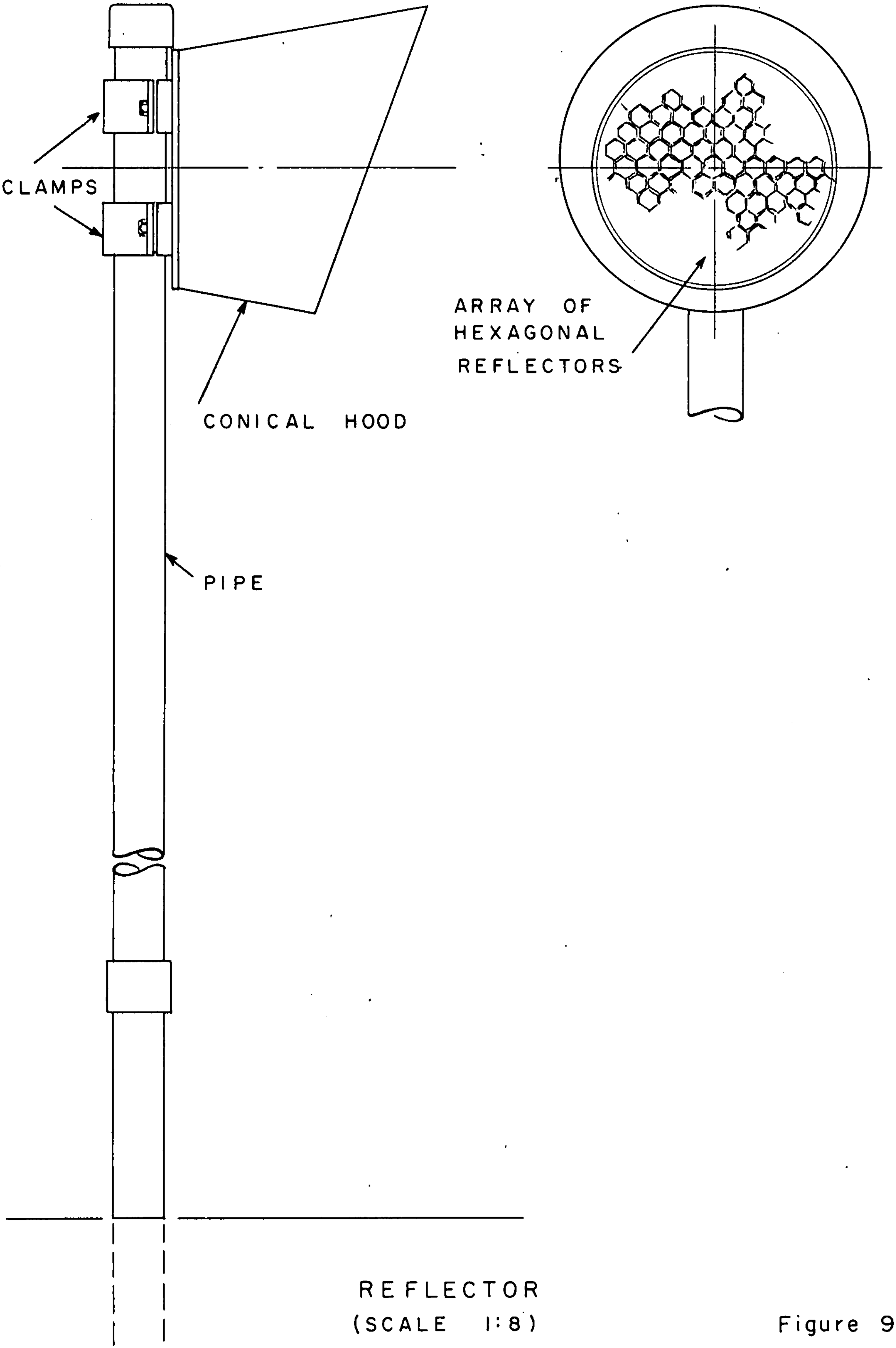
Mounting of the Reflectors. It will be shown in Section 3 of this report that a cluster of 103 hexagonal reflectors must be used at each reflector station, except the "$\frac{1}{4}$ mile" position where 19 of the rectangular reflectors are placed in a duplicate of the mechanical mounting shown in Figure 11. A proposed mounting for such a cluster is shown schematically in Figure 9. Each hexagonal reflector is bonded to a flat



MOULDED PLASTIC RETRODIRECTIVE REFLECTORS.

The "Specific Intensity" on axis of these reflectors is approximately equal.

Fig. 8.



REFLECTOR
(SCALE 1:8)

Figure 9

metal plate which is clamped to a pipe set in the ground. The use of a conical hood is recommended in order to decrease the exposure of the reflectors to the night sky, for it was found in the field trials of the system that fogging of the reflector surfaces by condensed moisture sometimes occurred unless a hood was used. Much less rain, snow, and sleet reaches the surface of a hooded reflector than a fully exposed one. The conical shape of the hood is suggested in the interest of making these units nest for compactness in shipment and to reduce the probability of a decrease in effective area due to the misalignment of the unit with respect to the observer.

3. SYSTEM DESIGN

3.1 Introduction

It has been shown in the preceding discussion of the visual requirements for a compressed system that it is necessary to fix the observer's adaptive state at 1 foot-lambert, and a viewbox for accomplishing this has been described. It remains to set forth the technical basis for the design of the system, including specification of the intensity and beam characteristic of the searchlight, the area of the reflectors, and the required searchlight-to-reflector distances. This will be done in the following paragraphs.

3.2 Visual Requirement

When the normal human observer is adapted to a uniform luminance of 1 foot-lambert, non-intermittent light, a source of small angular size, i.e., a "point" source, will be at the threshold of detectability* if it produces an increment of illuminance of 2.35×10^{-8} foot-candles at the eye of the observer. The visual requirement on the searchlight-and-reflector system is, therefore, that it produce this illuminance at the position of the observer despite the transmission loss imposed by the atmosphere.

3.3 Measurement of Atmospheric Transmittance

The transmittance of the atmosphere could, in principle, be measured by means of a series of reflectors placed at known distances from the

---

* Probability of detection is 0.99 if the observer knows exactly where to look and has no time restriction on his observation.

searchlight. By noting the distance of the last detectable reflector, the transmittance of the path traversed by the light could be calculated by means of equations given at the end of this section. This information could, in turn, be converted to any desired form of physical specification, such as transmittance per mile, attenuation coefficient, reciprocal attenuation coefficient, and meteorological range, etc.

Alternatively, reflectors could be placed at distances such that when any given reflector produces threshold ΔE a path of specified length has an arbitrarily selected standard transmittance. If, for example, the third light in the particular system specified in Section 3.9 of this report is visible at the threshold of detection, the transmittance of a path one statute mile in length is 5 per cent. The choice of the criterion value 5 per cent is arbitrary; if a system were designed for a criterion value of $1/e = 0.37$ the threshold distance would be the reciprocal of the attenuation coefficient (often called the attenuation length or mean-free photon path); if a criterion value of 2 per cent were used, the indicated distance would be the meteorological range. The symbols V_5, V_{37}, V_2 are used to denote, respectively, the three distances just described, the subscript indicating the criterion value of atmospheric transmittance upon which the unit is based. The units are, of course, related in size; thus, $V_5 = 3\ V_{37}$, and $V_2 = 3.9\ V_{37}$. All three are physical measures of atmospheric transmittance (T); thus, if the searchlight-to-reflector distance is d,

$$T = \exp(-d/V_{37}) = \exp(-3d/V_5) = \exp(-3.9d/V_2).$$

3.4 Measurement of Visibility

Visibility as used in meteorology is not precisely defined in physical terms, but operational definitions are given which, of necessity, are different for night observations than for day conditions. For climatological purposes it is desirable to report a single number (a distance) descriptive of the atmosphere without regard to day or night but which correlates with some important visual performance capability by day and some different but equally important visual performance capability at night. Thus, day observations are reported in terms of large dark objects seen against the horizon sky and night observations ordinarily make use of any available distant lights. As stated earlier, it is assumed that the reader of this report has carefully read pages 218 through 224 of Middleton's book "Vision through the Atmosphere" wherein it is related that several investigators have sought a correlation between physical measure of atmospheric transmission and meteorological observations. The general conclusion from these studies is that, for apparently inescapable practical reasons, visibility observation is not a precise art and no truly accurate correlation with physical measures of atmospheric clarity is possible. Nevertheless, different agencies have used V_2, V_3, V_5, and $V_{5.5}$ for this purpose; the best choice depends upon the use to be made of the data. In the system described in Part 3 of this report V_5 has been used in the belief that it will correlate best with existing practice at most Air Force Bases.

3.5 The Visual Range of Lights at Night

If the intensity of a given light in the direction of the observer is known and if the atmospheric clarity is specified in physical terms, the horizontal visual detection range of the light can be calculated from the visual threshold data. A nomographic alignment chart was constructed during 1944 under the supervision of one of the authors of this report and published on page 129 in Volume II of the Summary Technical Report of N.D.R.C. Division 16 (Columbia University, 1946). The same nomograph was republished by Middleton on page 139 of his book "Vision through the Atmosphere" (Toronto Press, 1952) after displacing the (logarithmic) intensity scale on the right boundary of the chart by a factor of 2 in order to shift the probability of detection to 95 per cent in accordance with a suggestion by S. Q. Duntley. This chart, however, embodies certain undesirable algebraic approximations which lead to serious errors in some circumstances. Its use should be discontinued.

