# HumRRO



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Task SWINGSHIFT

RESEARCH MEMORANDUM

MOONLIGHT AND NIGHT VISIBILITY


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# PREFACE

This report presents a summary and discussion of published data and information relevant to visibility under low levels of natural illumination. Those changes that occur in the nature and intensity of light between sunset and sunrise are described and related to the visibility of objects of military significance. Six field studies of night target detection are reviewed and assessed as to comprehensiveness in terms of a set of factors that affect visual perception. Suggestions for future research are offered and procedures for the preparation of moon diagrams and charts that provide comprehensive information on the potential availability of moonlight are described.

This work was undertaken as part of Task SWINGSHIFT's program of research and development directed toward improvement of individual and squad Infantry operations under conditions of limited visibility. Preliminary investigation indicated that the importance of illumination factors had not been given adequate attention in field studies and that there was no single source of information about the changes in natural light that occur between the hours of sunset and sunrise. The material presented was, therefore, gathered and prepared from widely scattered sources as an essential preliminary to further systematic study and experimentation directed toward improving the performance of visual tasks required by Infantry night operations.

In addition to being of interest to those concerned with field research on visual perception, the content of this report has obvious significance for all those responsible for the planning and conduct of night training and night operations.

CHAPTER 1

# MAJOR VISIBILITY FACTORS

The visual performance requirements of military personnel assigned to Infantry night operations have yet to be determined. As a result, the necessary skills in seeing and the development of proper attitudes have, to date, been defined only in terms too general to be useful in the design and implementation of training procedures. Furthermore, relatively little is known about the actual capabilities and limitations of night vision under field conditions. Hence, the gathering of empirical data under controlled field conditions representative of typical Infantry night operations is prerequisite to the development of more effective training procedures.

The vital role of field studies in advancing our knowledge of vision under low levels of natural illumination makes it essential that such studies be carried out and reported in such a way that the work may be replicated, thus enhancing the validity and reliability of results. To this end, it seems useful to emphasize the importance of considering all the factors that affect visual perception in the planning, implementation, and reporting of such field studies.

It seems reasonable to assume that a common set of factors determines the visual perception of objects under all conditions of observation. This is not to deny that, under certain conditions, the contribution of a given factor may apparently be quite negligible. However, to assure adequate control and to facilitate replication, it is important, even in such cases, to explicitly account for each of the factors in the set whenever data on visual detection and identification under field conditions are collected and reported.

The following six major categories provide a convenient way of specifying the variables and conditions affecting visual perception in outdoor settings. The entries under each category are illustrative of the kind of information required about each factor and are not intended to be exhaustive.

1. Atmospheric conditions - degree of clearness, presence of fog, haze, dust, rain, snow.
2. Illumination conditions - intensity, directional or diffuse, orientation of source to observer, orientation of source to object.
3. Object variables - area, shape, movement, orientation to observer, general brightness level, brightness contrast with immediate background, intra-object brightness contrasts.

4. Background variables - brightness level, textural effects.
5. Observer variables - visual adaptation level, acuity at adaptation level, attention, motivation, training.
6. Situational variables - instructions, time permitted for judgments, degree of search required, criteria for correctness of response.

Since the dramatic change in the nature and intensity of illumination that distinguishes night from day has far reaching effects on visibility, the specification of illumination conditions during the hours between sunset and sunrise warrants the special attention of those concerned in any way with visual perception. The value of field studies designed to advance our knowledge of night vision under natural illumination is in proportion to the rigor with which illumination conditions are specified. Furthermore, accurate forecasts of illumination conditions are of significant value to those who plan, as well as to those who carry out, night operations either as part of training or under actual combat conditions. For these reasons, we now turn to a consideration of the varieties of natural illumination that occur between the hours of sunset and sunrise.

The two succeeding chapters of this report are specifically concerned with the characteristics of low levels of natural illumination and their effects on visibility. First, studies which present data on the luminosity of the sky under "no-moon" conditions are analyzed. Then, pertinent facts about the moon and their significance for visual perception are presented and discussed.

## CHAPTER 2

## TWILIGHT AND THE LUMINOSITY OF THE NIGHT SKY UNDER MOONLESS CONDITIONS

### INTRODUCTION

Military writing and doctrine have oftentimes compartmentalized activities into the separate areas of day operations and night operations. In this chapter, twilight and the light of the night sky are discussed in terms of variations in illumination which exist under these conditions, and evidence will be presented which demonstrates that the gross categories of day and night do not adequately represent the wide variety of light situations.

### TWILIGHT

By definition, at the exact moment the upper rim of the sun meets the true horizon, sunset is said to occur (1). However, because the light of the sun is still reflected back to the earth from various layers in space, complete darkness does not start with this occurrence. In fact, it has been found that there is little loss of visible light for some time. The period from sunset until the time darkness occurs has been labeled the period of twilight.

The phenomenon of twilight has been extensively studied since the early 1900's. As a means of classification, it has been broken down into three separate time periods. These periods are called civil, nautical, and astronomical twilight, and each of these shall be discussed separately.

### CIVIL TWILIGHT

Civil twilight is defined as that period of time occurring from sunset until the center of the sun is 6 degrees below the horizon. Under ordinary conditions, this period offers enough light to carry on normal daytime activities. The US Army considers that normal artillery fire adjustment is possible, and Visual Flight Rules for aircraft apply during this period (5, 17).

### NAUTICAL TWILIGHT

The period of nautical twilight is that time during which the center of the sun moves from 6 to 12 degrees below the horizon. Although there is a reduced amount of illumination, enough light is provided to carry on most types of ground movement without difficulty. Army doctrine indicates that visibility during this time is limited to about 400 meters (5, 17).

## ASTRONOMICAL TWILIGHT

As the center of the sun passes 12 degrees below the horizon, the period of darkness, for United States military purposes, is said to start (5, 17). However, there is a further period of twilight that occurs as the sun moves from 12 to 18 degrees below the horizon, and this is called astronomical twilight. This period offers only meager light, and normal daytime activities cannot be carried out unless an artificial light source is provided. For astronomical purposes, the period of darkness starts as the sun passes through 18 degrees below the horizon. The relative illumination gradient for nautical and astronomical twilight is presented in Figure 1.

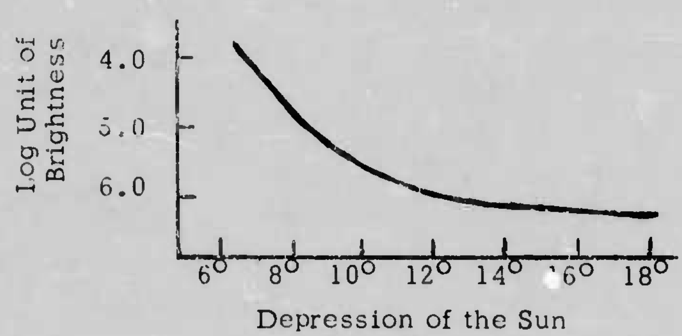



FIGURE 1. ILLUMINATION GRADIENT FOR NAUTICAL AND ASTRONOMICAL TWILIGHT (Adapted from Chiplonkar, 3)

## TWILIGHT AT SUNRISE

As the earth continues its rotation, the time cycle continues and the sun starts to come above the horizon. The three stages of twilight now repeat themselves in reverse order from the sunset cycle. That is, as the center of the sun passes through 18 degrees below the horizon, astronomical twilight starts. The sun's passing of 12 degrees declination signals the start of nautical twilight, and its movement past 6 degrees starts the period of civil twilight. Sunrise occurs exactly at the moment the upper rim of the sun comes above the true horizon.

DURATION OF TWILIGHT

The durations of the three periods of twilight vary with the latitude of the observer and the season of the year. At the equator, the twilight periods are almost exactly equal, being about 22 minutes in length regardless of the season. In the higher latitudes, however, especially above 50 degrees, there is such seasonal variability that no general rule can be established. For the portion of the earth between 50 degrees north and south latitude, the periods of twilight are each about 22 to [illegible] minutes long, and, although there are some seasonal variations, the preceding times can be used as a general rule (1). Much of the inhabited portion of the earth lies between 50 degrees north and 50 degrees south latitude including all of the United States with the exception of Alaska.

LIGHT OF THE NIGHT SKY

As the sun moves a sufficient distance below the horizon that its light is no longer reflected back upon the earth, the celestial bodies of the universe come into view. These bodies act as a source of light, either by internal illumination or by acting as reflecting surfaces for an exterior light source. Although not all the illuminating sources of the universe have been identified, the entire amount of visible light that is present on a clear night, with no moon, shall be referred to hereafter as the light of the night sky (LNS).

MEASUREMENT OF LNS

Many investigators have made systematic measurements of the LNS. Although the literature on this is by no means limited, the results cannot be considered as definitive. The major difficulty in assigning a specific intensity value to the LNS is that it has been found that there are geographical variations, seasonal variations, and even local variations in intensity. These variations are due to physical phenomena in the universe and are independent of any purely local light source (such as the reflected lights of a large metropolitan area) which may also influence the amount of visible light present at any one time.

SEASONAL VARIATIONS IN LNS

The fact that there are seasonal variations in LNS intensity is rather well documented. Early work (4) demonstrated that there appeared to be a maximum intensity about June and a minimum in December. Later work (2, 4) supported this view but also offered some evidence that there may be two lesser maxima occurring in spring and fall. For the purposes of this report, it is enough to say that there will be seasonal variations in LNS intensity, although the amount of these variations has yet to be determined.

## GEOGRAPHICAL VARIATIONS IN LNS

Geographical variations in the intensity of the LNS have been reported for many years. These are usually reported as "lights" of the night sky, and, during the recent International Geophysical Year, all known types of night lights were investigated. The IGY data have not yet been reported in detail, but brief descriptions of the more common LNS phenomena are given below (15).

Aurora (northern lights) - These are bright lights often seen in the far northern or southern sky (depending upon the hemisphere of the observer) and are usually colored, many times being red or green. These are probably caused by an excitation of the magnetic field of the earth. The lights move across the sky with the usual movement being toward the east. These lights are rarely seen between 40 degrees north or south latitude, although they have been infrequently reported at all latitudes.

Airglow - This is a phenomenon about which very little is known. Airglow is said to exist whenever the night sky is strangely bright and the illumination is not focused, but, rather, is spread out over a large part or all of the sky. Although it has been reported all over the earth, it apparently occurs most often in the more northerly and southerly latitudes. It is hypothesized that there is a link between airglow and the inner Van Allen radiation belt. Most of the time the light has been reported as greenish in color.

Zodiacal light - This light appears as a belt of light across the sky, and it is seen most often between the tropics of Cancer and Capricorn, although it has occasionally been reported slightly to the north and to the south of this region. It has been hypothesized that it is produced by light shining on dust in the atmosphere; however, it is not known why this usually occurs only in the tropic zone.

Gegenschien (opposite shine) - This is a faint, circular spot of light that appears in the heavens directly opposite the sun. Thus, it appears only after sunset and disappears at sunrise. This phenomenon is reported only rarely, but it seems to occur most often in the tropic zone. There is no known scientific explanation of this phenomenon.

Noctilucent clouds - These are luminous clouds that appear to be very high in the sky. They are a rare sight, seen primarily during summer twilight near the horizon in Canada, Europe, and the Soviet Union. They appear to move with great speed. It has been hypothesized that they are clouds of meteoric dust illuminated by sunlight or by incoming atomic particles.

## LOCAL VARIATIONS IN LNS

Little research has been done on local variations in LNS intensity. One investigator (12) reported that, at one station, the ratio in brightness from one night to another was sometimes as high as 2 to 1. However, further research which studied LNS variations at three different geographical locations found that, although there were variations at each station, the daily variations did not correlate with one another (12).

