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NIGHT AERIAL SEARCH FOR AVIATORS DOWNED AT SEA
(OPTIMUM SEARCH PROCEDURES)

by

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(OPTIMUM SEARCH PROCEDURES)

1. INTRODUCTION AND SUMMARY

Navy tests[1] have demonstrated that the helmet of a Naval aviator downed and afloat at night can be sighted from a searchlight-equipped rescue helicopter if the helmet is covered with a retrodirective reflecting material. Samples of red and white reflective plastic adhesive tapes presently recommended for this purpose by the Bureau of Naval Weapons are mounted below.

The new H2(HU2K) rescue helicopter* is equipped with an electrically-controlled spotlight for night sea-search; this report specifies the optimum search procedures.

A newly marketed, improved reflecting material produces a 10-fold increase in area search-rate and a greater probability of detection when white caps are present. Optimum procedures for using the new material are specified by this report.

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*This helicopter will be referred to as the H2 throughout this report.

1.1 Summary of this Report

This report presents optimum search procedures, derived by engineering calculations and supported by a field test, for

(a) the H2 rescue helicopter as presently equipped with an electrically-controlled G.E. No. 4580 spotlight, or

(b) the H2 when equipped with the new AN/AVQ-4(XN-1) four-million candlepower airborne searchlight for helicopter use presently under development by the Bureau of Naval Weapons,

when:

(c) used with any of four different reflective treatments for flight helmets,

(d) under three atmospheric conditions (clear, haze, dense haze), and

(e) with wind velocities up to 20 knots.

For <u>each</u> <u>combination</u> of (a) through (e) above there exists:

(1) an optimum flight altitude,

(2) an optimum flight speed,

(3) an optimum angle of depression for the beam of light,

(4) an optimum angular sweep,

(5) an optimum rate of sweeping,

(6) an optimum zone in which to look within the beam of light,

(7) an optimum search pattern for the helicopter, and

(8) a maximum probability of detection.

For all combinations, the optimum procedures are:

(a) depicted graphically in 44 perspective drawings,

(b) summarized in two tables, and

(c) compared for area search-rate by means of histograms.

Later sections of the report describe:

(1) a static test at sea of the performance of both airborne lights and all four helmet treatments, and

(2) the engineering methods by which the recommendations were obtained.

A semi-automatic control system for establishing the optimum search procedure under any prevailing weather condition is proposed on the next page of this report.

2. AUTOMATIC CONTROL OF NIGHT SEA-SEARCH

The results of the night sea-search study described by this report lead in a natural way to an automatic means for controlling the search procedure. As will be seen later in this Section, the crew of the helicopter need only decide which of several degrees of atmospheric clarity prevails, touch the corresponding control button, and follow the light beam with their eyes. Instructions printed on the instrument panel specify the optimum flight altitude and ground speed. When the search is flown in this way, optimum area search-rate and maximum detection probability will be achieved.

Each of the perspective drawings in Sect. 4 of this report illustrates the optimum search procedure for one particular light, one particular helmet, and one particular atmospheric condition. After a specific helmet has been standardized by the Navy, installation of a particular type of spotlight or searchlight on a helicopter can be accompanied by the installation of a control system of the type to be described. Both the spotlight now carried by the H2 helicopter and the 4 million candlepower airborne searchlight presently under development are electrically-operated in order that the observer may direct them by means of a simple hand-operated control. It is suggested that a programming mechanism be added to the control in order that the optimum angle of depression for the beam of light, the optimum angular sweep, and the optimum angular rate of sweep will be automatically established whenever the mechanism is supplied with information about the prevailing atmospheric clarity. This would be accomplished by means of a small control panel mounted within the helicopter cockpit. Figure 1 shows a concept of the appearance of such a control panel.