A new chart has recently been prepared by the Visibility Laboratory which contains no approximations and produces valid visual ranges; it supercedes the earlier nomograph described in the preceding paragraph. The new chart is included as Figure 10 of this report. It should be noted that the value of atmospheric clarity called for on the left vertical scale is meteorological range (V_2). The distance V_5 determined by means of the portable visibility lights can be converted to V_2 by means of the relation $V_2 = 1.3 V_5$.

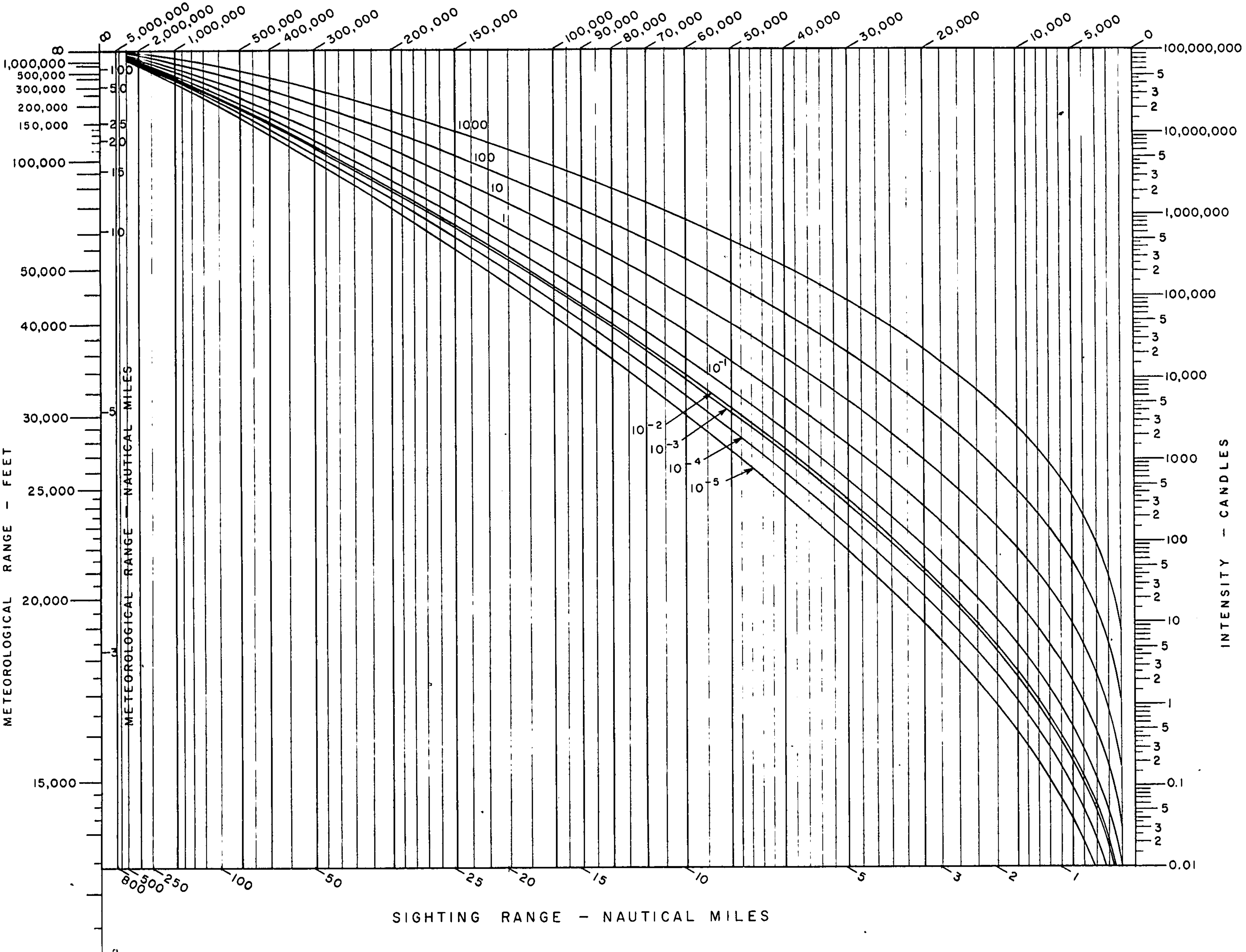

∞
5,000,000
2,000,000
1,000,000
500,000
400,000
300,000
200,000
150,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
5,000
0
∞
1,000,000
500,000
300,000
200,000
150,000
100,000
50,000
40,000
30,000
25,000
20,000
15,000
METEOROLOGICAL RANGE - FEET
100
50
25
20
15
10
5
3
METEOROLOGICAL RANGE - NAUTICAL MILES
1000
100
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
100,000,000
10,000,000
1,000,000
100,000
10,000
1000
100
10
1
0.1
0.01
5
3
2
INTENSITY - CANDLES
800
500
250
100
50
25
20
15
10
5
3
2
1
SIGHTING RANGE - NAUTICAL MILES

FIG. 10

To use the nomograph, connect the appropriate value of V_2 on the left vertical scale with the intensity of the lamp on the right scale by means of a straight line. Find the intersection of this line with the curve marked with the adaptation level (in foot-lamberts) of the observer's eyes and proceed vertically to the visual detection range (sighting range) of the lamp. Detection probability in the absence of search is 0.95 for this nomograph.

Example: If V_2 = 15,000 feet a lamp of intensity 20 candles is visually detectable at 12,000 feet when the adaptation luminance is 10^{-1} foot-lamberts.

3.6 Design Principles

It was shown in Section 3.2 that the visual requirement on the search-reflector combination is that it produce an increment of illuminance $\Delta E = 2.35 \times 10^{-8}$ foot-candles at the eye of the observer. No diffuse reflector would be sufficiently efficient to produce this increment if used with a small incandescent searchlight, but because of a close analytic analogy between the retrodirective reflector and the diffuse reflector it is interesting to write the equations for the diffuser first and later to modify them to allow for the special characteristics of retrodirective reflectors.

Diffuse Reflectors. Assume a small, perfect, plane diffuse reflector having reflectance R and area A to be centered on and perpendicular to the axis of a searchlight at distance d. The illuminance E on the diffuse reflector due to a searchlight of intensity I at distance d is IT/d^2 if the transmittance of the atmosphere for the searchlight beam is T. The luminance of the reflector in the direction of the searchlight is $B = ER/\pi$, and its intensity is BA. The increment of illuminance ΔE on the eye of an observer stationed at or near the searchlight is, therefore, BA/d^2. Combining these relationships,

$$\Delta E = IT^2 (R/\pi) A/d^4 \qquad (1)$$

Equation (1) neglects the contribution to the illuminance at the eye by light scattered from the searchlight beam by the atmosphere. Hulburt[*] has discussed this effect and has showed that it can be minimized by separation of the observer from the searchlight. Since the magnitude of the scattered light depends upon the state of the atmosphere in a somewhat different way than does the beam transmittance under measurement it is desirable to minimize the scattering effect sufficiently to render equation (1) a sufficient approximation. This was accomplished in the final system described in Section 3.7 by stationing the observer 10 feet from the searchlight.

Retrodirective Reflectors. If a triple-mirror type of retrodirective reflector could be made mechanically perfect it would direct all of the light from the searchlight precisely back into the searchlight again, except for the effect of diffraction.

---

[*] E. O. Hulburt, "Optics of Searchlight Illumination," J. Opt. Soc. Am. 36, 483 (1946)

The individual triple-mirror elements which comprise both the hexagonal and the rectangular Stimsonite reflectors have an inscribed diameter of approximately 2 millimeters. Acting alone, one of these tiny elements would produce a diffraction pattern 2 meters in diameter at 4000 meters. Partial coherence between the reflections from adjacent triple-mirror elements might reduce the size of this diffraction pattern, but this is not important because any mechanically perfect retrodirective reflector would be of no use in the portable visibility light system since it is important to separate the observer from the searchlight by the order of 10 feet in order to minimize the effect of scattering from the nearby searchlight beam.

Fortunately, imperfections in manufacture always introduce minute angular misalignments of the reflecting surfaces of a retrodirective reflector which separate the single incident beam into six beams emergent from the reflector. These beams may emerge in virtually any direction, including coincidence. If a number of retrodirective reflectors are assembled as a mosaic array, the approximate random distribution of the beams will integrate into a cone of light flux directed back toward the source but of greater divergence than the cone from a mechanically perfect reflector. The greater efficiency of the hexagonal reflectors is due to the fact that their divergence is less than that of the rectangular reflectors.