## PERIOD OF NIGHT

Accepted United States military doctrine defines the duration of night as that time period from the End of Evening Nautical Twilight (EENT) until the Beginning of Morning Nautical Twilight (BMNT) (5, 17). Other nations of the world do not necessarily use this same system, but, because the sun cycle follows natural laws, most of the methods of categorizing twilight are quite similar. For example, the armed forces of the United Kingdom use the terms first light and last light. This period includes a slightly greater period of twilight (0-9 degrees) than that defined by the United States term of civil twilight (17). The complete cycle of sunset to sunrise, with the appropriate time periods labeled, is shown in Figure 2.

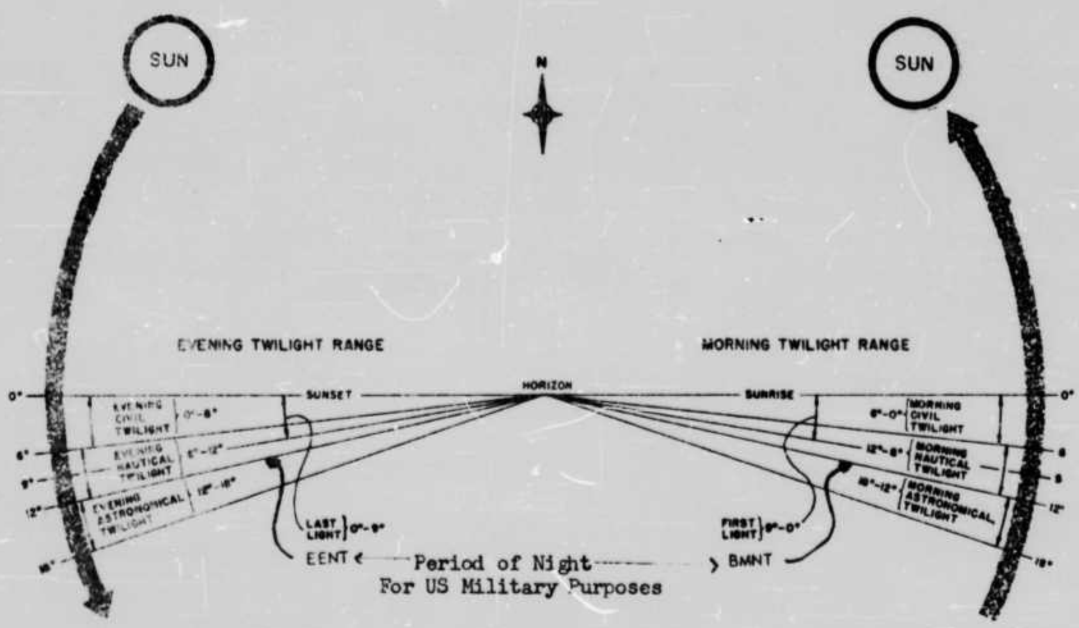



FIGURE 2. PERIODS OF TWILIGHT

## CONCLUSIONS

The occurrence of sunset does not mark the beginning of a period devoid of militarily useful natural illumination. Since the transition from day to night and from night to day is gradual, sufficient light is available for considerable periods of time immediately after sunset and immediately before sunrise to permit the execution of ground operations without undue loss of proficiency and effectiveness.

The period of time designated as night has been defined in various ways depending upon the purposes of those who formulated the definitions. On moonless nights under standard atmospheric conditions (clear, no haze or other obscuring weather conditions), there is always some light in the night sky. This light is variable and dependent on such factors as geographical location, season of the year, unidentified atmospheric phenomena, and local conditions. However, enough light is present to make possible a restricted range of visibility.

The regular cyclic nature of the sun's apparent movements makes it possible to predict the gradient of natural illumination to be expected between sunset and sunrise under moonless conditions and without regard for local weather conditions. This predictability is useful to those who plan military operations and to those who study visual perception under relatively low levels of natural illumination.

CHAPTER 3

# THE MOON

## INTRODUCTION

The presence or absence of moonlight is an especially salient feature of natural illumination during the hours of darkness. Research has demonstrated that visibility is determined, in large part, by the nature, intensity, and direction of incident light with reference to the object and to the observer. In the absence of moonlight, natural incident lighting at night is diffuse, i.e., there are no sharp shadows and there is a lessening of definition of objects. Moonlight, on the other hand, is directional, and, if of sufficient intensity, casts shadows that may change the apparent shape and brightness of objects. Facts about the moon and its apparent movements as they relate to visibility would thus seem to have direct application not only in field research on visual perception but also in the planning and implementation of military night operations. The purpose of this section is to discuss those moon facts that have a direct bearing on illumination at night.

## PHASE CYCLE

Since moonlight is reflected sunlight, the amount of moonlight received on earth depends principally on how much of that portion of the moon which is lighted by the sun can be seen from the earth. How the moon appears, i.e., its phase, depends on where it is in relation to the earth and to the sun. The moon completes its cycle of phases, e.g., from new moon to new moon, in twenty-nine and one-half days. The new moon phase occurs when the moon lies between the earth and the sun. During this phase, the moon rises and sets with the sun, no light is reflected to the earth, and, as a result, we are unable to see it.

The moon's position in the sky shifts to the east about 13 degrees each day. This eastward movement results in a daily delay of about 51 minutes in time of moonrise and a daily change in the point on the horizon at which the moon appears. Thus, a few days after new moon, the moon's position will be about 30 degrees east of the sun and it will be seen as a thin crescent.setting shortly after sunset. The size of the crescent increases daily until full moon, when the earth is between the moon and the sun. During the full moon phase, the moon rises just as the sun sets, and we can see it during the entire night. Following the full phase, the moon rises later and later and reflects less and less light until the cycle of phases is complete. Before full moon, the eastern side of the crescent (the left side in the northern hemisphere), and after full moon the western side, is the dark edge.

EFFECTS OF PHASE ON INTENSITY

Since the illumination of equal surface areas on a solid sphere decreases as the obliqueness of the rays of incident light increases, moonlight intensity is not a simple function of phase. The first quarter moon, for example, is half of the disc visible at full moon, but the measured intensity of illumination received from it is only one-twelfth that received from the full moon (14). The striking rapidity with which illumination changes from one phase to the next is shown in Figure 3. The illumination received from the full moon is shown as 100 percent in this figure, which deals only with the period from new moon to full moon.

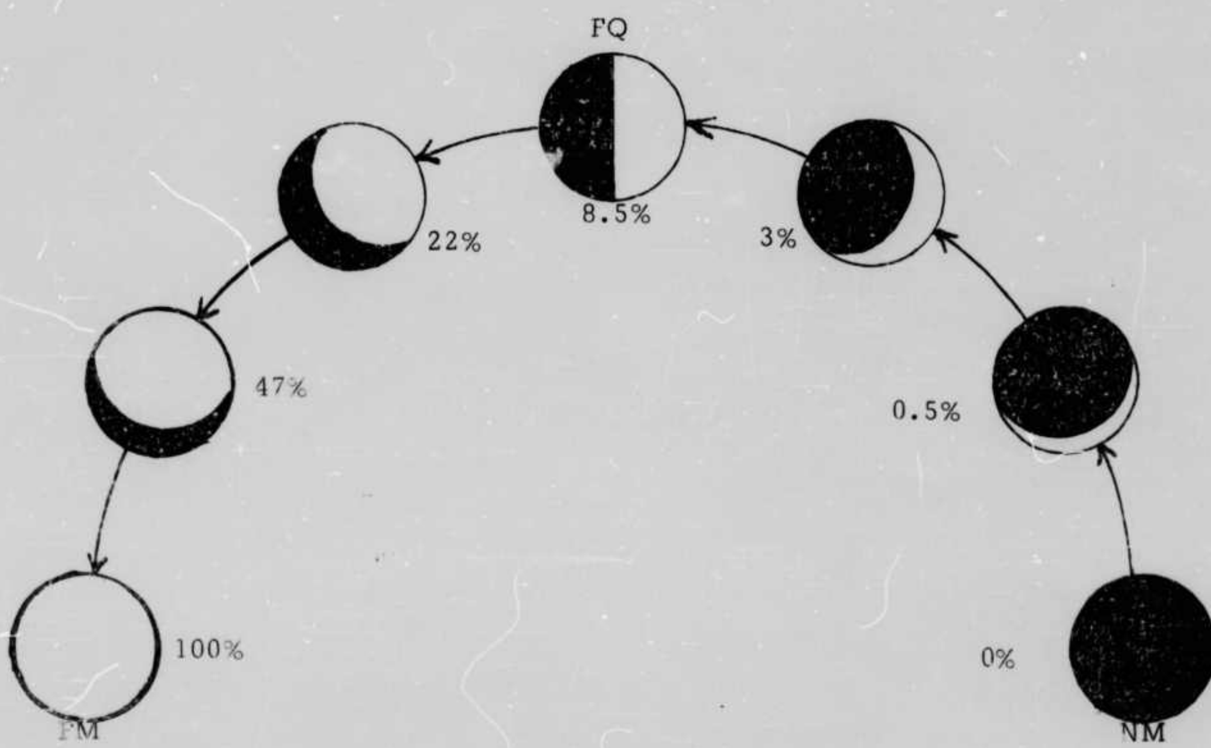



FIGURE 3. INTENSITY OF THE LIGHT GIVEN BY THE MOON AS A FUNCTION OF ITS PHASE
(Adapted from Rudaux and de Vaucouleurs, 14)

Due to the fact that dark areas on the moon's surface are preponderant during the period from full moon to new moon, the phases after full moon are slightly less brilliant than those before.

EFFECTS OF ELEVATION ON INTENSITY

The height of the moon above the horizon also has a significant effect on the amount of light received. This effect is a joint function of the length of the light path within the earth's atmosphere, since the terrestrial atmosphere absorbs light, and the angle of incidence, since the moon's rays are increasingly concentrated as its inclination to the horizon is increased. Hence, the moon's brightness is reduced when it is near the horizon, i.e., at rising or setting. Absorption of light by the earth's atmosphere becomes negligible when the moon reaches an elevation of 45 degrees or more above the horizon. Figure 4 illustrates the effects of atmosphere absorption of light on the visibility of stars. When observed at an elevation of 10 degrees above the horizon, a star will appear to be about two and one-half times fainter than it does when observed at an elevation of 45 degrees or more above the horizon.

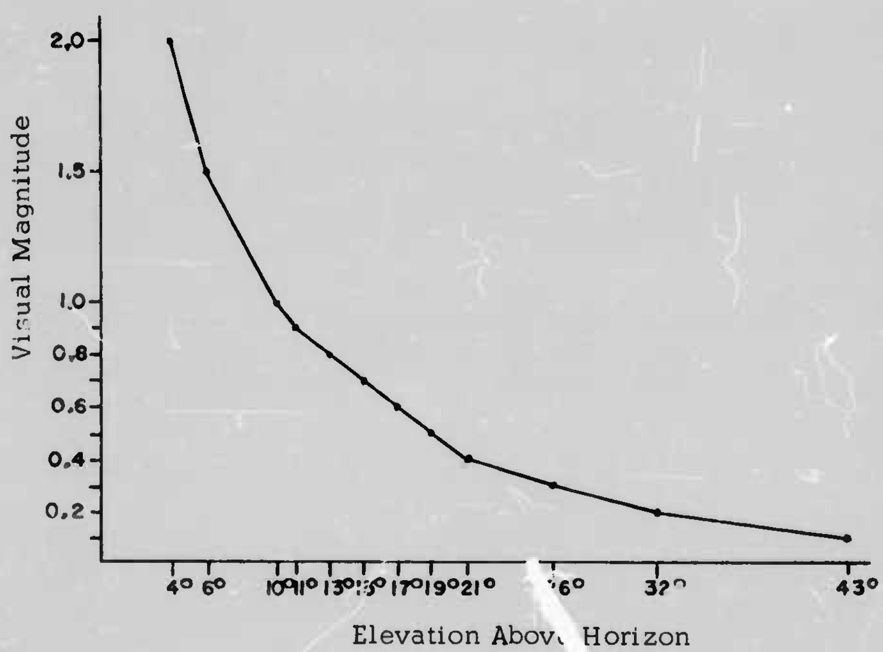



FIGURE 4. EFFECTS OF LIGHT ABSORPTION BY THE EARTH'S ATMOSPHERE ON THE VISIBILITY OF STARS
(Prepared from data in Rudaux and de Vaucouleurs, 14)

Additional evidence of the effects of phase and elevation on the intensity of moonlight is shown in Table 1. These data, gathered at an approximate latitude of N 50°, were extracted from a publication of the Canadian School of Aviation Medicine (13) and are expressed in terms of ground brightness. It is instructive to consider the ground brightness values of the other phases as expressed in terms of percentage values of the ground brightness value at new moon. Thus, from Table 1, for the quarter-moon phases, an increase in elevation from 15 degrees to 35 degrees doubles the ground brightness, and an increase from 15 degrees to 55 degrees triples it. The effects of elevation at full moon are even greater. Similarly, at an elevation of 15 degrees, the full moon produces a ground brightness five times that of a quarter moon and twenty-five times that of a new moon. These ratios increase with increasing elevation until at 55 degrees the ground brightness produced by the full moon is six and one-half times that at quarter moon and ninety times that at new moon.