SPOTLIGHT CONTROL FOR SEA-SEARCH			
VISIBILITY	>16 MILES	4 MILES	1 MILE
WEATHER	CLEAR	HAZY	DENSE
BEST ALTITUDE	550 FEET	265 FEET	210 FEET
BEST GROUND SPEED	120 KNOTS	90 KNOTS	60 KNOTS
SWEEP WIDTH	950 YARDS	350 YARDS	320 YARDS
FOLLOW THE BEAM LOOK IN THE CENTER 	MANUAL	OFF	

Fig. 1

The observer in the helicopter must estimate the prevailing atmospheric clarity or ascertain it by radio from a nearby Naval vessel. Prevailing conditions will be characterized by three (or more) broad terms such as CLEAR, HAZY, or DENSE, or by the statement (in meteorological terms) that the visibility is greater than 16 miles, 4 miles, or 1 mile. Having made this decision, the observer turns on the spotlight by pressing the appropriate control button. This act automatically sets the light beam at the optimum angle of depression and causes it to begin sweeping horizontally through the optimum angle at the optimum rate of sweep.

Illustrative Example

Figure 1 has been drawn for the case of the presently used G.E. No. 4580 spotlight and the flight helmet equipped with the improved retrodirective reflector material. In this case, pressing the CLEAR button would (see Fig. 9-1) cause the spotlight beam to be depressed 20° below the horizon and swept through a total angle of 142° (71° each side of the flight path), each sweep being completed in 5.2 sec. The pilot is told by the lettering on the control panel directly below the CLEAR button (see Fig. 1) that the optimum ground speed is 120 knots, that the optimum flight altitude is 550 feet, and that the sweep width is 950 yards. The information on the control panel reminds him to follow the beam with his eyes and concentrate his gaze in the central portion of the beam pattern, as shown by the small diagram (see Fig. 1). In addition, the officer in charge of the sea-search operation will know that 0.92 square nautical miles of ocean surface are being searched each minute with a probability of detection approaching 100 per cent if the wind velocity is below 8 knots and diminishing to a probability of 0.85 when the wind velocity is 20 knots.

If the observer pushes the second button marked HAZE, the automatic programming device will automatically depress the spotlight 20° below the horizon and sweep it through an angle of 94° (i.e., 47° each side of the flight path), each 3.4 sec. The information on the control panel in the cockpit will inform the pilot that the best ground speed for this condition is 90 knots at an altitude of 265 feet, and that his sweep width is 350 yards. The officer in charge of the mission will have the information that 0.26 square nautical miles of ocean surface are being swept each minute with a probability of detection approaching 100 per cent when the wind velocity is less than 8 knots and falling to 85 per cent when the wind velocity is 20 knots.

A decision that the haze is dense and characterized by a visibility of about 1 mile would cause the third button (marked DENSE) to be pushed. This would cause the spotlight to be depressed 20° below the horizon, swept through a total angle of 112° (56° each side of the flight path), each 4.3 sec. The information on the control panel in the cockpit would inform the pilot that the best ground speed for this condition is 60 knots, the best altitude is 210 feet, and that his sweep width is 320 yards. The officer in control of the mission would also know that under these circumstances 0.15 square nautical miles of ocean surface is being searched each minute with a probability of detection approaching 100 per cent if the wind velocity is less than 8 knots and diminishing to 85 per cent when the wind velocity is 20 knots.

Manual Control

When the floating aviator has been sighted, the observer has only to touch the lower left button marked MANUAL to establish hand-operated control of the spotlight. The lower right-hand button marked OFF extinguishes the light; it can be turned on again by touching any of the other four buttons on the control panel.

Summary

The results of the engineering study contained in this report are incorporated into the mechanism of the spotlight control system and displayed in abbreviated form on the control panel in the cockpit. Optimum search is achieved automatically once a decision is made concerning the prevailing clarity of the atmosphere. Shipboard instruments can measure atmospheric clarity and techniques for estimating it visually are available.

Caution

The numerical values cited in the above Illustrative Example and shown in Fig. 1 apply only to the case of the G.E. No. 4580 spotlight and a flight helmet equipped with the improved reflecting material. Numerical values applicable to 11 other helmet-and-searchlight combinations are given in the charts and tables contained in this report. Important gains can be achieved through the use of binoculars. Optimum procedures for search with binoculars are also described.