Reflector Efficiency. The cone of light emanating from the array of hexagonal or rectangular reflectors is not uniform, but depends upon direction. For a mosaic array of individual reflectors there is, however, radial symmetry, and the reflected intensity can be specified in terms of the divergence angle a; this is the angle between the axis of the reflector and the observer's line of sight. Equation (1) can be adapted for use with retrodirective reflectors by replacing R/π in equation (1) by C_a, a dimensionless measure of reflector efficiency usually called "specific brightness" by the reflector manufacturers and often stated in units of candles/(foot-candle x square inches).* It is interesting to note that whereas R/π for a diffuse reflector cannot exceed 0.32, the maximum value of C_a for the hexagonal retrodirective reflector is 13,450 candles/(foot-candles x square feet). This is a factor of gain of 42,300 over a diffuse reflector of equal size. Figures 11 and 12 are plots of measured values of C_a vs a for the rectangular and hexagonal Stimsonite reflectors, respectively.

It will be noted that the measured value of C_a at a divergence angle $a = 0.1$ degrees is 14.9 for the rectangular reflector and 74 for the hexagonal reflector. The latter is, therefore, 74/14.9 or 5.0 times more efficient as a reflector than the former at this divergence angle. Except in the case of the "$\frac{1}{4}$ mile" unit all of the reflectors

---

* The Visibility Laboratory would prefer the use of the units candles/(foot-candle x square feet) for C_a but in deference to commercial practice Figures 13 and 14 have been plotted in terms of candles/(foot-candle x square inches). Manufacturers sometimes give the product C_aA which they call specific intensity and state in units of "candles per foot-candle."

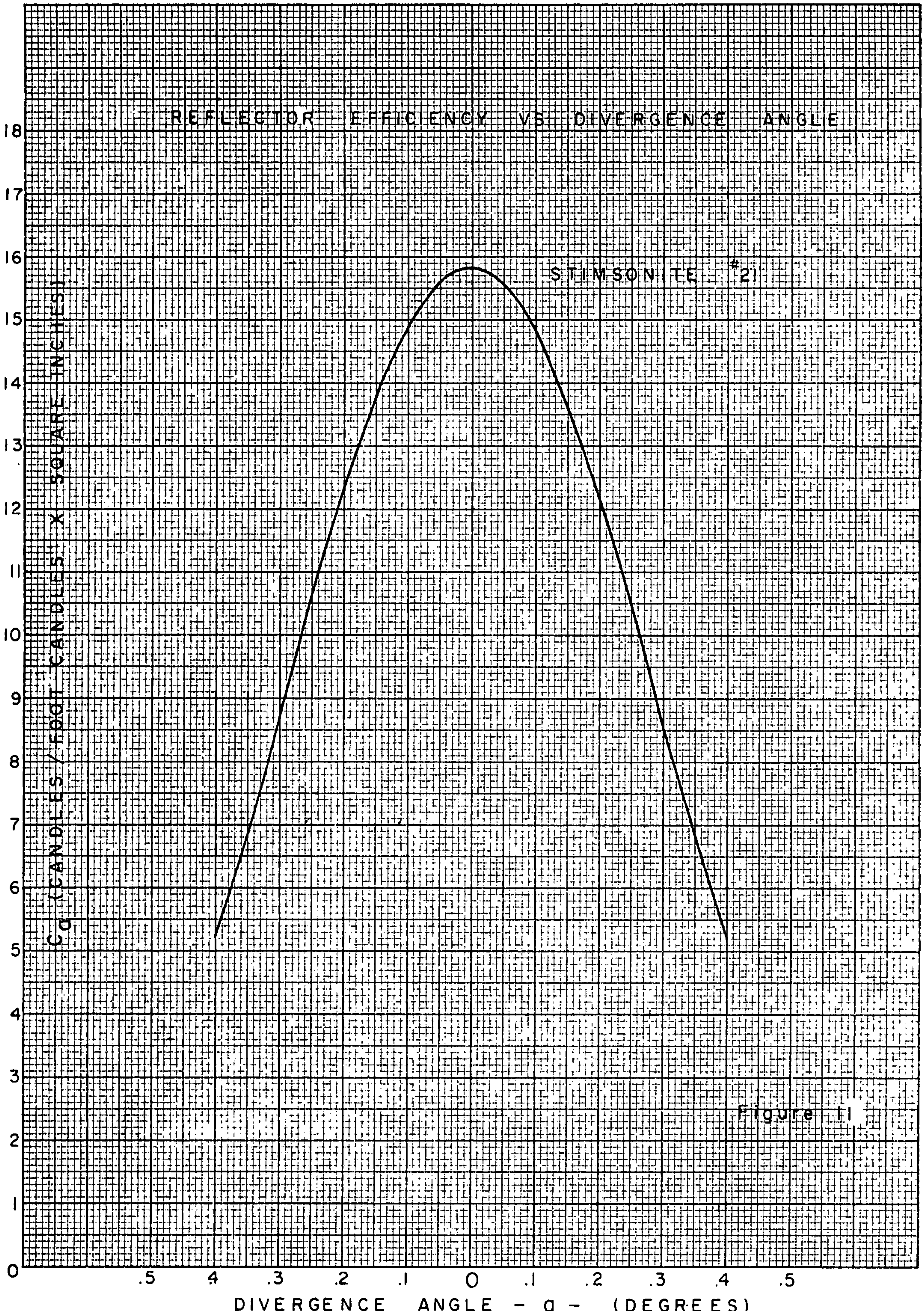
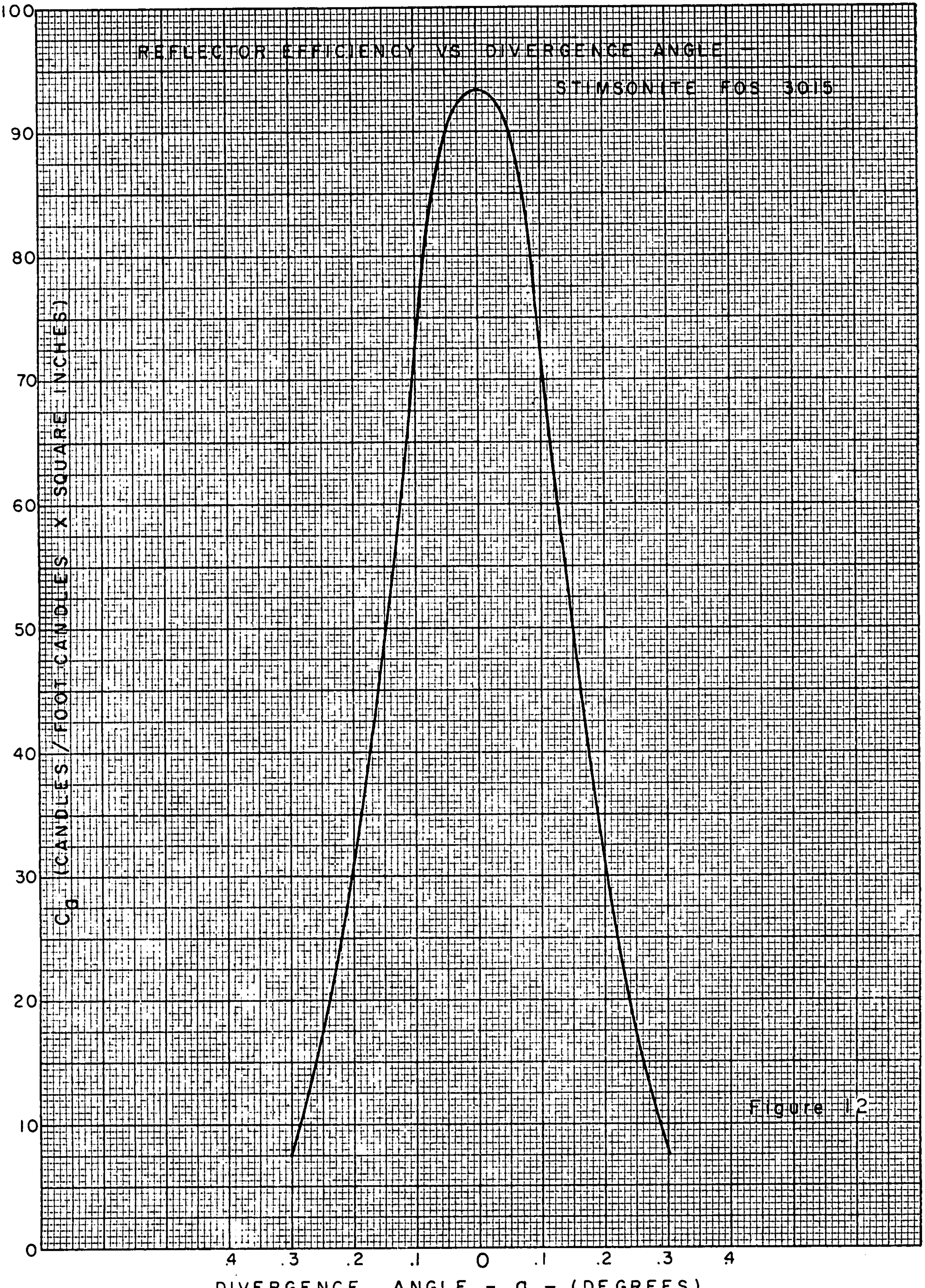

REFLECTOR EFFICIENCY VS DIVERGENCE ANGLE
STIMSONITE #21
C_a (CANDLES / FOOT CANDLES X SQUARE INCHES)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
DIVERGENCE ANGLE - a - (DEGREES)

Figure 11



REFLECTOR EFFICIENCY VS DIVERGENCE ANGLE — STIMSONITE FOS 3015

Figure 12

in the portable visibility light system are of the hexagonal type since these have higher efficiency at the divergence angles employed. In the case of the "¼ mile" reflector, however, the required divergence angle is so large that the rectangular units must be used.