TABLE 1

EFFECTS OF PHASE AND ELEVATION ON INTENSITY OF MOONLIGHT EXPRESSED IN TERMS OF GROUND BRIGHTNESS
(Prepared from data published in 13)

| Phase of Moon | Elevation (degrees) | Ground Brightness (LgMML) | Ground Brightness (mfl) | Percent of New Moon Value |
|---|---|---|---|---|
| New | 15 | 4.33 | 20 | |
| | 35 | 4.33 | 20 | |
| | 55 | 4.33 | 20 | |
| First Quarter | 15 | 5.02 | 100 | 500 |
| | 35 | 5.33 | 200 | 1000 |
| | 55 | 5.51 | 300 | 1500 |
| Full | 15 | 5.73 | 500 | 2500 |
| | 35 | 6.15 | 1300 | 6500 |
| | 55 | 6.29 | 1800 | 9000 |
| Third Quarter | 15 | 5.02 | 100 | 500 |
| | 35 | 5.33 | 200 | 1000 |
| | 55 | 5.51 | 300 | 1500 |

## SEASONAL VARIATIONS IN INTENSITY

Seasonal variations in the intensity of moonlight are due primarily to changes in the maximum attainable elevation of the moon. The maximum northern latitude attained by the moon is N 28° 35' and occurs on winter solstice (about 22 December). Thus, the northern hemisphere receives its greatest amount of illumination from the moon during winter. Following winter solstice, the maximum northern latitude attained by the moon declines until summer solstice (21 or 22 June) at which time it reaches its minimum value of N 18° 19'. For all points on the earth's surface with the same latitude, the apparent movement of the moon will take place in the same way. The effects of seasonal variations in the maximum elevation of the moon are illustrated in Table 2 in terms of degrees of elevation above the horizon and units of corresponding ground brightness.

TABLE 2

SEASONAL VARIATIONS IN MAXIMUM ELEVATION OF THE MOON
AND CORRESPONDING CHANGES IN GROUND BRIGHTNESS
AT APPROXIMATELY 50° NORTH LATITUDE
(Prepared from data published in 13)

| Season | Phase | Elevation (degrees) | Ground Brightness (LgMML) | (mfl) |
|---|---|---|---|---|
| Spring | New Moon | 35 | 4.33 | 20 |
| | First Quarter | 55 | 5.51 | 300 |
| | Full Moon | 35 | 6.15 | 1300 |
| | Third Quarter | 15 | 5.02 | 100 |
| Summer | New Moon | 55 | 4.33 | 20 |
| | First Quarter | 35 | 5.33 | 200 |
| | Full Moon | 15 | 5.73 | 500 |
| | Third Quarter | 35 | 5.33 | 200 |
| Autumn | New Moon | 35 | 4.33 | 20 |
| | First Quarter | 15 | 5.02 | 100 |
| | Full Moon | 35 | 6.15 | 1300 |
| | Third Quarter | 55 | 5.51 | 300 |
| Winter | New Moon | 15 | 4.33 | 20 |
| | First Quarter | 35 | 5.33 | 200 |
| | Full Moon | 55 | 6.29 | 1800 |
| | Third Quarter | 35 | 5.33 | 200 |

An illustration of seasonal and bihourly changes in moonlight intensity is provided in Table 3 in terms of degrees of elevation above the horizon and units of ground brightness.

TABLE 3

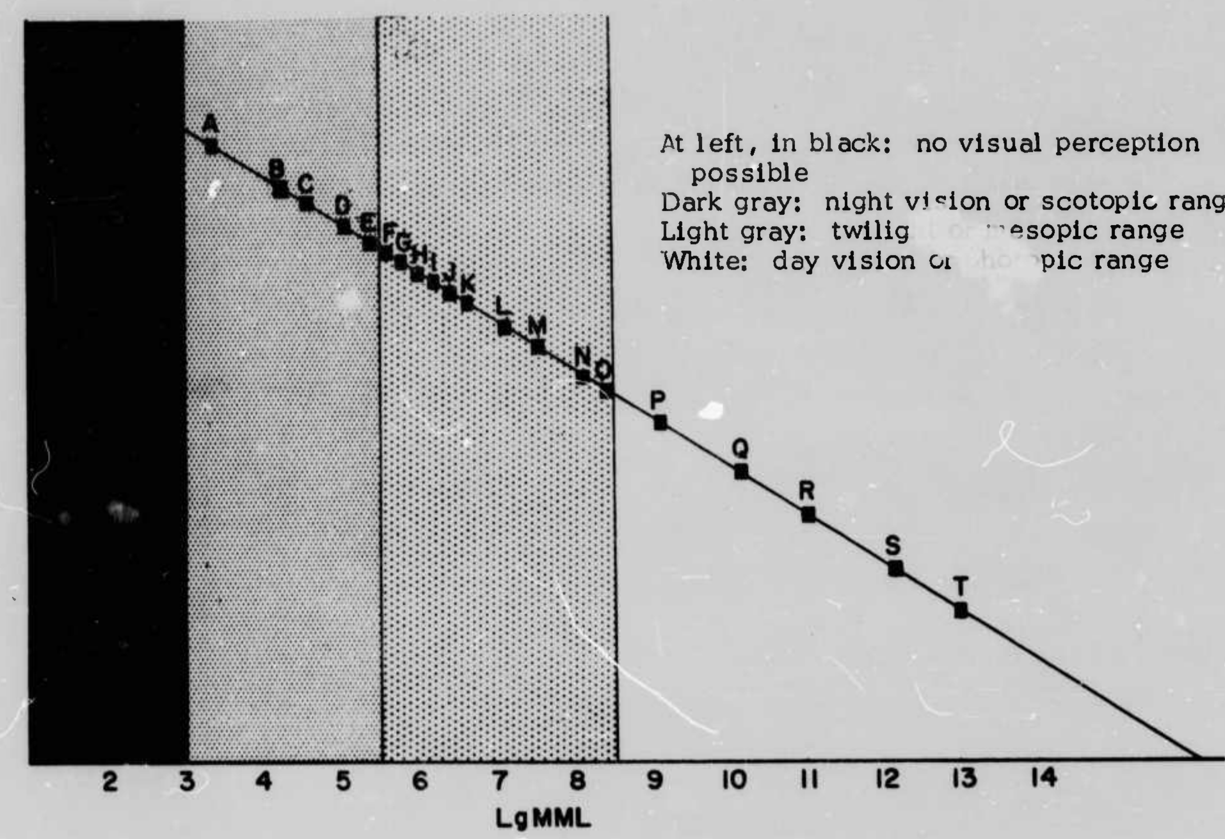
BIHOURLY AND SEASONAL CHANGES
IN MOONLIGHT INTENSITY
(Adapted from Jayle, et al., 8)

| | Midwinter | | Midsummer | |
|---|---|---|---|---|
| Hours | Moon Elevation (degrees) | Ground Luminance (LgMML) | Moon Elevation (degrees) | Ground Luminance (LgMML) |
| 1600 | 0 | 4.35 | | |
| 1800 | 13 | 5.70 | | |
| 2000 | 31 | 6.05 | 6 | 5.35 |
| 2200 | 47 | 6.20 | 16 | 5.77 |
| 2400 | 56 | 6.25 | 18 | 5.80 |
| 0200 | 50 | 6.22 | 13 | 5.65 |
| 0400 | 35 | 6.10 | 0 | 4.35 |
| 0600 | 17 | 5.85 | | |
| 0800 | 3 | 4.75 | | |

VISIBILITY AND LUMINANCE

The preceding paragraphs have indicated that the amount of light available from the moon at any one time is quite variable. However, many investigators have attempted to measure the average amount of light supplied by the moon during the different phases under ideal atmospheric conditions. Although the results of the various studies are not in absolute agreement, the measurements obtained can be grouped into meaningful patterns. In order to establish the amount of available light present during twilight, moonlight, and starlight, Figure 5 has been prepared.

The graphic representation of luminance ranges shown by Figure 5 indicates, in general, that, as the sun sets below the horizon, there will be no effect on vision for about 15 minutes. After this time, there is a shift in the visual process so that both the rods and the cones are used by the individual at the same time. The incident light may stay in this mesopic range during the entire period from sunset to sunrise if the light from a full moon is available during this time. Even if there is as much light available as is reflected by a quarter moon (about one-half of the total moon area), there may be times during the night when mesopic




On the oblique line luminance values indicate differing lighting conditions.

SQUARES INDICATE

A. Night ground luminance with overcast sky, no moon. (Guide of Canadian AF)
B. Clear starlight (after CAF)
C. Sky luminance, full moon (after CAF)
D. First quarter moon, 15 degrees elevation (after CAF)
E. Half moon (after CAF)
F. First quarter moon, 55 degrees elevation (after CAF)
G. Full moon, 15 degrees elevation (after CAF)
H. Ground luminance, full moon (after CAF)
I. Full moon, 35 degrees elevation (after CAF)
J. Full moon, 55 degrees elevation (after CAF)
K. Sky luminance, full moon (after Middleton)
L. Sky luminance, full moon (after CAF)
M. Sky luminance 1/2 hour after sunset (after Middleton)
N. Mean luminance of street lighting in town (after LeGrand)
O. Sky luminance 1/4 hour after sunset (after Middleton)
P. Mean weak artificial lighting (after LeGrand)
Q. Good reading luminance for white paper (after Sheard)
R. Good artificial lighting (after LeGrand)
S. Mean diurnal lighting (LeGrand)
T. Snow luminance in noonday sun (after LeGrand)

(Sources referenced in Jayle, et al., 8)

FIGURE 5. GRAPHIC REPRESENTATION OF LUMINANCE RANGES FOR VARIOUS LIGHT SOURCES

vision is utilized. These times will occur if the quarter moon rises at least 55 degrees in elevation above the horizon. However, for all light levels of less than quarter moon, the ground luminance will be sufficient to excite only the rods of the eye, and thus, true night vision will occur.

## CONCLUSIONS

The foregoing discussion makes clear the importance of knowledge about the moon and its apparent movements through the sky to the planning and conduct of visual research and military operations. Forecasts of the duration, intensity, and directional characteristics of moonlight for any given night may be made with a knowledge of the phase and local times of moonrise and moonset. Sources of this information and the preparation of moon charts are discussed in Appendix A.

CHAPTER 4

# A REVIEW OF STUDIES ON TARGET DETECTION UNDER LOW LEVELS OF ILLUMINATION

## INTRODUCTION

Relatively few studies of visual perception under low levels of natural illumination have been published. A diligent search of the literature covering the past three decades (Appendix B) revealed only six major investigations in which visibility data were gathered on the detection or identification of objects of military significance under low levels of natural light. These six studies will now be reviewed and discussed.