Before presenting the detailed results of the engineering study, a description of the equipment will be given.

3. EQUIPMENT

The results depicted graphically in Sects. 4 and 5 of this report are critically affected by certain characteristics of the helicopter, the airborne light, and the helmet. The pertinent characteristics of each of these components will now be discussed.

3.1 The Aerial Vehicle

The new H2 helicopter manufactured by the Kaman Aircraft Company is now in use by the Navy. It is specially designed as a search and rescue vehicle; it carries automatic stabilization equipment and hovering lights for night rescue work. It is capable of operating at the speeds specified by this report and it is also capable of a slow hover, a capability having search potentials discussed in a later section. It is understood that the H2 can hover in wind speeds up to 20 knots without combing the blades.

The H2 helicopter seats two pilots side by side. In the forward direction each man is able to see from high above the horizon to 25° below it. The latter limitation imposes an unfortunate limitation on the night search capability of the helicopter, particularly when dense haze prevails.

Figure 2 depicts the downward field of view to the right of the flight path as seen by the right-hand observer; this figure is based on drawings of the helicopter supplied by the manufacturer. The shaded area in the upper portion of Fig. 2 shows, in terms of depression angle, the directions in which the observer cannot see the surface of the ocean. In the lower portion of Fig. 2, this information is translated into a map of the ocean surface when the helicopter is at an altitude of 100 feet. The shaded area shows the portion of the surface of the sea which cannot be viewed from the helicopter cockpit and the limitation may not seem serious. This is, however, a false impression when hazy and dense atmospheric conditions prevent sightings at long range. It will be clear in Appendix D5 that the cockpit cutoff imposes a rather severe limitation on the H2 search capabilities using the spotlight under these circumstances. The cockpit cutoff also precludes the use of the hover lights altogether except when the observer looks out of the side window of the cockpit; it will be demonstrated in Appendix D3 that this is not a good way to conduct a visual search.

3.2 Light Sources

Three tungsten light sources have been considered in this study. They are, respectively, the General Electric No. 4580 spotlight presently carried by the H2 helicopter, the (3) stationary hover lights (General Electric No. 4582 floodlights), also carried by the H2, and an experimental airborne searchlight, the AN/AVQ-4(XN-1), loaned to the Visibility Laboratory for test purposes by the Bureau of Naval Weapons. See Fig. 3.

Spotlight

A G.E. No. 4580 sealed beam spotlight, producing a beam spread of 14° vertically and 13° horizontally and producing a maximum of intensity of 4×10^5 candles, is carried by the H2 in a retractable, electrically-operated mounting at the forward end of the helicopter beneath the center of the fuselage slightly forward of the pilot. The perpendicular distance