In terms of C_a equation (1) for the increment of illuminance at the eye is

$$\Delta E = IT^2 C_a A/d^4 \tag{2}$$

The five reflectors in the portable visibility light system are used at divergence angles of 0.054°, 0.082°, 0.122°, 0.199°, and 0.356°, respectively, in the system layouts shown in Section 3.9. The manufacturer's data did not include data for divergence angles less than 0.1 degree, and it was necessary, therefore, to measure the efficiency of the reflector at the smaller angles. This was accomplished in the laboratory by means of a beam-splitter, utmost care being exercised to minimize any effect due to scattering in this optical element. Considerable uncertainty in this work was inevitable because only one sample of the hexagonal reflector was available, and this showed pronounced orientation effects. Four orientations of the single hexagonal reflector were measured and averaged, but measurement of an assembled array of reflectors would have been a more accurate procedure; unfortunately the production lot of hexagonal reflectors was received too late for an array to be assembled and measured for the purposes of this report. It is recommended that full-scale efficiency measurements be made on an array of hexagonal reflectors when one of these units has been completed.

It was found that within the range of divergence angles of interest, the efficiency data on both the rectangular and the hexagonal reflectors could be fitted as well by a simple gaussian-type curve as by any non-analytic curve. Such a representation of the data facilitates the system design and, therefore, the curve of reflector efficiency C_a vs a shown in Figure 11 for the rectangular reflector is a plot of the equation

$$C_a = 15.9 \exp(-6.90\ a^2)$$

In the case of the hexagonal reflectors, the efficiency data are best fitted by using different numerical constants above and below a = 0.11 degrees. Thus, the curve of reflector efficiency C_a vs a for the hexagonal reflectors shown in Figure 12 is a plot of the equations

$$C_a = 92.74 \exp(-28.25a^2) \text{ when } a > 0.11^\circ$$

and

$$C_a = 93.40 \exp(-23.90a^2) \text{ when } a \leq 0.11^\circ.$$

When these expressions are substituted in equation (2) the effective area A of the reflector must be in <u>square inches</u> . The small divergence angle a may be expressed in terms of the searchlight-to-reflector distance d and the searchlight-to-observer distance s by means of the relation a = 57.3 s/d (degrees).

Angular Spacing of the Reflectors. Studies of the effect of nearby bright ("glare") sources on visual thresholds indicate that the angular spacing of the reflectors as seen by the observer should not be less than 0.4 degrees. At narrower spacings there is a danger that a reflector which should be visible at or near threshold will not be seen due to the presence of the nearer, more intense reflectors.

The searchlight used in the portable visibility light system and described in Section 2.3 has a useful beam spread of 1.8 degrees. Thus it is suitable for a 5-reflector system with an angular spacing of 0.4 degrees.

3.7 Calculation of Reflector Area

The design principles described in the preceding section must be combined to produce the design of a portable visibility system. Analytic relations for reflector efficiency C_a, atmospheric transmittance T for the path d in terms of visibility V_5 (i.e., $T = \exp(-3d/V_5)$, and divergence angle a can be combined with equation (2); thus

$$\Delta E = \pi^{-\frac{1}{2}} Nh \exp(-3.28 \times 10^3 h^2 s^2/d^2)\ IAd^{-4}[\exp(-3d/V_5)]^2, \qquad (3)$$

where N and h are constants.

Equation (3) can be solved for reflector area A. Thus,

$$A = (\pi^{\frac{1}{2}} \Delta E\ d^4/NhI) \exp\ (3.28 \times 10^3 h^2 s^2 d^{-2} + 6.0d/V_5). \qquad (4)$$

The first step in the design of the compressed system of portable visibility lights is to calculate the area A of a mosaic array of hexagonal reflectors which will be just visible at two miles ($d = 2$ miles) when the visibility V_5 is 5 miles. For the hexagonal reflectors,

$Nh/\pi^{\frac{1}{2}} = 93.4$ and $h^2 = 23.9$ when $d \geq 5208$ feet[*].
$\Delta E = 2.35 \times 10^{-8}$ foot-candles; $I = 600{,}000$ candles; $s = 10$ feet; $d = 10{,}560$ feet. When these values are substituted in equation (4) the required area $A = 61.7$ square inches. An array of 103 hexagonal reflectors will have this effective area.

In the interest of mechanical simplicity, identical reflectors are used at the positions corresponding to visibilities of ½, 1, 3, and 5 miles. The high divergence angle at the "¼ mile" position, however, requires the use of the rectangular reflectors. An array of 19 rectangular reflectors can be assembled in the same type of mechanical mounting (shown in Figure 9) as that used for the array of hexagonal reflectors; the effective area of 19 rectangular reflectors is 64.1 square inches and for these units $Nh/\pi^{\frac{1}{2}} = 15.9$ and $h^2 = 6.94$.

3.8 Calculation of Reflector Distances

The scale of the compressed system of portable visibility lights was set in the preceding section by specifying the area of reflector array which will be just visible at 2 miles (10,560 feet) when the visibility $V_5 = 5$ miles. It remains to calculate the distances at which the remaining four reflectors must be placed in order to complete the system. This is done by solving equation (4) for V_5. Thus,

$$V_5 = 6.0d / \left[\ln(NhIA\,\pi^{-\frac{1}{2}} d^{-4}\,\Delta E^{-1}) - 3.28 \times 10^3 h^2 s^2 d^{-2} \right]. \qquad (5)$$

---

[*] The distance $d = 5208$ feet when divergence angle $a = 0.11$ degrees. When $d < 5208$ feet, $Nh/\pi^{\frac{1}{2}} = 92.7$ and $h^2 = 28.25$ for the hexagonal reflectors.

Figure 13 is a plot of equation (5), using the constants given in Section 3.7. The searchlight-to-reflector distances d are read from this graph. The user of the system is free to select any five values of visibility V_5 which suits his requirements.

Choice of Visibility Ranges. For the purposes of the three illustrative ground-layouts given in the following paragraph (Section 3.9), reflector distances corresponding to visibilities (V_5) of 5, 3, 1, ½, and ¼ statute miles were chosen. This choice was made because air-traffic control procedures change at these values of prevailing visibility according to the Manual of Surface Observations (WBAN), Chapter 9, Section 9132.3. The corresponding searchlight-to-reflector distances were read from Figure 13 as 10560, 8520, 4710, 2880, and 1610 feet, respectively.

3.9 Ground Layout

The portable visibility light system described in the preceding sections requires a site, preferably level, two statute miles in length. Three possible layouts for the system are discussed and illustrated in the following paragraphs.

Observer on the ground. The observations of an observer standing on the ground near the threshold of the runway and observing reflectors mounted parallel to the runway may have greater validity with respect to the landing of aircraft than those of observers stationed elsewhere. Figure 14 illustrates a convenient method of laying out the system by means of a straight line 2-miles long. Appropriate offsets perpendicular to this line are indicated to fulfill the requirement that the observer's