## STUDY ONE

The first experiment was done at the Japanese Infantry School during the mid-1930's (11). The basic documents that originally reported these studies were evidently destroyed during World War II. The cited reference was compiled by a group of Japanese officers after the war at the request of the US War Department. Some of the figures reported were obtained from existing training manuals; however, there is apparently some material included that was compiled from memory. Because of this, parts of the document may be of questionable origin, but the target detection studies are still quite valuable for reference purposes.

### Procedure

Possibly as a result of the method of compilation, the Japanese report very little information about experimental procedure. The number of subjects and the basic statistical analyses are lacking. It is reported that the "experiments were conducted on the Visibility Range by well trained soldiers at the Infantry School." The exact training of the observers is not reported, but a general outline of the subjects discussed is mentioned. These subjects include off-center vision, scanning, dark adaptation, variations in visibility according to the age, slant, and position of the moon, cloud conditions and the development of confidence in night seeing ability.

### Results

The results of the studies, including description of the phys ' surroundings used in the experiments, are presented in Tables 4 and 5. It is .ated whether the distances reported are detection distances or identification distances. Also, it is not made clear whether the visibility distance is a mean, or whether 100 percent of the observers saw targets at these distances.

TABLE 4

VISIBILITY AT NIGHT

| Moon Age | Ground and Background | Object: Single Soldier (meters) | Object: Patrol (meters) | Object: Unit (meters) |
|---|---|---|---|---|
| Starlit Night | Level, Grassy Ground | 25 | 30 | 40 |
| | Level, Bare Ground | 30 | 40 | 45 |
| | Dark Background | 10 | 10 | 15 |
| | Silhouetted Against Sky | 35 | 55 | 80 |
| 12th Day from the Full Moon (Crescent) | Level, Grassy Ground | 30 | 60 | 75 |
| | Level, Bare Ground | 30 | 45 | 50 |
| | Dark Background | 10 | 15 | 20 |
| | Silhouetted Against Sky | 130 | 140 | 180 |
| 7th Day from the Full Moon (Half) | Level, Grassy Ground | 60 | 70 | 80 |
| | Level, Bare Ground | 35 | 50 | 55 |
| | Dark Background | 10 | 15 | 20 |
| | Silhouetted Against Sky | 140 | 170 | 230 |
| 3d Day from the Full Moon (3/4) | Level, Grassy Ground | 70 | 75 | 120 |
| | Level, Bare Ground | 40 | [illegible] | 70 |
| | Dark Background | 15 | 20 | 25 |
| | Silhouetted Against Sky | 160 | 220 | 280 |
| 15th Day of the Moon (Full) | Level, Grassy Ground | 75 | 100 | 150 |
| | Level, Bare Ground | 50 | 80 | 100 |
| | Dark Background | 15 | 20 | 25 |
| | Silhouetted Against Sky | 180 | 250 | 300 |

Notes:

1. Patrol is three or four men. Unit is a platoon in column. The above figures show the visible range when the object is not in motion. It is easier to identify an object in motion especially when it is moving crosswise.

2. This experiment was conducted on clear nights during January and February. It can be assumed that the brightness is practically equal for two or three nights before and after each age of the moon in the chart.

3. This chart applies for visibility after the full moon as well as before.

TABLE 5

VISIBILITY ON MOONLIGHT NIGHTS

| Object | | Observer | Single Soldier (meters) | Unit (meters) |
|---|---|---|---|---|
| Standing Position | Halted | Facing moon | 190 | 264 |
| | | With moon behind | 115 | 113 |
| | In motion | Facing moon | 223 | 310 |
| | | With moon behind | 121 | 151 |
| Kneeling Position | Halted | Facing moon | 128 | 171 |
| | | With moon behind | 69 | 102 |
| | In motion | Facing moon | 150 | 184 |
| | | With moon behind | 75 | 76 |
| Prone Position | Halted | Facing moon | 79 | 127 |
| | | With moon behind | 41 | 56 |
| | In motion | Facing moon | 83 | 131 |
| | | With moon behind | 45 | 59 |

Notes:

1. Soldiers employed in the experiment were equipped with full pack and camouflaged.
   The unit was approximately a squad in extended order.
2. 16th day of the moon (Full Moon), p[illegible]n 60 degrees from the ground, no background. Ground covered with g[illegible]0 centimeters high. There was no haze, but a high percentage of humidity.

Discussion

This was evidently a well designed and carefully conducted investigation. The omissions that occur in reporting are probably due to the way the material was compiled. This study is the only one that has been discovered that included the illumination conditions of quarter moon, half moon, and three-quarters moon. Further, there was systematic variation of target backgrounds. The main shortcomings are that the visual distances reported are not identified as to type (detection or identification) and there is no index of score variability.

STUDY TWO

At Camp Blanding, Florida, in 1944 an experiment was done on the detection and identification of targets under no-moon conditions (6). This was one of the early studies accomplished by the Personnel Research Section of the Adjutant General's Office, United States Army.

Procedure

On an unused rifle range, a field course of 12 marked lanes was set up on which various pieces of military equipment were used as targets (range in size, 50-caliber machinegun to M-2 tank). Subjects were first given a 30-minute lecture in a dark room on the techniques of using their eyes for scotopic vision and then were taken to one of the 12 lanes and told to look in a prescribed direction. If they could not see the target, they were told to walk on the path toward the target area until they saw "something." This was labeled the "Perception Distance." Subjects then continued to walk forward until they could recognize the target, and this was called the "Identification Distance." Two series of targets were used over the same marked lanes. This study was completed by 560 soldiers on moonless, cloudless nights.

Results

A correlation between series scores on specific lanes (e.g., observers' scores on Lane 1, Series 1, were correlated with observers' scores on Lane 1, Series 2), regardless of equipment on the lanes, yielded a Pearson $r$ of .936. A correlation between specific pieces of equipment, regardless of which lanes they were on, gave an $r$ of .603. These results imply that the physical characteristics of the target backgrounds for the specific lanes were more important in detection and identification distances than were the physical characteristics of the equipment itself. Unfortunately, the physical backgrounds of the target areas used in this study are not adequately described.

In Table 6 are listed the combined mean detection and identification distances for each lane, regardless of the specific equipment on the lane. These means were combined from the data of the various military groups used in the investigation.

TABLE 6

VISIBILITY DISTANCES FOR SPECIFIC LANES

| Lane | Detection (yards) | Identification (yards) |
|---|---|---|
| 1 | 47.06 | 23.34 |
| 2 | 50.09 | 30.74 |
| 3 | 48.46 | 21.67 |
| 4 | 77.06 | 34.68 |
| 5 | 53.36 | 36.14 |
| 6 | 51.87 | 27.50 |
| 7 | 47.13 | 32.12 |
| 8 | 61.32 | 35.15 |
| 9 | 81.13 | 22.15 |
| 10 | 44.60 | 26.46 |
| 11 | 51.91 | 26.03 |
| 12 | 52.13 | 31.32 |

As can be seen, there is a greater range of scores for the detection distances than for the identification distances. The identification distances are remarkably similar, having a range of from 21.67 yards to 36.14 yards. The combined means for all stations and all pieces of equipment give a detection score of 55.51 yards and a recognition score of 28.94 yards.

Discussion

It is unfortunate that more description is not given in this study about the physical characteristics of the various target areas. Because of the vast array of equipment that is available for military night operations, it would be a difficult task to determine what the visibility distances are for specific pieces of equipment.

A more rewarding approach would seem to be an unspecified kind of target against a specified type of background. Although the high correlation obtained for lanes implies that there may be some general rules on visual range for specific target backgrounds, this study does not help in the identification of them.

STUDY THREE

This research was conducted by the U. S. Army Infantry Human Research Unit at Fort Benning, Georgia (16). Although a large number of variables were investigated the results reported here will be limited to those pertaining to night target identification distances.

Procedure

This experiment investigated these four major variables:

1. Night Vision Training of Observer - Group 1, Classroom Training (2-hour lecture), (Problem 1220, USAIS); Group 2, Field Training (2 hours of target detection practice in the field); Group 3, Classroom and Field Training (1 hour of lecture and 1 hour in the field); Group 4, No Training.
2. Level of illumination - no moon or full moon
3. Position of target - standing, kneeling, prone
4. Position of observer - standing, kneeling, prone

After the appropriate training, the 216 subjects were taken to a field detection course in a very flat, grass-covered area of the reservation. There, subjects were dark adapted, assigned to one of nine lanes, and told to assume specific positions. In order to ensure that successive subjects were in approximately the same positions, a series of stakes were driven in the ground and the subjects were told to place their chins upon the stakes when making observations.

The subject looked down the lane for a target. All targets were humans dressed in fatigues but not otherwise camouflaged. The targets were at various distances down the lanes (for any one lane there was just one target) and had assumed various positions. The observer, if he saw a target, was required to write down the target's assumed position on a standardized score card. The primary data collected was number of correct responses as a function of target distance. The authors report that the full moon moved slightly behind the observers' positions; however, no elevation data are given.

Results

The general results were:

1. Night vision training has no significant effect on the correctness of identification under either illumination condition.
2. Under the no-moon conditions, the position of the observer (standing, kneeling, prone) did not affect the correctness of identification.

3. Under full moon, standing observers could identify targets approximately 9 to 17 yards beyond kneeling observers, who could identify targets approximately 20 to 30 yards beyond prone observers.

4. Under no moon, standing targets could be seen 7 to 8 yards beyond kneeling targets, which could be seen 9 to 11 yards beyond prone targets.

5. Under full moon, standing targets could be seen 13 to 20 yards beyond kneeling targets, which could be seen 12 to 25 yards beyond prone targets.

6. In general, the full moon conditions (mean observation range for all variables about 85 meters) extended the range of observation approximately three times the range for no moon (mean observation range about 28 meters). (See Figures 6 and 7.)

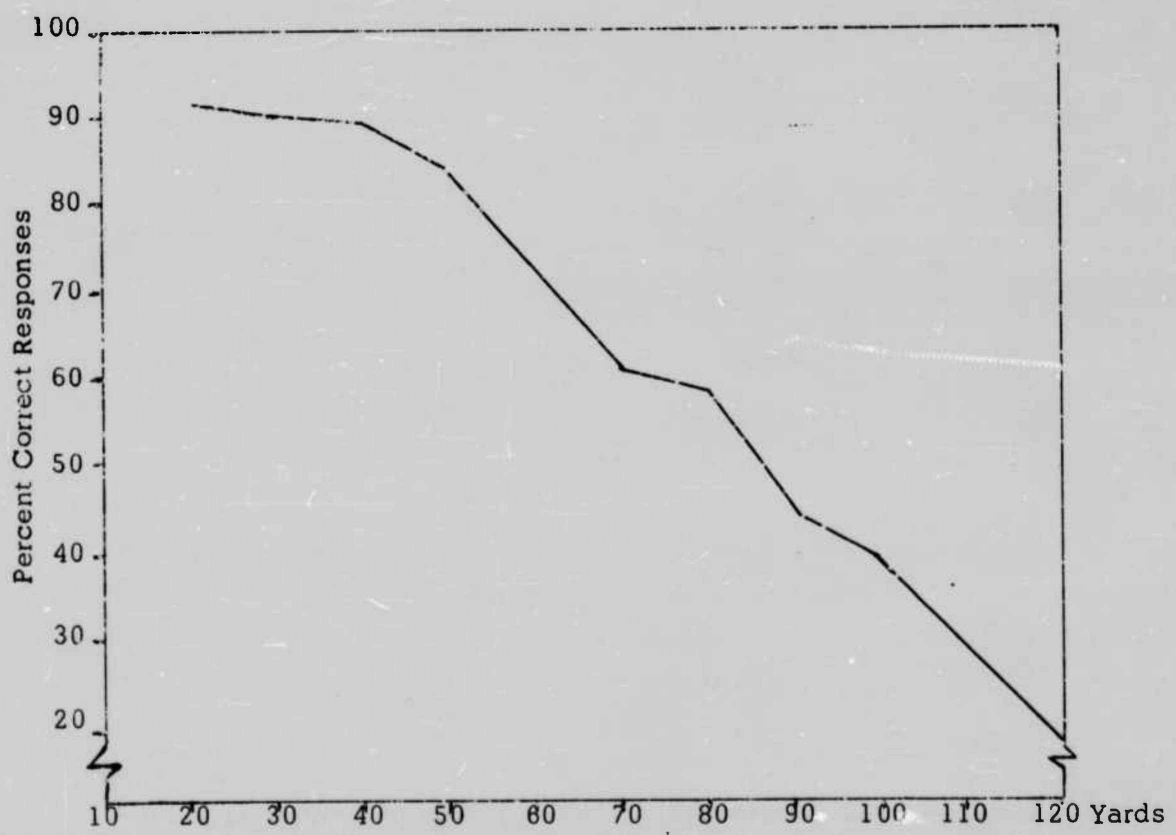



FIGURE 6. EFFECTS OF DISTANCE ON TARGET IDENTIFICATION FOR COMBINED OBSERVER AND TARGET POSITIONS (FULL-MOON EXPERIMENT)