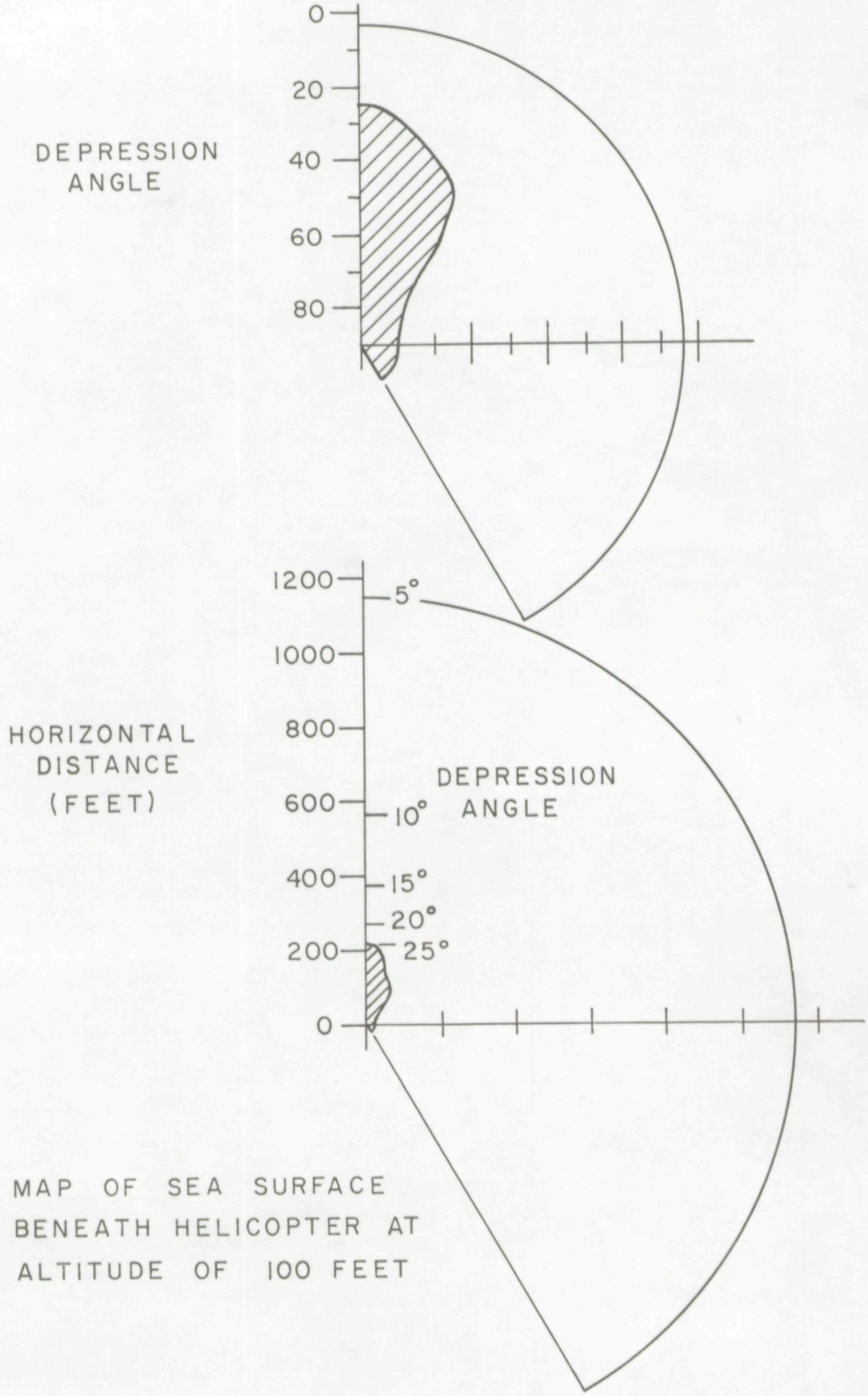


FIGURE 2 - FIELD OF VIEW FROM H2

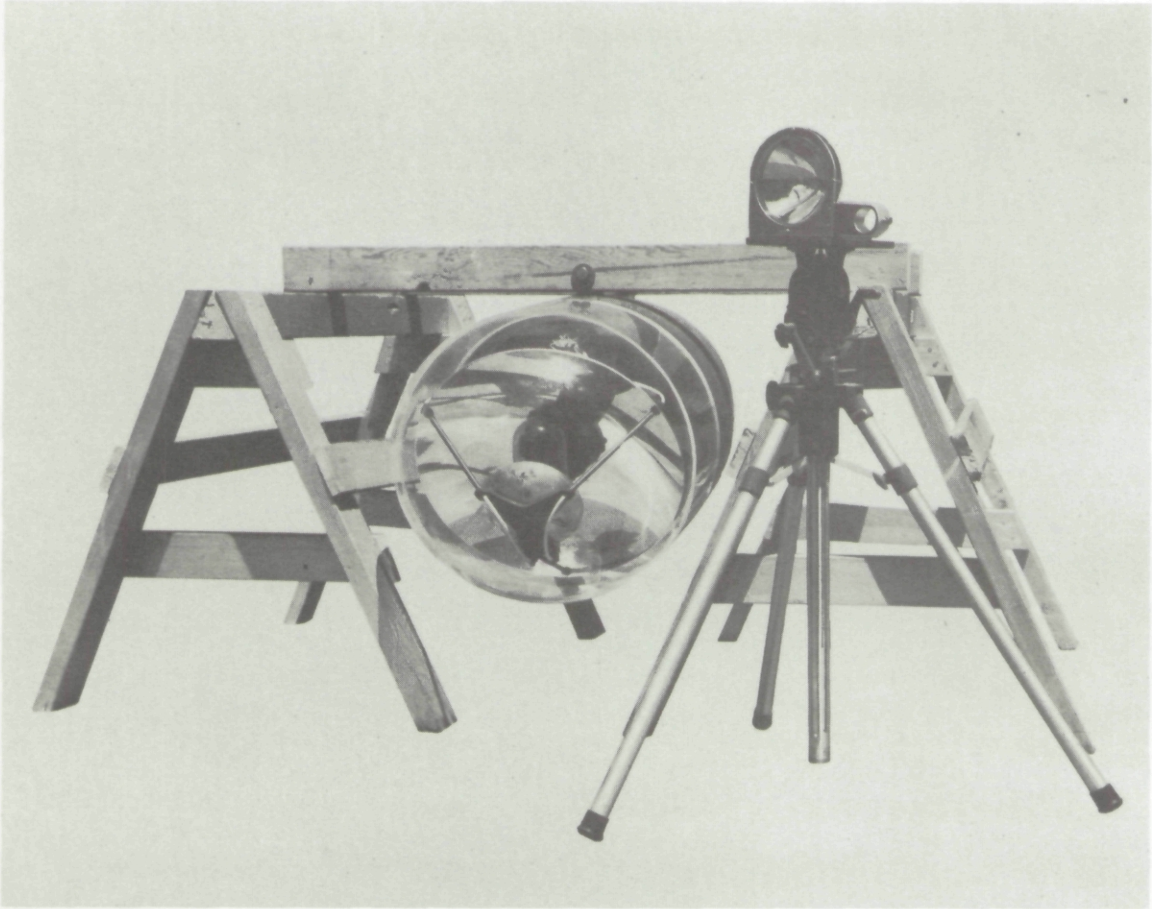


Figure 3. The AN/AVQ-4(XN-1) searchlight and the spotlight.

between the center of the spotlight and the path of sight of the observer varies with the angle of sight. When, for example, the light beam is directed forward and depressed one-half degree below the horizon, the center of the beam is 5.5 feet from the path of sight of the observer, but when the spotlight is depressed 25° below the horizon, the corresponding distance is 3 feet. The spotlight is controlled by means of a small button on a short stem capable of being moved to any position easily by the thumb of the observer. The spotlight is capable of being pointed anywhere in the hemisphere below the helicopter.* The G.E. No. 4580 sealed beam spotlight is 5.75 inches in diameter and 3.75 inches deep. One of these lamps, mounted on a tripod, appears in Fig. 3.

Floodlight

The H2 helicopter has three stationary sealed beam No. 4582 floodlights, each of which produces a beam spread of 60° vertically by 50° horizontally. The maximum intensity of these units is 2×10^{4} candles. They occupy the same size envelope as the sealed beam No. 4580 spotlight. The three floodlights are stationary and are primarily for the purpose of hovering or landing. The potential usefulness of these lights for night sea-search is discussed in Appendix D5 of this report.

Searchlight

Figure 3 is a photograph of the AN/AVQ-4(XN-1) experimental searchlight designed for airborne application and loaned to the Visibility Laboratory by the Bureau of Naval Weapons for the purpose of the studies described in this report. Our measurements show that it has a beam spread of 3° vertically and 8° horizontally and produces a maximum

*The information on the control of the spotlight was supplied verbally by Mr. William Murray, Vice President in charge of testing, Kaman Aircraft Company.

intensity of 2 x 10^6 candles. It is contained in a streamlined mounting 21 inches in diameter and 5 feet long. The front of this enclosure is a plastic dome inside which there is a tungsten filament projection lamp located at the focal point of a parabolic reflector. The lamp and reflector unit are remotely aimed by the co-pilot, who has a control stick for this purpose. The searchlight is capable of being positioned from 5° above the horizontal to 45° below the horizon, and it can be swung 90° in azimuth (45° on each side of the flight path). The control stick can be moved azimuthally and vertically simultaneously, or it can be locked at any vertical angle and made to move azimuthally only.