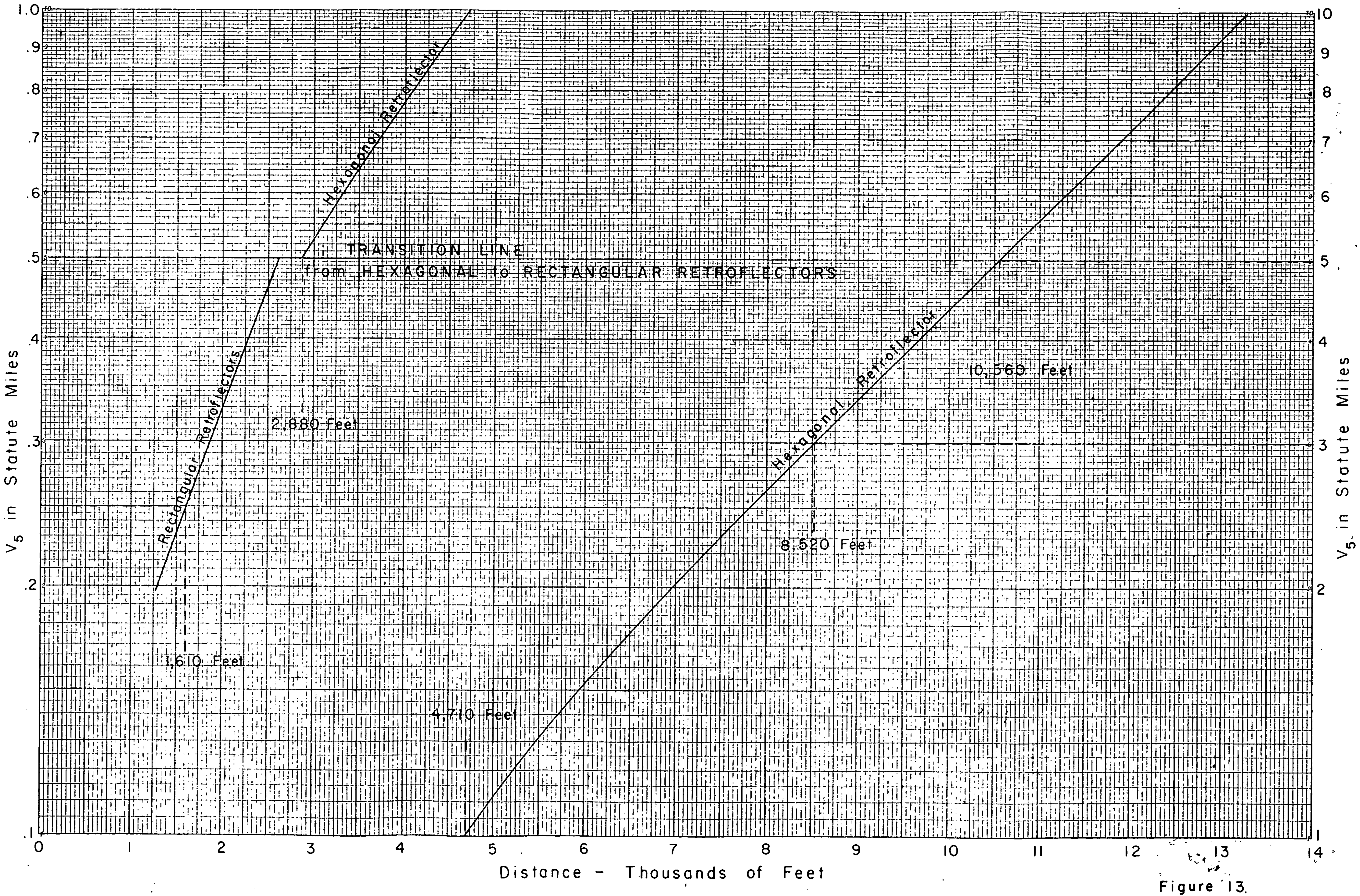
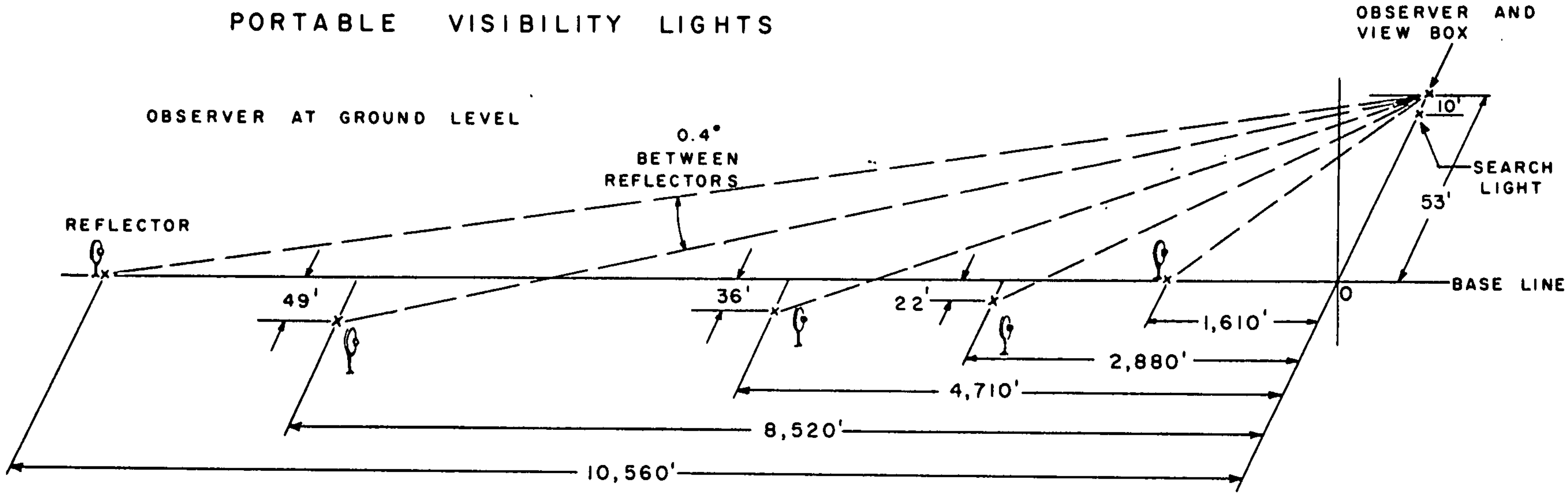

1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10
9
8
7
6
5
4
3
2
1
V_5 in Statute Miles
V_5 in Statute Miles
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Distance – Thousands of Feet
Hexagonal Retroflector
Rectangular Retroflectors
Hexagonal Retroflector
TRANSITION LINE
from HEXAGONAL to RECTANGULAR RETROFLECTORS
2,880 Feet
1,610 Feet
4,710 Feet
8,520 Feet
10,560 Feet

Figure 13

GROUND LAYOUT of PORTABLE VISIBILITY LIGHTS



NOTES: 1. SEARCHLIGHT IS LOCATED 10' FROM OBSERVER TOWARDS POINT "O".
2. SCALES EXAGGERATED FOR CLARITY.

FIGURE 14

lines of sight to the five reflectors be separated by 0.4 degrees. The transverse scale of this drawing is highly exaggerated; there is no significant difference between the length of the lines of sight (dashed lines) and the distances measured along the base line. This horizontal layout is recommended by the Visibility Laboratory in preference to the two alternative plans which follow.

Observer 25 feet above the ground. If the observer uses the viewbox 25 feet above the ground (or at any lower height) no change in the placement of the reflectors is necessary. The proper position of the observer and searchlight is shown in Figure 15.

Observer 53 feet above the ground. If the observer uses the viewbox 53 feet above the ground, he must be stationed directly above the end of the 2-mile base line and somewhat different off-sets must be used in the case of the "½ mile," "1 mile," and "3 mile" reflectors. This is illustrated by Figure 16.

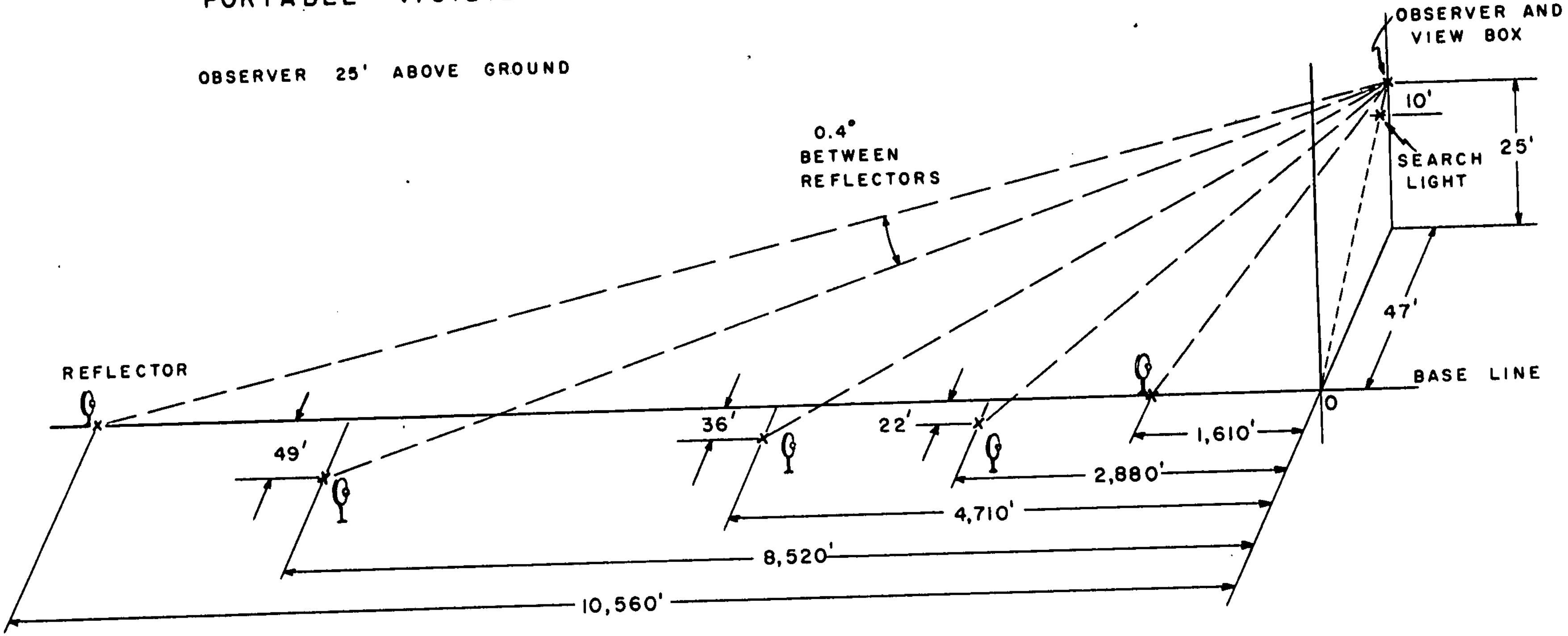
3.10 Adjustment and Maintenance

The searchlight beam is directed at the reflectors when the visibility is greater than five miles and should cover the array of reflectors. The searchlight is then locked and need not be reaimed unless there is cause to doubt its position. Thereafter, only the switch and the rheostat need be operated.