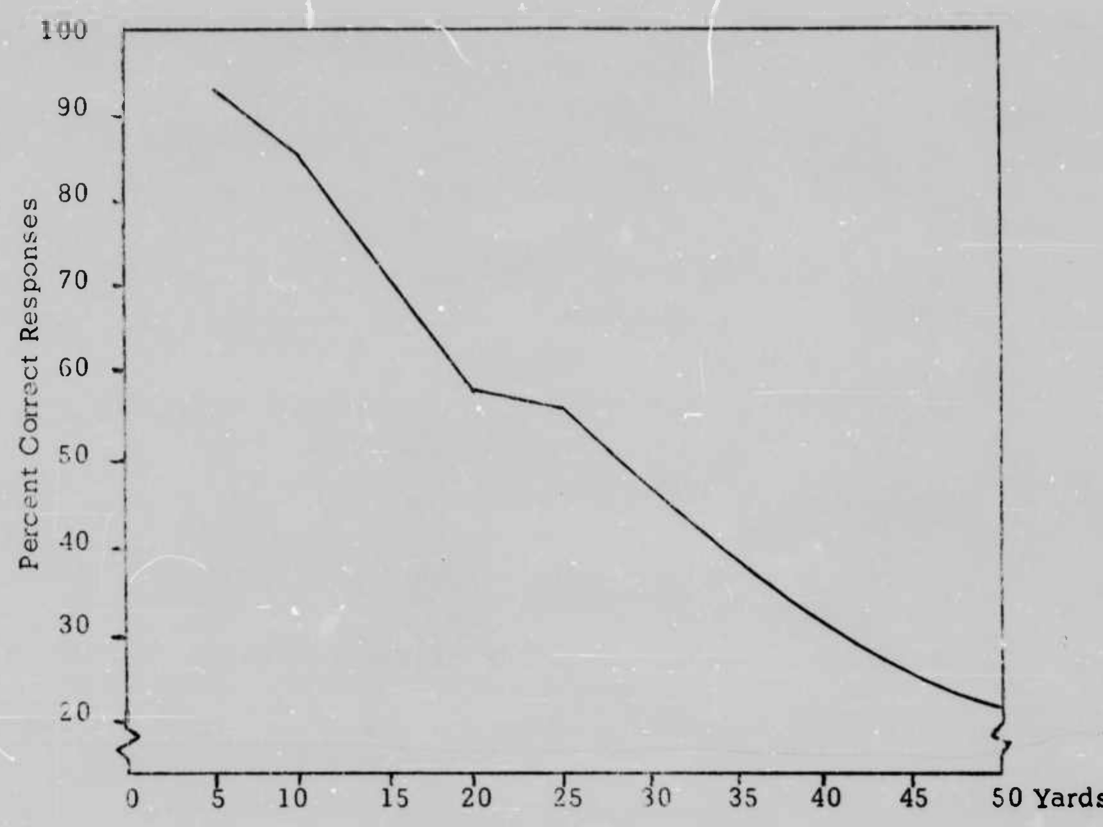



FIGURE 7. EFFECTS OF DISTANCE ON TARGET IDENTIFICATION FOR COMBINED OBSERVER AND TARGET POSITIONS (NO-MOON EXPERIMENT)

Discussion

The data of this experiment are reported differently than were the data of the first two studies. In this study, the percent of correct responses as a function of distance is reported. This is very helpful for determining the extreme range of detection distances, but it makes comparison with other studies that have not accomplished this more difficult.

STUDY FOUR

The next study was done in 1957 by the U. S. Army Armor Human Research Unit at Fort Knox, Kentucky (10). The primary goal of the investigation was to study the recognition distances of vehicles which were silhouetted by an 18-inch, 2000-watt searchlight. However, since a control group under a no-searchlight condition was included, these results are of primary interest for this report.

Procedure

A group of 180 soldiers from the Armor Center was used as subjects in the study. A field detection course was set up which had four paths on a flat, grass-covered field. Path 1 was 60 yards to the left of the observer, Path 2 was immediately to the front of the observer, Path 3 was 50 yards to the right of the observer, and Path 4 was 125 yards to the right of the observer. These paths extended approximately 1500 yards to the front of the observer's position.

Two pieces of equipment, an M-48 tank or a 2-1/2-ton truck were used as targets. Under the no-searchlight conditions (no moon), a target drove down one of the paths until the observer detected it and then continued driving until the observer identified it.

In order to mask the sound of the motors of the targets, a loud speaker which played white noise was positioned behind each observer. The variables studied were the two types of targets, the four paths, and the two sound conditions (noise or no-noise).

Results

The data are shown in Table 7. The authors reported that there was no statistical difference between detection and recognition ranges; so all data are median recognition ranges expressed in yards. The authors stated that the median was used since there were cases when the targets were never seen, and, thus, there were zero scores.

TABLE 7

RECOGNITION RANGES (YARDS) FOR THE M-48 TANK AND THE 2-1/2-TON TRUCK

| | Tank | | Truck | |
|---|---|---|---|---|
| Path | Noise | No Noise | Noise | No Noise |
| 4 | 111 | 210 | 86 | 77 |
| 3 | 126 | 192 | 100 | 95 |
| 2 | 184 | 155 | 83 | 108 |
| 1 | 152 | 165 | 91 | 97 |
| Paths combined | 140 | 173 | 85 | 81 |

Discussion

This study is the only one reviewed which varied the position of the target to the right and left of the observer. Although this apparently caused differences in the scores, the results do not establish a definite trend that can be generalized to other situations.

The presence or absence of noise did not appear to affect the scores in any systematic way. The authors suggest that the noise may not have been of the appropriate frequency, or of sufficient intensity, to mask the sound of the vehicles.

STUDY FIVE

The next study was accomplished at Fort Knox in 1959 (9). Although the determination of visibility distances was not the primary purpose of this investigation, some of the data reported are of interest.

Procedure

The 83 subjects used were enrolled in Armor Advanced Individual Training. On a relatively flat, grass-covered field, a detection course was established which had 14 lanes. For 10 of the lanes, a piece of equipment was placed in the target area; a kneeling target was used in one lane, and the remaining lanes contained no targets. Subjects were dark adapted and then required to walk along the lanes until they detected "something." They were then asked to continue walking until they recognized the target. All testing was done under moonless and cloudless conditions.

Results

The targets were grouped into three categories according to size. "Large" targets included such things as a 2-1/2-ton truck, "medium" targets included such things as a jeep, and 2-man tents and similar size material were grouped as "small" targets. The mean scores reported in Table 8 are measurements in yards. These scores were derived from data presented in the report by combining the means of the two experimental groups.

TABLE 8

VISIBILITY RANGES FOR TARGETS GROUPED ACCORDING TO SIZE

| | Detection Scores (yards) | Recognition Scores (yards) |
|---|---|---|
| Large Targets | 73.5 | 45.0 |
| Medium Targets | 43.2 | 24.3 |
| Small Targets | 16.6 | 11.4 |

Discussion

The procedure in this study was remarkably similar to the Camp Blanding investigation (Study Two). No range of scores was reported, but the analysis of data as a function of target size is of interest.

STUDY SIX

The last study that will be discussed was conducted in 1962 at Fort Benning (7). Once again, the primary purpose of the study was other than target detection; however, some of the data are relevant to the purposes of this report.

Procedure

Ten observers were seated about 60 feet above a very large, flat, grass-covered field. Targets, which were camouflaged human figures, were presented at varying distances to the front of the observers, and the observers were required to detect the targets within a two-minute time limit. The targets were either standing or were walking (relative direction not given). This investigation was conducted under full moonlight conditions, but no data are given about the position of the moon relative to the observer or about moon elevation.

Results

The results are presented in Table 9. The data are the percent of targets detected for varying distances. No targets were presented at distances of less than 100 meters because of a limitation in the physical characteristics of the experimental area.

TABLE 9

VISIBILITY RANGES FOR HUMAN TARGETS

| Distance (meters) | Percent Detected: Standing Target | Percent Detected: Walking Target |
|---|---|---|
| 250 | 25 | No data |
| 180 | 50 | 25 |
| 130 | 75 | No data |
| 100 | 90 | 45 |

Discussion

Since a complete report of this study has yet to be published, the data presented here were taken from a condensed version. For our purposes, it is regrettable that no targets were presented at distances of less than 100 meters, since it prevents comparisons with the other studies which include data for this range. It is interesting that the observers were apparently better able to detect a stationary target than a moving target. No reason is given by the authors for this finding.

SUMMARY

In this summary we shall first determine the adequacy of the target detection studies in their treatment of the visibility factors which were identified in Chapter 2, and then discuss the results of the investigations with regard to specific distances.

Table 10 outlines the six major visibility factors previously presented. Each study is rated on the significant variables, with each column indicating a specific study. It is clear from Table 10 that some of the major factors are described more adequately by the studies than others. For example, the parameters of illumination conditions and situational variables are at least partially described by almost all of the studies. However, the factors of atmospheric conditions and background variables are discussed only sketchily, if at all. The six studies appear to be generally consistent in that a variable discussed in one study was usually mentioned in the others; and, likewise, some variables, particularly those having to do with target background, were usually not reported.

Because of the omissions in the studies, it is judged that it would be extremely difficult to replicate the exact experimental conditions that were used in most of the investigations. This problem will be discussed further in Chapter 6, in which some specific suggestions for future research in this area will be made.

Because each of the preceding six studies on target detection under low levels of illumination used a somewhat different experimental procedure, it is very difficult to make meaningful comparisons among the results of the various investigations. In order to give some categorization to the divergent data, a somewhat standardized reference situation must be established and selected data must be used.