Figure 4 shows data on the candlepower distribution of the AN/AVQ-4(XN-1) searchlight. These data are based upon irradiance measurements at a range of 193 feet from the searchlight. Three configurations were measured: (1) without a plastic dome over the filament and the reflector; (2) with the plastic dome over the projector and with the searchlight pointed dead ahead; and (3) with the plastic dome over the projector and the searchlight pointed 45° to the left of dead ahead.

No provision has been made in the design of the H2 helicopter for the installation of this experimental searchlight. No engineering studies are known to have been made concerning where this unit might be mounted. Inasmuch as the perpendicular distance between the center of the searchlight beam and the path of sight of the observer critically affects detection capabilities, it was necessary to make some assumption concerning the location of the searchlight if it were carried by the helicopter. It was assumed that the searchlight could be placed in the same position as the retractable spotlight. This assumption was made in order to get a direct comparison between the capabilities of the two lights under other-

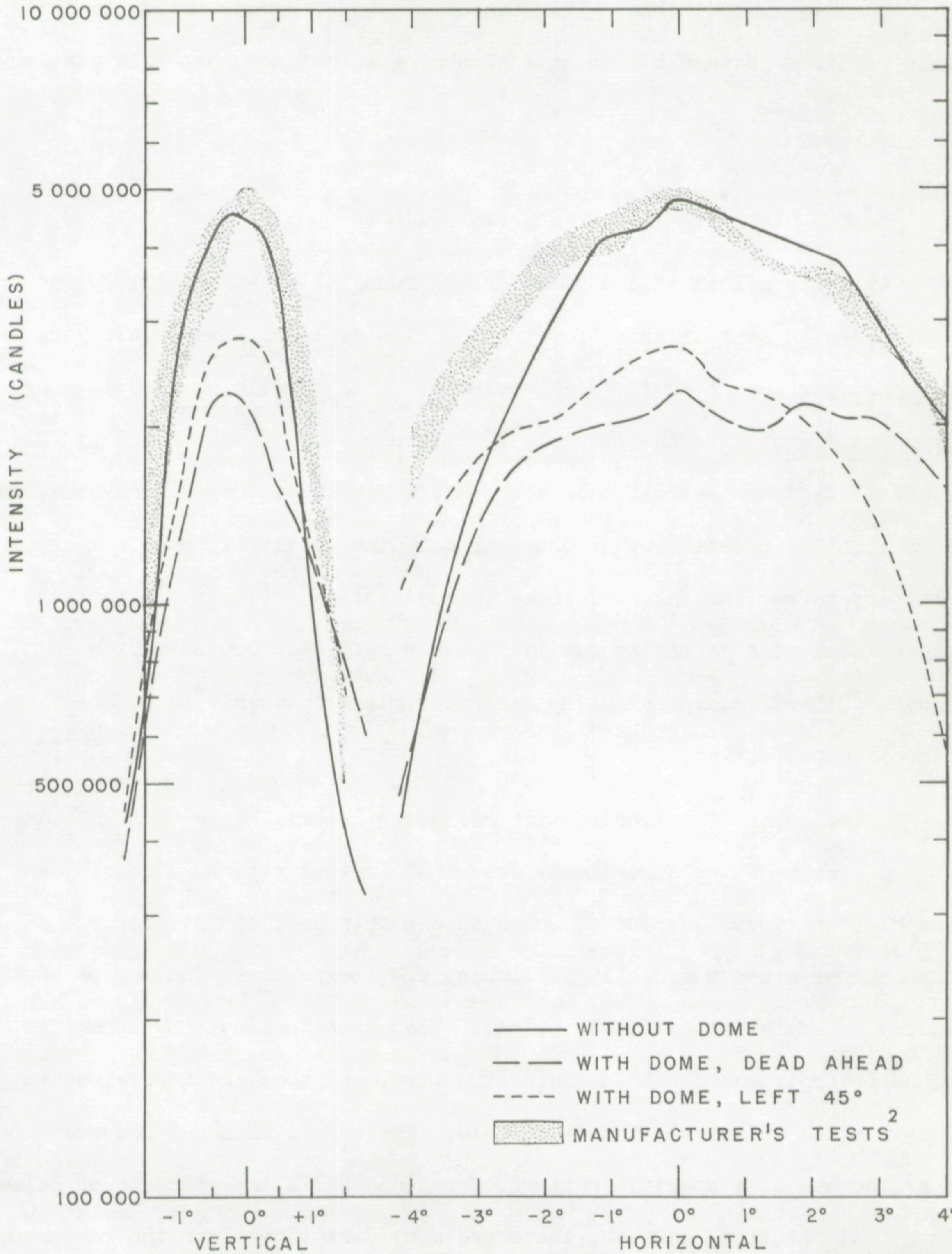


FIGURE 4 - CANDLEPOWER DISTRIBUTION OF AN/AVQ-4 (XN-1)

wise identical conditions. This choice of location does not imply that this position is feasible in an engineering sense, nor that this particular placement is optimum.

3.3 Helmets

Aviators afloat at sea would not be found at night by helicopters equipped with searchlights if retrodirective reflective materials were not incorporated in their flight helmets. Such materials, used in many roadside signs, have the property of returning light back toward its source. Because the return is concentrated into a rather narrow cone, much more light is received by an observer near the spotlight than from any ordinary reflecting surface. Some retrodirective reflective materials are optical analogs of the familiar corner reflector commonly used in radar. Others incorporate tiny spherical glass beads having retrodirective properties.