The reflectors after being set on their posts should be adjusted for height so that, to the observer, all five reflectors appear at the same level. The aiming of the reflectors is not critical but they

GROUND LAYOUT of PORTABLE VISIBILITY LIGHTS

OBSERVER 25' ABOVE GROUND

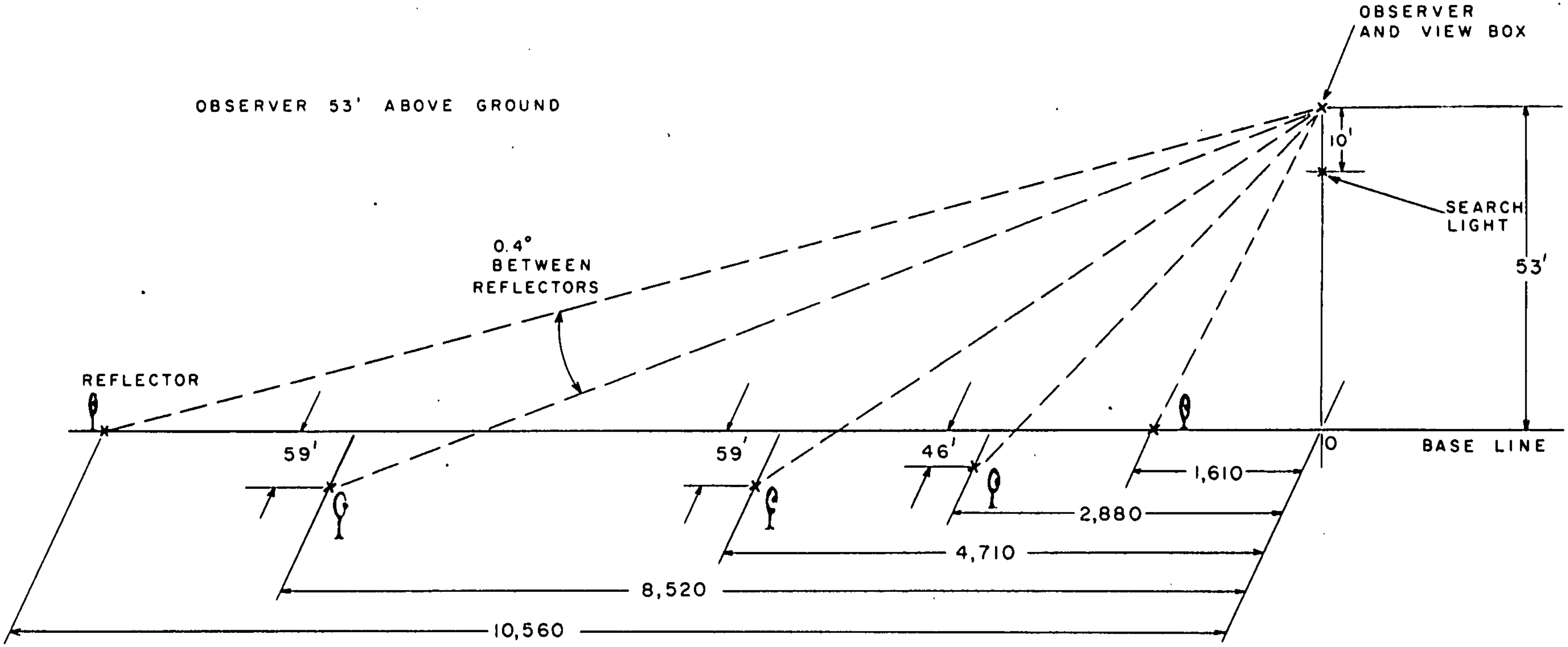


NOTES: 1. SEARCHLIGHT IS LOCATED 10' FROM OBSERVER TOWARDS POINT "O".
2. SCALES EXAGGERATED.

FIGURE 15

SIO - 60 - 16

GROUND LAYOUT of
PORTABLE VISIBILITY LIGHTS



NOTES: 1. SEARCHLIGHT IS LOCATED 10' BELOW OBSERVER TOWARDS POINT "O"
2. SCALES EXAGGERATED FOR CLARITY.

FIGURE 16

should be directed perpendicular to the searchlight beam within ± 15° due to the protection hood. The reflectors should be cleaned periodically, perhaps once a week, and a de-fogging compound such as the Stock* R-51 BuAer-XAE-101-8 wiped on at the time of cleaning. If dirt and dust is allowed to accumulate on these reflectors the observation errors will increase. (See Figure 19)

Replacement of Parts. Under normal usage the only parts in need of periodic replacement will be the lamps. The searchlight lamp will require replacement most often, the viewbox lamps very seldom. The GE No. 1238 searchlight lamps are operated at 3.4 amperes, a value slightly below their nominal rating. They should be replaced after 120 to 150 hours of operation at 3.4 amperes. The standard directions given by the Crouse-Hinds Company for adjustment of the searchlight lamp should be followed when the lamp is replaced.

Access to lamps in the viewbox can be seen in Figures 2 and 3. The automobile-type storage batteries should be charged whenever necessary, usually after the equivalent of about 20 hours of continuous operation. Need for recharging can be easily determined by observing the response of the meter when the searchlight is turned to full power: If the indicator points to 10.3 microamperes, the time for recharging is approaching.

If it is assumed that about 5 minutes operation is required for each set of observations and that, on the average, 12 sets of observations will be made each night, the equipment will accumulate one hour's operation a day.

It may be safe to assume, therefore, that the batteries will require recharging about every 20 days and the lamp will need replacing every 4 to 5 months.

3.11 Tolerances

The absolute accuracy of night visibility observations made in accordance with present standard practice is very poor. Attention is again invited to Middleton's "Vision through the Atmosphere," pages 218 through 224. The use of a viewbox to anchor the adaptative state of the observer would doubtless greatly improve the accuracy of standard (full scale) observing practice, but no device of this type is known to be in use today. The coefficient of variation of the absolute values obtained by present methods probably exceeds ± 100 per cent, although the reproducibility of the reports given by any given observer at a given station may, at times, be somewhat better than this value.

A better study of the absolute accuracy achievable with the portable visibility light system can be made after proper field tests have been conducted, but the engineering analysis made thus far indicates that it should be an easy matter to achieve a higher level of accuracy than that of present (full scale) practice. It was decided, in fact, to design the components of the system around a tolerance of ± 10 per cent in visibility V_5. This close tolerance is believed to be eminently practical for an operational system; there seems little doubt that somewhat closer tolerances could be held if required.

Variations in Searchlight Characteristics. Figure 8 shows the beam characteristic of the searchlight prepared for use in the portable visibility light system. Figure 17 has been prepared to show the allowable percentage errors in searchlight intensity for ± 10 per cent errors in V_5. The horizontal axis of this plot is d/V_5, (with both d and V_5 measured in the same units). This is a measure of the compression of the system. It will be noted that $d/V_5 = 1$ represents a full-scale condition; in this case the searchlight intensity may depart by more than ± 42 per cent before a ∓ 10 per cent change in V_5 occurs. In the case of the reflector which corresponds with V_5 = 5 miles, however, the ratio $d/V_5 = 0.40$, and Figure 17 shows that the searchlight intensity must be within ± 19 per cent of the nominal if no error greater than ∓ 10 per cent is to occur in V_5.

The available tolerances in searchlight intensity are illustrated by the cross-hatched area in Figure 8. Obviously, some variability in the searchlight beam characteristic and in aiming can be accepted without exceeding the 10 per cent tolerance limit. It is unnecessary, moreover, to use more than a representative average value of searchlight intensity, such as I = 600,000 candles, in calculating the searchlight-to-reflector distances. If an attempt should be made to operate the portable visibility light system with tolerances closer than ± 10 per cent, allowance should be made for the shape of the beam characteristic. It must be remembered that minor changes in the beam characteristic take place during the aging of the lamp due to sagging of the filament and that lamp replacement or adjustment always alters