In order to summarize the data on detection and identification of stationary targets, either the mean detection or identification distances for stationary targets have been used, or, if the data is reported as the number of correct responses as a function of range, the distance that 50 percent of the observers

TABLE 10

RATING OF TARGET DETECTION STUDIES ON VISIBILITY FACTORS

| | Target Detection Study | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1. Atmospheric Conditions | | | | | | |
| Degree of clearness | clear | clear | clear | clear | clear | clear |
| Presence of fog | | | | | | |
| Haze | none | | | | | |
| Dust | | | | | | |
| Rain | | | | | | |
| Snow | | | | | | |
| 2. Illumination Conditions | | | | | | |
| Intensity | given | N/A | no moon or full moon | N/A | N/A | full moon |
| Directional or diffuse | directional | N/A | directional | N/A | N/A | directional |
| Orientation of source to observer | back & front | N/A | back | N/A | N/A | |
| Orientation of source to object | back & front | N/A | front | N/A | N/A | |
| 3. Object Variables | | | | | | |
| Area (size) | men | vehicles & equipment | men | tank & truck | given | men |
| Shape | men | vehicles & equipment | men | tank & truck | given | men |
| Movement | given | none | none | given | none | given |
| Orientation to observer | facing | facing | facing | facing | facing | facing |
| General brightness level | | | | | | |
| Brightness contrast with immediate background | given | | | | | |
| Intra-object brightness contrasts | | | | | | |
| 4. Background Variables | | | | | | |
| Brightness level | | | | | | |
| Textural effects | given | | | | | |

| | Target Detection Study | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 5. Observer Variables | | | | | | |
| Visual adaptation level | dark adapted | dark adapted 30 min. | dark adapted 30 min. | dark adapted | dark adapted | dark adapted |
| Acuity at adaptation level | | | | | | |
| Attention | | | | | | |
| Motivation | | "poor" for one group | | | | |
| Training | well trained | no special | given | no special | no special | no special |
| 6. Situational Variables | | | | | | |
| Instructions | | look in spec. dir. | look in spec. dir. | look in gen. dir. | look in spec. dir. | look in gen. dir. |
| Time permitted for judgments | | | 15 sec. | 3 sec. | | 2 min. |
| Degree of search required | | little | little | some | little | some |
| Criteria for correctness of response | | I & D | I | I & D | I & D | D |

Notes:

1. A blank space indicates that the variable was not mentioned in the write-up of the study.
2. N/A indicates that the variable is not applicable to the specific study.
3. Given indicates that the measurement of the variable is described, but is too extensive to include in this summary table.
4. I & D indicate identification and detection, respectively.

saw the target has been chosen as the criterion. Using these parameters as a means of consolidating the data, Figure 8 has been prepared. This figure presents in graphic form the general results of the various experiments on target detection.

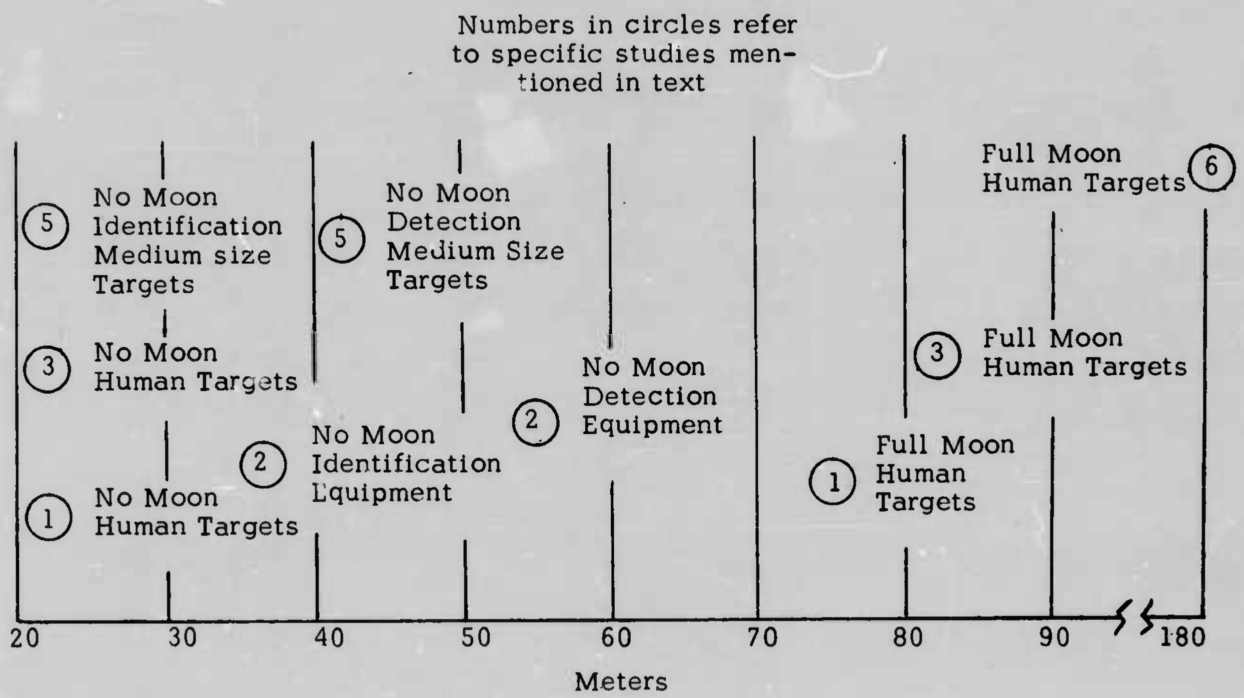



FIGURE 8. VISIBILITY OF TARGETS UNDER EITHER NO-MOON OR FULL-MOON CONDITIONS

Figure 8 demonstrates that even when data standardization is attempted, a definitive picture is not obtained for stationary target detection and identification distances under either no-moon or full-moon conditions. There are two general statements that can be made from the present data:

1. Under no-moon conditions, the maximum visibility range was about 55 meters.
2. Under full-moon conditions, the minimum visibility distance was about 75 meters.

Thus, the data for stationary targets indicate a discontinuous distribution with the maximum visibility distance under no-moon conditions being separated from the minimum visibility distance under full-moon conditions by about 20 meters. However, consideration must be given to the fact that group means are presented here, and, thus, for any one individual, it is possible that the no-moon and full-moon visibility distributions ay overlap.

## CHAPTER 5

## SUGGESTIONS FOR FUTURE RESEARCH

### INTRODUCTION

Although the target detection studies reviewed in Chapter 5 provide data for certain specific situations, they are by no means definitive in scope. Moreover, few general conclusions applicable to a wide variety of situations were established. Further research is thus needed if a more adequate understanding of the capabilities and limitations of unaided visual perception under low levels of natural illumination is to be achieved. Several suggestions, formulated to foster the soundness, replicability, and validity of such research, will now be offered for consideration.

### COMPREHENSIVENESS

The shortcomings of the reviewed studies demonstrate the need to take into account, within each investigation, all of the factors known to affect visual perception. Ideally, each factor should receive specific attention during the planning, should be varied or controlled during the implementation, and should be accounted for in the write-up of every piece of research. A checklist based on the set of perceptual factors presented in Chapter 1 should prove useful for this purpose. In comparison with past studies, such research could more easily be replicated, and the findings would provide much sounder and more valid bases for conclusions.

### ATMOSPHERIC CONDITIONS

Studies of the effects of the presence of dust, fog, haze, rain, smoke, and snow in the atmosphere on the visibility of military targets are virtually non-existent. Thus, solutions for many problems of visual detection, identification, and range estimation under these conditions in daylight and darkness--including the development of performance, training, and instruction techniques--await the findings of future research.

### ILLUMINATION CONDITIONS

Past studies have limited themselves almost exclusively to the two extreme conditions of full moon and no moon. More often than not, the position of the moon with respect to the target and the observer has not been specified. Thus, even with respect to full-moon conditions, much remains to be learned of the specific effects of elevation and directionality on visibility. The effects of intermediate phases of moonlight remain largely unexplored. The systematic investigation of the effects of changes in moon phase, elevation, and direction with respect to observer and target would fill what is perhaps one of the most serious gaps in our knowledge in this area.

OBJECT VARIABLES

Little has been done toward determining those object characteristics that increase and those that decrease the probability of detection and identification under low levels of natural illumination. The effects of size and motion have been investigated in a limited way. The findings with respect to motion, as reported in two of the reviewed studies, are contradictory. Research on the effects of such attributes as area, brightness level, brightness contrast with immediate background, internal brightness contrasts, movement, orientation to observer, and shape would contribute not only to knowledge of the stimulus correlates of visual perception but also to the development of techniques both for raising and for lowering the likelihood of the visual detection and identification of objects under low levels of natural light.

BACKGROUND VARIABLES

The effects of variation in background variables have not been systematically investigated. In fact, the scant attention that has been paid to these variables has generally been limited to nominal description. Hence, the effects of change in the brightness level, proximity, and texture of backgrounds on the visibility of objects under low levels of natural illumination have yet to be explored.

OBSERVER VARIABLES

So few studies have been conducted in the natural environment that practically no direct knowledge about observer characteristics is at hand. Findings of laboratory studies of the dark-adapted eye and the dark-adaptation process have been used in the past as a basis for the development of selection and training procedures without verification of their validity for the detection and identification of objects in outdoor settings under low levels of natural illumination. As shown in Chapter 4, the range of light intensity varies from photopic through mesopic to scotopic levels during the hours from sunset to sunrise. It would be surprising, therefore, if visual perception under such conditions were found to be a simple function of the absolute threshold for light or of scotopic acuity. Consequently, the investigation of relationships between perceptual performance on a set of visual tasks representative of those encountered in Infantry night operations and photopic, mesopic, and scotopic visual acuity would significantly increase our understanding of the sensory requirements for effective perceptual performance.

Since so little is known about the effects of observer characteristics on the perceptual performances of interest, there is a need to identify those attributes that contribute to effective performance and those that detract from performance. The intensive study of a group of exceptionally effective observers and a group of exceptionally poor observers selected on a set of representative visual tasks could conceivably result in the isolation of such attributes. The leads derived from the study of extreme groups could then be followed up by experiments designed to establish the validity of a set of characteristics necessary for proficient perceptual performance. The results of such research would have important implications for the selection and training of observers and would contribute to our knowledge of perceptual processes.

Soundly based knowledge of the capabilities and limitations of visual perception under low levels of natural illumination would greatly aid the planning of both offensive and defensive night military operations. It is clear from the discussion in Chapter 5 that the data gathered to date are insufficient for this purpose. There is a need, therefore, for normative data based on the performance of a set of representative visual tasks by an adequate sample of personnel normally assigned to night operations.

SITUATIONAL CONDITIONS

Past research has demonstrated only slight concern for the representativeness of the visual tasks and the situational conditions under which performance has been evaluated. Fc xample, as shown in Chapter 5, observers were usually told the specific direction in which to look, thus little or no search was required. The compilation of a catalog of Infantry night operations and a subsequent analysis into component visual tasks and situational conditions would provide populations of tasks and conditions from which representative samples could be drawn.

CONCLUSIONS

In view of the small amount of research effort that has been expended on investigations of visual perception under low levels of natural illumination, it is not surprising that needs for further research are indicated for all of the visibility factors outlined in Chapter 2. That this area of visual perception has received so little attention is understandable when it is realized that Infantry night missions are about the only source of situations in which the detection and identification of objects under such conditions is a vital matter. Another factor has been the willingness to extrapolate the results of studies of the dark adapted eye under laboratory conditions to problems of the perception of actual targets under low levels of natural light. It seems clear that resolution of the many problems referred to is desirable and that improved techniques of performance, training, and instruction would derive from the indicated research.

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APPENDIXES

# APPENDIX A

# PREPARATION OF MOON DIAGRAMS AND CHARTS

Knowledge of the intensity and other characteristics of the illumination potentially available between the hours of sunset and sunrise is of considerable importance to those concerned with visual performance under natural illumination during those hours. The following items of information are especially pertinent to the planning and implementation of outdoor night operations and research:

1. Local times of sunrise and sunset
2. Local times and durations of
   a. civil twilight
   b. nautical twilight
   c. night
   d. moonlight
3. Moon phase
4. Path of moon across night sky

Astronomical tables, prepared and published locally in connection with the operation of air fields and weather stations, are prime sources of information on the above phenomena. Such tables are usually prepared for each month and include local times of sunrise, sunset, moonrise, moonset, beginning of morning nautical twilight, end of evening nautical twilight, beginning of morning civil twilight, end of evening civil twilight, and the phase of the moon for each day.

Accurate knowledge of the moon's phases and apparent movements across the sky during the hours of darkness is, without doubt, most helpful in the planning and execution of night operations. Such information, coupled with knowledge of the relative visibility ranges for personnel and equipment under various conditions of natural illumination, seems essential to the conduct of consistently successful Infantry missions at night.

To aid interested personnel in gathering and classifying visibility information, two methods of displaying moon data are presented. The first method is by means of a Moon Diagram. By plotting certain astronomical data on this diagram, the apparent path of the moon, including the azimuths for rising and setting and the elevation above the horizon, can be determined for any geographical position. The second means of data presentation is a Moonlight Availability Chart. By plotting information on this chart, the duration of night, the phase of the moon, and the amount of light available from the moon for any time during a night can be determined. Although the methods of data plotting for these two techniques are presented separately for the purpose of clarity, it should be understood that for complete moon information the two charts should always be used together.

PLOTTING A MOON DIAGRAM

To plot a moon diagram, the Local Mean Time (LMT) of each of the following events is required:

1. End of Evening Nautical Twilight (EENT)
2. Moonrise (MR)
3. Meridian Passage (Mer. Pass.)
4. Moonset (MS)
5. Beginning of Morning Nautical Twilight (BMNT)

True azimuths of MR and MS will also be needed. With the exception of the time of Mer. Pass. and the azimuths of MR and MS, all of the required data are available in locally published Astronomical Tables. Such Tables are prepared and distributed at Fort Benning, Georgia, by the 16th Weather Squadron-Det 10, 2d Weather Group (MATS), United States Air Force, Lawson Army Air Field (see Table A-1).

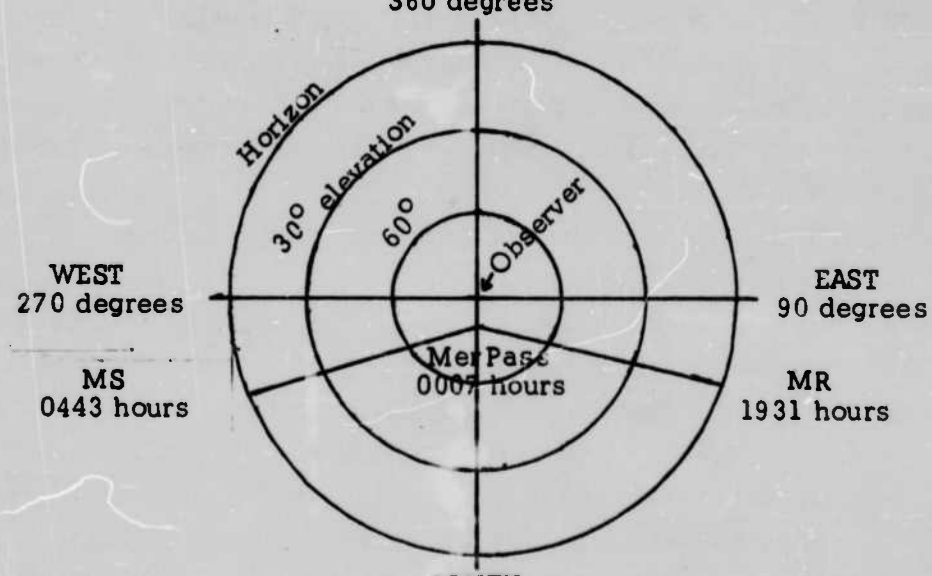


FIGURE A-1. MOON DIAGRAM

The time of Mer. Pass. and the azimuths of MR and MS may be taken from The Air Almanac issued three times a year by the Nautical Almanac Office, United States Naval Observatory, and available from the United States Government Printing Office, Washington, D.C.

The obtained data may be plotted on a diagram such as the one shown in Figure A-1. The outer circle represents the true horizon, the intermediate circle represents an elevation of 30 degrees above the horizon, and the inner circle represents an elevation of 60 degrees above the horizon. The common center of the concentric circles serves a dual purpose: it represents the location of the observer on the ground for determining azimuths, and it also represents the zenith (90 degrees above the horizon) for determining elevation.

On the diagram, the line running from north to south is called the meridian and represents the longitude of the observer. The line running from east to west, through the center of the circle, is the latitude of the observer. The latitude and longitude of any geographical location may be obtained from a map of the area.

To establish the apparent path of the moon for a specific geographical location, it is necessary to locate the three points of MR, MS, and Mer. Pass. on the diagram. Since the elevation of the moon at MR and MS is at the horizon, it is necessary to determine only the azimuths at which these events occur to locate the specific points representing them on the diagram.

To compute the azimuths for MR and MS, enter the appropriate daily sheet of The Air Almanac with the local time of occurrence for these events. Find the indicated time entry in the leftmost column, which is headed GMT (Greenwich Mean Time).[1] Follow this row across to the column headed "MOON" and extract the indicated GHA (Greenwich Hour Angle).[1] If the local time does not correspond exactly with a listed time entry, an adjustment should be made in the GHA value by consulting the Interpolation of GHA table[2] given on the inside front cover of The Air Almanac, for use with the A.M. pages, and on the flap, for use with the P.M. pages.

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[1] A complete description of GMT and GHA will be found in the Explanation Section of The Air Almanac.

[2] For an explanation of this table see Section 4, Page A5, The Air Almanac.

Next, convert the obtained GHA value to a true azimuth by adding 180 degrees to it if the value is less than 180, or by subtracting 180 degrees from it if the value is more than 180. When this is done, plot the points representing MR and MS on the outer circle of the diagram at the respective azimuth locations and enter the local times of occurrence.

To locate the point representing Mer. Pass., it is necessary to compute the time and elevation at which the moon crosses the meridian, i.e., an imaginary line running from north to south, at the observer's location. The exact time of Mer. Pass. may be determined by locating the GHA column for the moon on the appropriate daily sheet in The Air Almanac and determining when the GHA reaches 360 degrees. It is at this exact time that the moon will be at its highest point in its path across the sky. Since the times in The Air Almanac are given in 10-minute intervals, it will probably be necessary to again use the Interpolation of GHA Table to extract the amount of time to be added to that found in the GMT column so that the GHA value is adjusted to the required 360 degrees.

To compute the elevation of the moon at the time of Mer. Pass., extract from the Moon column the declination (Dec.) value corresponding to the GHA value that approximates 360 degrees, i.e., the GHA value that is nearest to 360 degrees. No interpolation is required. To convert the Dec. value to elevation above the horizon at the specific latitude of the observer, it is necessary, first, to subtract algebraically the Dec. value from the latitude of the observer, and, then, to subtract the remainder from 90 degrees. Thus, for locations in the northern hemisphere, if the Dec. value is preceded by N, that value is treated as a positive number and is subtracted from the latitude of the observer, then, the remainder is subtracted from 90 degrees. If, on the other hand, the Dec. value is preceded by S, that value is treated as a negative number and it is, in effect, added to the latitude of the observer and the sum is then subtracted from 90 degrees. For locations in the southern hemisphere, Dec. values preceded by N are treated as negative numbers and, in effect, are added to the latitude of the observer, and Dec. values preceded by S are treated as positive numbers and are subtracted from the latitude of the observer.

At the time of meridian passage, the moon reaches its highest apparent elevation in its path across the sky. The computed elevation value is plotted on the north-south line on the diagram at the proper distance from the center point to indicate the height of the moon above the horizon as seen by the observer at the time of meridian passage. The local time of meridian passage is also entered on the diagram as shown in Figure A-1.

The moon diagram is completed by drawing a line connecting the three points representing M[illegible] Mer. Pass., and MS. This line represents the path of the moon across the sky as seen on a specific nig[illegible] specific latitude. Although the true path would be more nearly represented by curved lines, straight lines provide sufficient exactness for our purpose. Due to the movement of the moon, it is necessary to plot a separate moon diagram for each night and for each change in latitude.

PREPARING A MOONLIGHT AVAILABILITY CHART

To construct a moonlight availability chart, the following data are required:

1. End of Evening Nautical Twilight (EENT)
2. Moonrise (MR)
3. Moonset (MS)
4. Beginning of Morning Nautical Twilight (BMNT)

It is recommended that Sunset (SS) be included on the chart, but it is not essential. All required data should be obtained from local weather stations, as moonlight availability charts are prepared for a specific geographical location.

Since the period during which moonlight is available usually extends from approximately 1800 hours one day to about 0600 hours the next day (for the portion of the earth between 50 degrees north and south latitude), it is convenient to present moonlight availability for this two-day period of time on one line. In the sample chart (see Figure A-2), you will notice that, on the top line of data on the far left, the date is Wednesday, 1 August, and directly across the top line to the far right is Thursday, 2 August.

The first step in the preparation of a moonlight availability chart is to determine the maximum time range for the month under consideration. To decide what range should be used in the chart, you must calculate the earliest time that moonlight is available on any evening during the month and the latest time that moonlight is available on any morning during the month.

When the time range for the entire month has been computed and the hours plotted across the top of the page, you are ready to proceed to the second step--preparing the graphic chart. Here, the days of the month, from the first day to the

August 1962 - Moonlight availability from "End of Evening Nautical Twilight" till "Begin Morning Nautical Twilight" the following day

CODES: SS - Sunset; EENT - End of Evening Nautical Twilight; MR - Moonrise; MS - Moonset; BMNT - Beginning of Morning Nautical Twilight

| Day and | Date | SS | EENT | MR | MS | Phase | BMNT | Day and | Date |
|---|---|---|---|---|---|---|---|---|---|
| Wednesday | 1 | 1938 | 2034 | 0651 | 2034 | New | 0459 | Thursday | 2 |
| Thursday | 2 | 1937 | 2033 | 0746 | 2110 | New | 0500 | Friday | 3 |
| Friday | 3 | 1936 | 2032 | 0841 | 2142 | 1/4 | 0500 | Saturday | 4 |
| Saturday | 4 | 1935 | 2031 | 0933 | 2213 | 1/4 | 0501 | Sunday | 5 |
| Sunday | 5 | 1934 | 2030 | 1026 | 2244 | 1/4 | 0501 | Monday | 6 |
| Monday | 6 | 1933 | 2028 | 1118 | 2315 | 1/4 | 0501 | Tuesday | 7 |
| Tuesday | 7 | 1932 | 2027 | 1213 | 2347 | 1/2 | 0502 | Wednesday | 8 |
| Wednesday | 8 | 1931 | 2025 | 1307 | XXX | 1/2 | 0502 | Thursday | 9 |
| Thursday | 9 | 1930 | 2024 | 1403 | 0022 | 1/2 | 0503 | Friday | 10 |
| Friday | 10 | 1929 | 2023 | 1501 | 0100 | 1/2 | 0504 | Saturday | 11 |
| Saturday | 11 | 1927 | 2021 | 1559 | 0145 | 3/4 | 0504 | Sunday | 12 |
| Sunday | 12 | 1926 | 2020 | 1658 | 0234 | 3/4 | 0505 | Monday | 13 |
| Monday | 13 | 1925 | 2018 | 1753 | 0331 | 3/4 | 0506 | Tuesday | 14 |
| Tuesday | 14 | 1923 | 2017 | 1946 | 0433 | 3/4 | 0506 | Wednesday | 15 |
| Wednesday | 15 | 1921 | 2015 | 1935 | 0540 | Full | 0507 | Thursday | 16 |
| Thursday | 16 | 1920 | 2013 | 2021 | 0648 | Full | 0508 | Friday | 17 |
| Friday | 17 | 1918 | 2012 | 2102 | 0758 | Full | 0509 | Saturday | 18 |
| Saturday | 18 | 1917 | 2011 | 2142 | 0907 | 3/4 | 0510 | Sunday | 19 |
| Sunday | 19 | 1916 | 2010 | 2221 | 1014 | 3/4 | 0511 | Monday | 20 |
| Monday | 20 | 1915 | 2008 | 2301 | 1121 | 3/4 | 0512 | Tuesday | 21 |
| Tuesday | 21 | 1914 | 2007 | 2342 | 1225 | 1/2 | 0513 | Wednesday | 22 |
| Wednesday | 22 | 1913 | 2006 | XX | 1329 | 1/2 | 0514 | Thursday | 23 |
| Thursday | 23 | 1912 | 2005 | 0025 | 1429 | 1/2 | 0515 | Friday | 24 |
| Friday | 24 | 1911 | 2004 | 0112 | 1527 | 1/2 | 0516 | Saturday | 25 |
| Saturday | 25 | 1910 | 2003 | 0202 | 1620 | 1/4 | 0517 | Sunday | 26 |
| Sunday | 26 | 1909 | 2002 | 0255 | 1709 | 1/4 | 0518 | Monday | 27 |
| Monday | 27 | 1908 | 2001 | 0350 | 1753 | 1/4 | 0519 | Tuesday | 28 |
| Tuesday | 28 | 1907 | 2000 | 0444 | 1835 | 1/4 | 0520 | Wednesday | 29 |
| Wednesday | 29 | 1906 | 1959 | 0539 | 1910 | New | 0521 | Thursday | 30 |
| Thursday | 30 | 1905 | 1958 | 0634 | 1943 | New | 0521 | Friday | 31 |
| Friday | 31 | 1905 | 1958 | 0727 | 2015 | New | 0522 | Saturday | 1 |