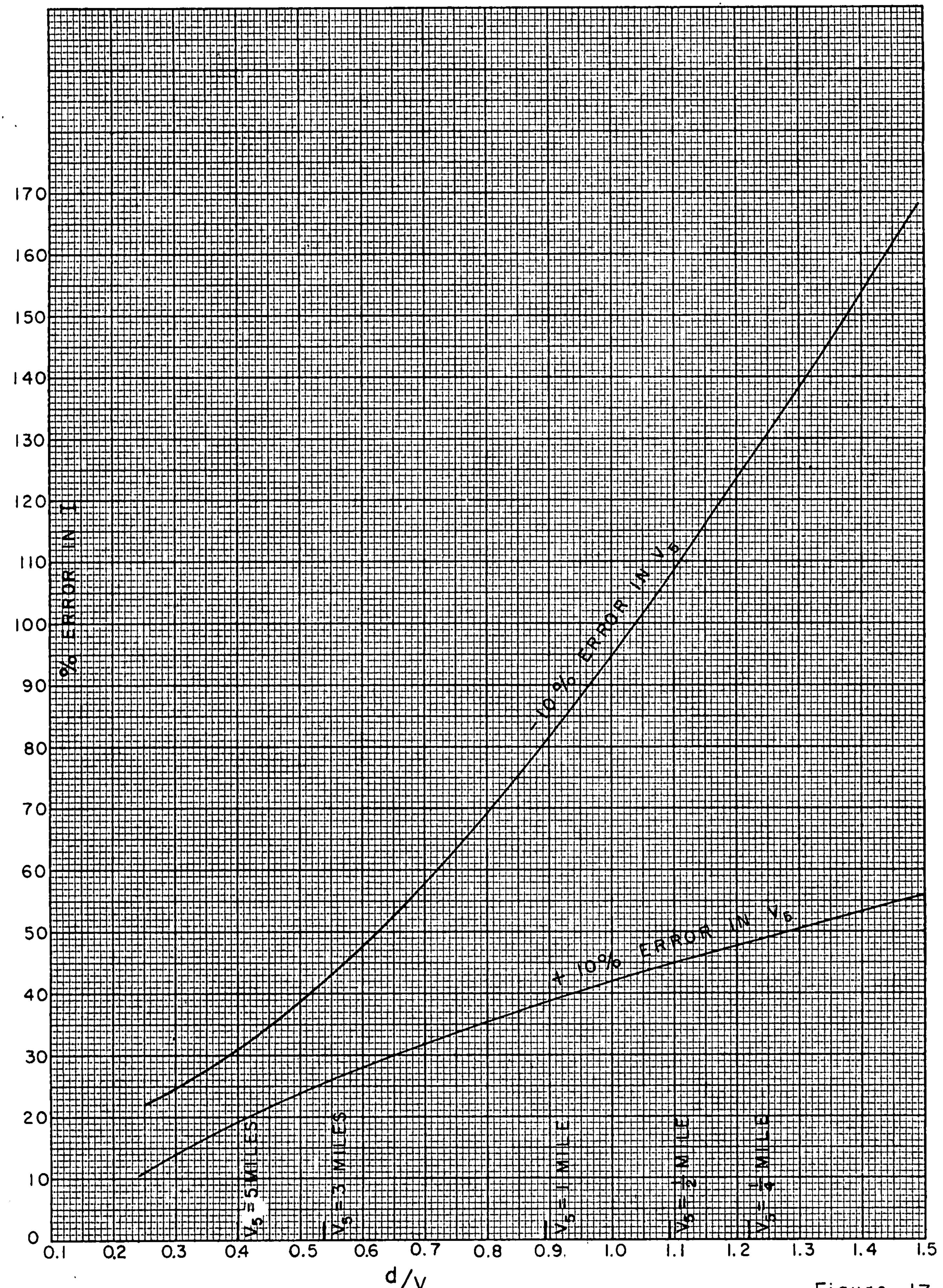

% ERROR IN I
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
d/V5
-10% ERROR IN V5
+10% ERROR IN V5
V5 = 5 MILES
V5 = 3 MILES
V5 = 1 MILE
V5 = 1/2 MILE
V5 = 1/4 MILE

Figure 17

the beam characteristic somewhat. Neither of these effects is likely to be serious within the recommended ± 10 per cent tolerance.

Errors in Layout

Errors in the searchlight-to-reflector distances d will, of course, be reflected as errors in reported visibility V_5. Figure 18 shows the magnitude of error in d which can be accepted without exceeding the ± 10 per cent tolerance in V_5. Even in the most stringent case, at 10560 feet, nearly ± 4 per cent error in d is acceptable. It is obvious, therefore, that high precision surveying techniques are not a critical requirement.

Variations in the Cleanliness of Surfaces. It was mentioned in Section 3.8 that the surfaces of the searchlight and the reflectors should be cleaned periodically and that treatment with an anti-fogging agent may be necessary under some conditions. Measurements on the magnitude of the effect of lack of cleanliness on the reported visibility V_5 are not available but Figure 19 is provided to indicate the computed influence of lowered transmittance of the surfaces.

Fogging of the windows of the viewbox can create a major error. The observer should check on this carefully prior to making his observation. Fogging of the viewbox should not be a problem if it is kept indoors between observational sorties.