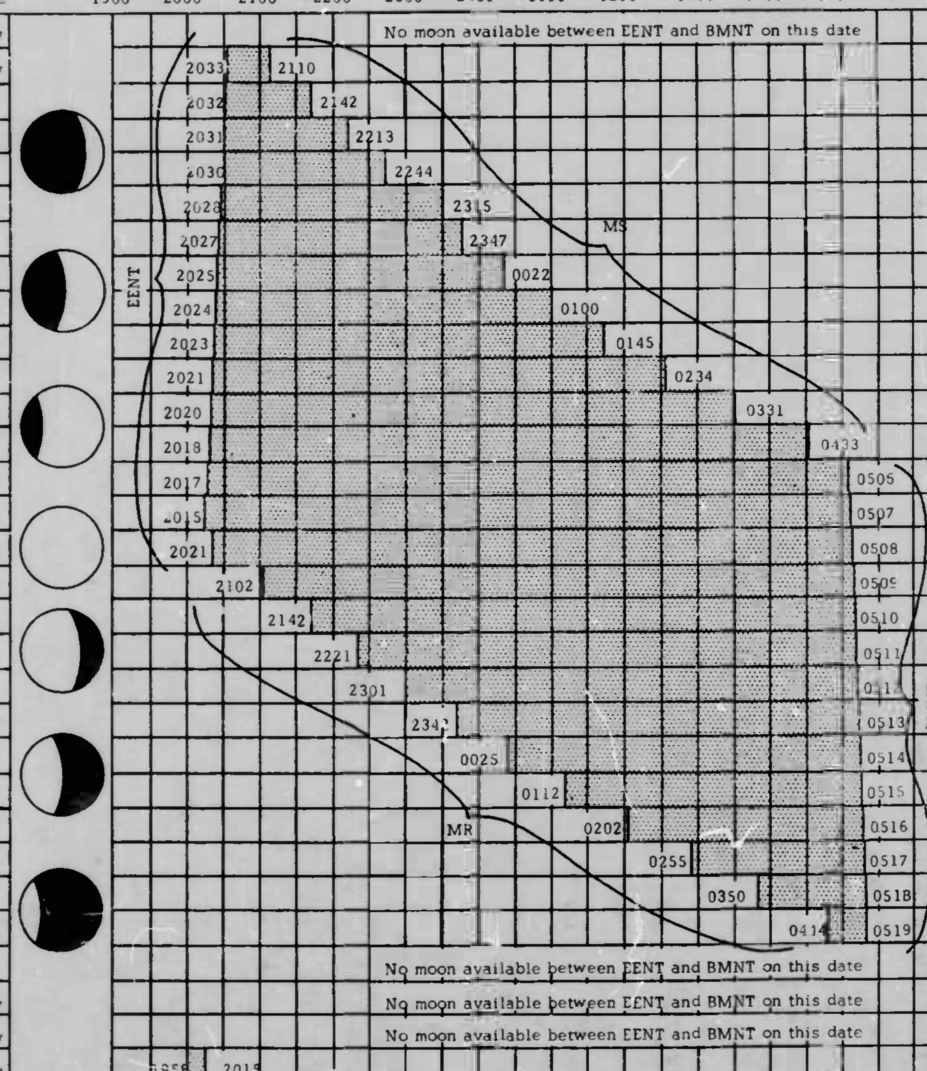


FIGURE A-2. MOONLIGHT AVAILABILITY CHART last day of the month, are listed in sequence on the left side of the chart. Listed directly to the right of each day of the month are the data indicating the time of SS, EENT, MR, MS, and the phase of the moon for that day. These specific data were obtained from the Climatological Summary for August 1962, Lawson Army Air Field Bulletin, Astronomical Tables, page 2 (see Table A-1). Listed, in sequence, on the far right of the chart is the BMNT for each day of the month from the second day of the month to the first day of the next month.

In the center of the chart, the period of time moonlight is available for any given night is shown in graphic form. Notice that on the left side, the time given for beginning of the period of available moonlight is given either as EENT or MR. This is due to the fact that sometimes the moon will rise before dark (before the EENT), making this moonlight "unusable" until after dark. If the moon rises before the EENT, then the EENT is used as the beginning time for the period of moonlight availability; but if the moon rises after the EENT, then the time of MR is used as the beginning time.

Now, the same reasoning applies to the process of determining the time of termination of the moonlight availability period, i.e., if the moon sets before the BMNT, then MS is used as the end of the period of moonlight availability, but if the MS is after the BMNT, then the time of the BMNT is used as the end of the period of moonlight availability.

Variations in MR and MS can cause confusion in preparing the graph unless it is remembered that sometimes the moon will rise on one day and not set on that day, or the moon will set on a day with no moonrise. These situations occur when the moon either rises or sets after 2400 hours (midnight) of the day under consideration. These instances are depicted on the chart by the symbol "XX," used in the absence of moonrise, and by the symbol "XXX," used to indicate the absence of moonset for that particular 24-hour period. Of course, the moon will eventually rise or set, but if it either rises or sets after 2400 hours, it will be considered to have occurred during the next day, and not during the day on which it had originally started its movement.

Occasionally, there will be no moonlight available for a certain night even though the moon is in one of its light-giving phases (see Wednesday, 1 August, Figure A-2). This phenomenon will occur when the moon sets at the same time as, or before, the EENT.

APPENDIX A

## TABLE A-1

## ASTRONOMICAL TABLES
August 1962

| DATE | BMNT | BMCT | SR | SS | EECT | EENT | MR | MS | PHASE |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0459 | 0529 | 0555 | 1938 | 2004 | 2034 | 0651 | 2034 | NEW |
| 2 | 0459 | 0529 | 0555 | 1937 | [illegible] | 2033 | 0746 | 2110 | NEW |
| 3 | 0500 | 0530 | 0556 | 1936 | [illegible] | 2032 | 0841 | 2142 | 1/4 |
| 4 | 0500 | 0530 | 0556 | 1935 | 2001 | 2031 | 0933 | 2213 | 1/4 |
| 5 | 0501 | 0531 | 0556 | 1934 | 2000 | 2030 | 1026 | 2244 | 1/4 |
| 6 | 0501 | 0531 | 0557 | 1933 | 1959 | 2028 | 1118 | 2315 | 1/4 |
| 7 | 0501 | 0532 | 0557 | 1932 | 1958 | 2027 | 1213 | 2347 | 1/2 |
| 8 | 0502 | 0532 | 0557 | 1931 | 1957 | 2025 | 1307 | XXX | 1/2 |
| 9 | 0502 | 0533 | 0558 | 1930 | 1956 | 2024 | 1403 | 0022 | 1/2 |
| 10 | 0503 | 0533 | 0558 | 1929 | 1955 | 2023 | 1501 | 0100 | 1/2 |
| 11 | 0504 | 0534 | 0559 | 1927 | 1953 | 2021 | 1559 | 0145 | 3/4 |
| 12 | 0504 | 0535 | 0559 | 1926 | 1952 | 2020 | 1658 | 0234 | 3/4 |
| 13 | 0505 | 0535 | 0559 | 1925 | 1950 | 2018 | 1753 | 0331 | 3/4 |
| 14 | 0506 | 0536 | 0600 | 1923 | 1949 | 2017 | 1846 | 0433 | 3/4 |
| 15 | 0506 | 0536 | 0600 | 1921 | 1947 | 2015 | 1935 | 0540 | FULL |
| 16 | 0507 | 0537 | 0601 | 1920 | 1946 | 2013 | 2021 | 0648 | FULL |
| 17 | 0508 | 0538 | 0602 | 1918 | 1945 | 2012 | 2102 | 0758 | FULL |
| 18 | 0509 | 0539 | 0602 | 1917 | 1944 | 2011 | 2142 | 0907 | 3/4 |
| 19 | 0510 | 0540 | 0603 | 1916 | 1943 | 2010 | 2221 | 1014 | 3/4 |
| 20 | 0511 | 0541 | 0604 | 1915 | 1941 | 2008 | 2301 | 1121 | 3/4 |
| 21 | 0512 | 0541 | 0605 | 1914 | 1940 | 2007 | 2342 | 1225 | 1/2 |
| 22 | 0513 | 0541 | 0606 | 1913 | 1939 | 2006 | XX | 1329 | 1/2 |
| 23 | 0514 | 0542 | 0607 | 1912 | 1937 | 2005 | 0025 | 1429 | 1/2 |
| 24 | 0515 | 0543 | 0608 | 1911 | 1936 | 2004 | 0112 | 1527 | 1/2 |
| 25 | 0516 | 0544 | 0609 | 1910 | 1935 | 2003 | 0202 | 1620 | 1/4 |
| 26 | 0517 | 0545 | 0610 | 1909 | 1934 | 2002 | 0255 | 1709 | 1/4 |
| 27 | 0518 | 0546 | 0611 | 1908 | 1933 | 2001 | 0350 | 1753 | 1/4 |
| 28 | 0519 | 0547 | 0612 | 1907 | 1932 | 2000 | 0444 | 1835 | 1/4 |
| 29 | 0520 | 0548 | 0613 | 1906 | 1931 | 1959 | 0539 | 1910 | NEW |
| 30 | 0521 | 0549 | 0614 | 1905 | 1930 | 1958 | 0634 | 1943 | NEW |
| 31 | 0521 | 0549 | 0614 | 1905 | 1930 | 1958 | 0727 | 2015 | NEW |

XX Moon does not rise this date
XXX Moon does not set this date

BMNT Beginning of morning nautical twilight
BMCT Beginning of morning civil twilight
SR Sunrise
SS Sunset
EECT End of evening civil twilight
EENT End of evening nautical twilight
MR Moonrise
MS Moonset

The advantage of a moonlight availability chart is in its concise method of data presentation. By merely glancing at the chart, an observer can quickly determine the phase of the moon, the times of moonrise and moonset, and whether there will be any moonlight available during the period of time that is of interest to him. Thus, night operations in which the amount of moonlight present is a significant factor, can be accurately planned far in advance.

# APPENDIX B

# BIBLIOGRAPHY

## APPENDIX B

In attempting to identify studies on night target detection that were accomplished in a field situation, the following sources were surveyed.


1. ASTIA reference material covering the period 1952-1963 under the following Divisions and Subject Headings:

| | Divisions | Subject Headings |
| --- | --- | --- |
| 2. | Astronomy, Geophysics, | Detection |
| | and Geography | Identification |
| 6. | Detection | Military Training |
| 16. | Medical Sciences | Night Sky |
| 18. | Military Sciences and | Night Warfare |
| | Operations | Range Finding |
| 23. | Personnel and | Target Recognition |
| | Training | Targets |
| 28. | Psychology and Human | Visibility |
| | Engineering | Vision |
| | | Visual Acuity |
| | | Visual Perception |
| | | Visual Signals |
| | | Visual Threshold |

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