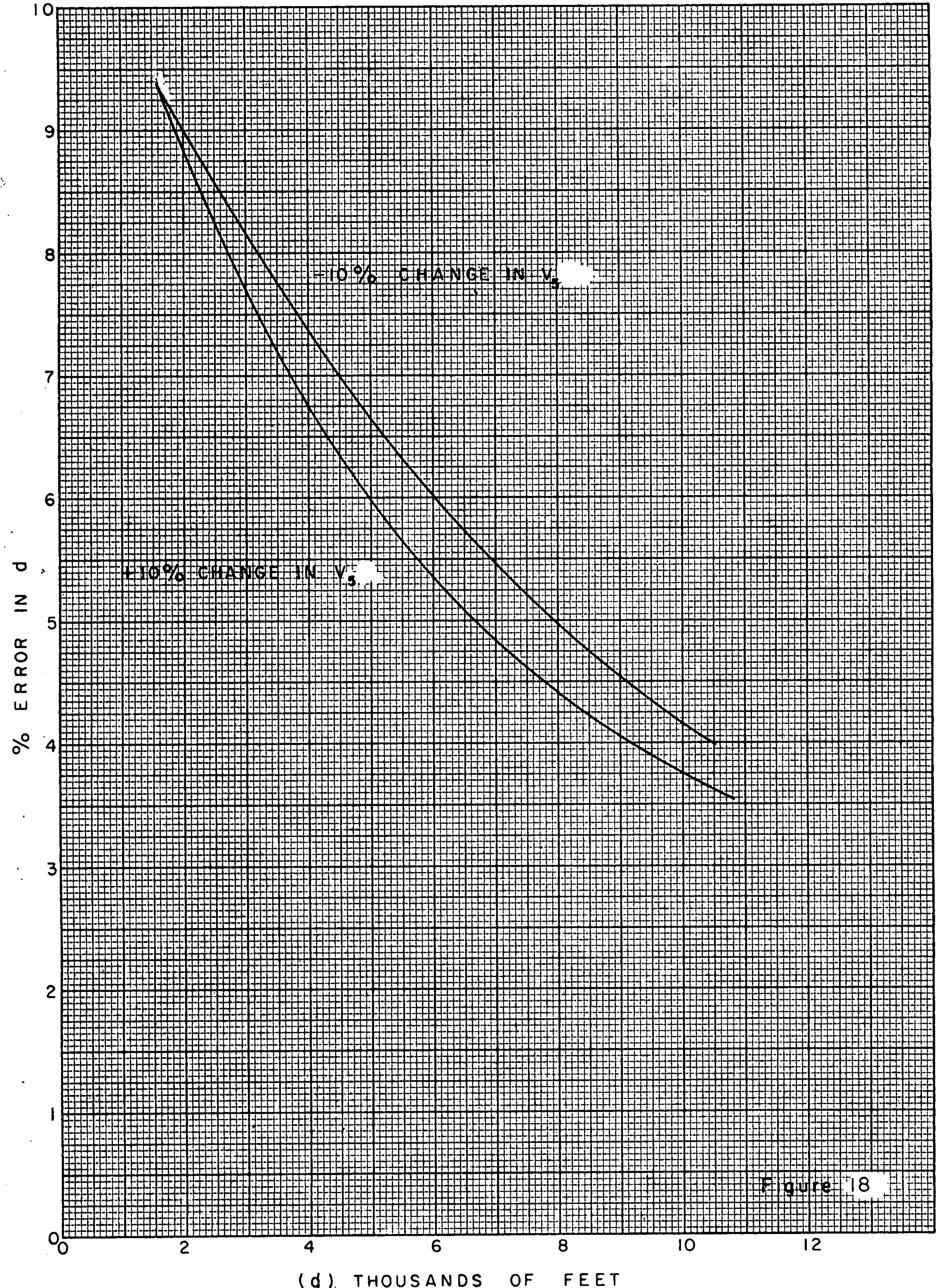

10
9
8
7
6
5
4
3
2
1
0
% ERROR IN d
0
2
4
6
8
10
12
(d) THOUSANDS OF FEET
-10% CHANGE IN V_5
+10% CHANGE IN V_5

Figure 18

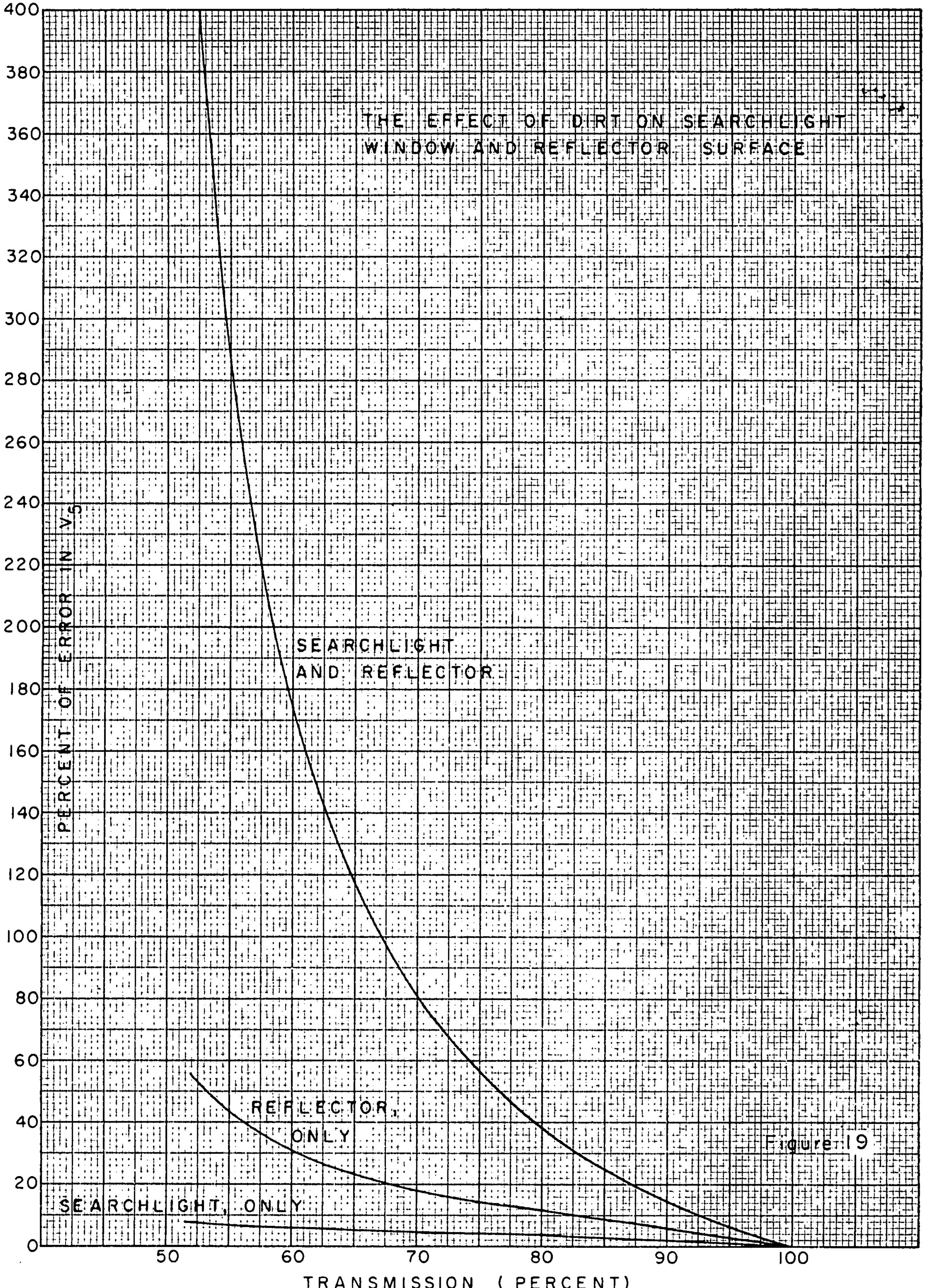
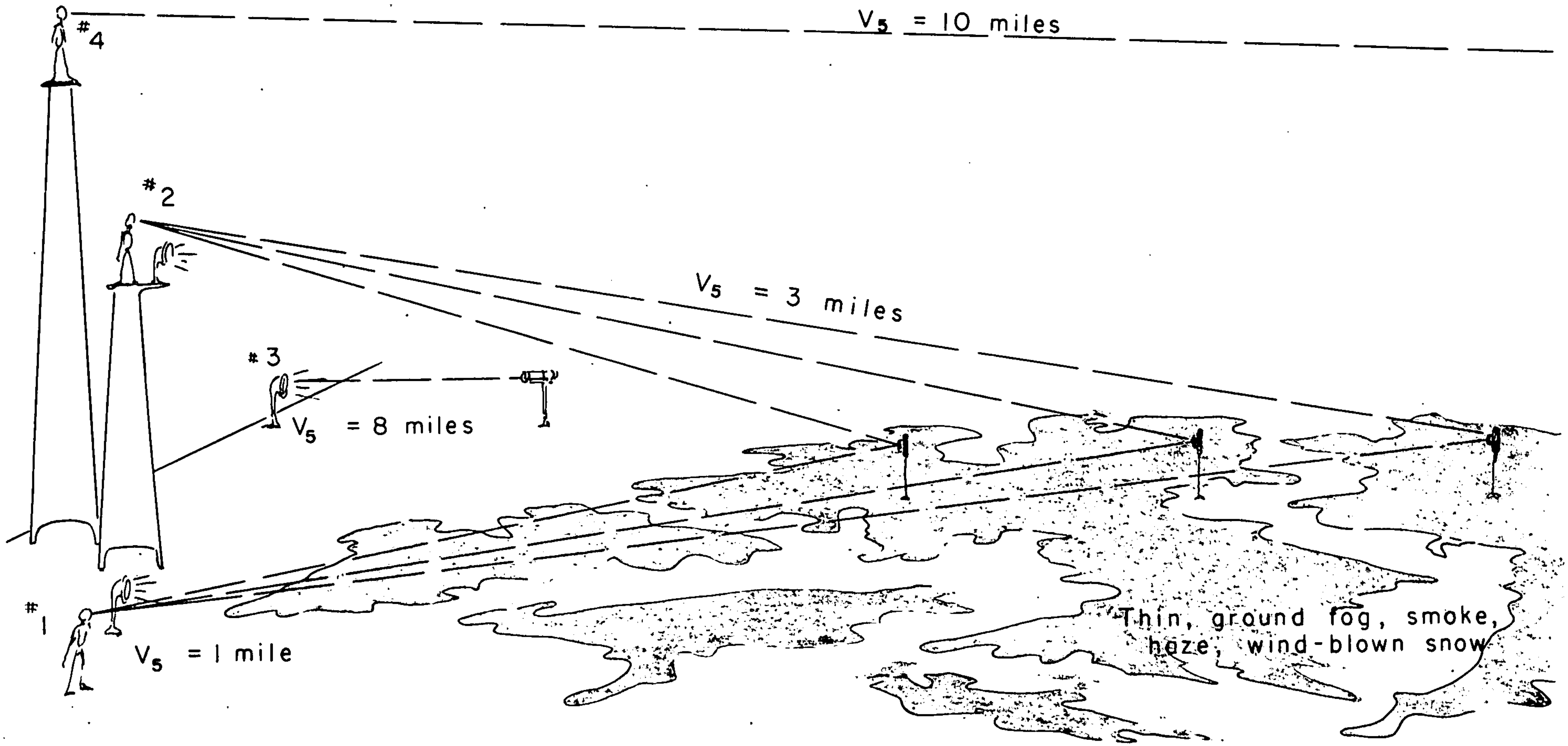

THE EFFECT OF DIRT ON SEARCHLIGHT WINDOW AND REFLECTOR SURFACE
PERCENT OF ERROR IN V_5
TRANSMISSION (PERCENT)
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
50
60
70
80
90
100
SEARCHLIGHT AND REFLECTOR
REFLECTOR, ONLY
SEARCHLIGHT, ONLY

Figure 19

4. COMPARISON WITH OTHER OBSERVATIONS

Visibility data secured by means of the portable visibility lights should agree closely with visibility observations by other techniques only if all observations are made simultaneously and along precisely the same path of sight. These conditions are rarely fulfilled and major disagreements are, therefore, not only possible but likely. Just as a thermometer can indicate no temperature but its own, so is a visibility measuring system restricted to determining visibility along the precise path of sight it uses. During the conditions of low visibility for which the portable light system is designed, atmospheric clarity can be expected to vary sharply from point to point and from moment to moment. Variations with height above the ground are especially likely at night when ground haze and fog are common. Thus, there is no reason to expect that visibility data reported by an observer on a high tower looking at very distant lights, often also located high above the ground, should agree with observations made along a path of sight situated close to the ground. Figure 20 is offered as a schematic illustration of this concept.



Observer #1 has the lowest visibility cause of the greatest path through ground fog.

Observer #2 is above the ground fog but the reflectors are within this fog. Visibility is reduced, but not as much as for Observer #1.

Transmissometer #3 has a short path and ground fog is not in the path or beam. It is located at a distance from Observer #1, and shows a high visibility.

Observer #4 is located on a tower or high building, and looks at distant lights at about the same height. He is above the ground fog, therefore the highest visibility is recorded.

Figure 20

Personnalia

Many individuals within the Visibility Laboratory contributed to the portable visibility light system. Mr. J. J. Rennilson was the project engineer. Visibility engineering was by J. I. Gordon, who also prepared Figure 12. Dr. J. H. Taylor suggested the adaptation-control principle which makes the compressed system possible and, with Dr. S. Q. Duntley, provided scientific guidance throughout the project. The various components were engineered by R. W. Austin, J. J. Rennilson, and T. J. Petzold. The report was written by S. Q. Duntley, J. J. Rennilson, R. W. Austin, and J. H. Taylor.