Three types of retrodirective reflector material have been tested in the course of the experiments described in this report. Two of them are plastic tapes, samples of which appear on page 1 of this report. These tapes are commercially available, are inexpensive, and may be applied easily to any existing flight helmet. They contain many tiny spherical glass beads imbedded within their structure, and they are impervious to moisture and relatively indestructible. The Bureau of Naval Weapons has recommended a specific pattern of red and white tape for use on helmets. In actual practice, however, there are many variations from the recommended pattern since the tape is applied by the individual aviator. Since optimized search patterns, such as those presented in this report, must be based upon helmets having specific optical properties, it will be necessary to adopt strict standards for the application of retrodirective reflector tape to the helmets. All helmets should conform to this specification in order that optimum search procedures can be used.

Figure 5 is a photograph of the four helmets upon which this report is based. They were used in the field tests described in Sect. 5. The four helmets were obtained from the Bureau of Naval Weapons Readiness Representative, PAC, NAS North Island. When received, the helmets, although mechanically identical, were painted different colors: gold, red, and white. For the sake of uniformity in the field tests, all four helmets were repainted a glossy white having a reflectance of 80 per cent. The helmet in the foreground of Fig. 5 bears the pattern of red and white plastic tape recommended by the Bureau of Naval Weapons. The helmet on the left in Fig. 5 is covered with all-white reflective tape. The rear helmet (bearing the numeral 3) has an identical coverage composed solely of red retrodirective tape. The fourth helmet, that on the right in the photograph, has a special treatment which will be described in this section. The basic shape of these helmets, apart from apertures for the face and neck of the pilot, is that of a sphere 10 inches in diameter.

Specifications for Taping Helmets

The Bureau of Naval Weapons provides the following specifications[3] for the reflective tape:

Item	FSN
Luminous reflectorized tape, red, 1-inch wide	D-8305-656-1494
Luminous reflectorized tape, silver, 6-inches wide	D-8305-558-0218

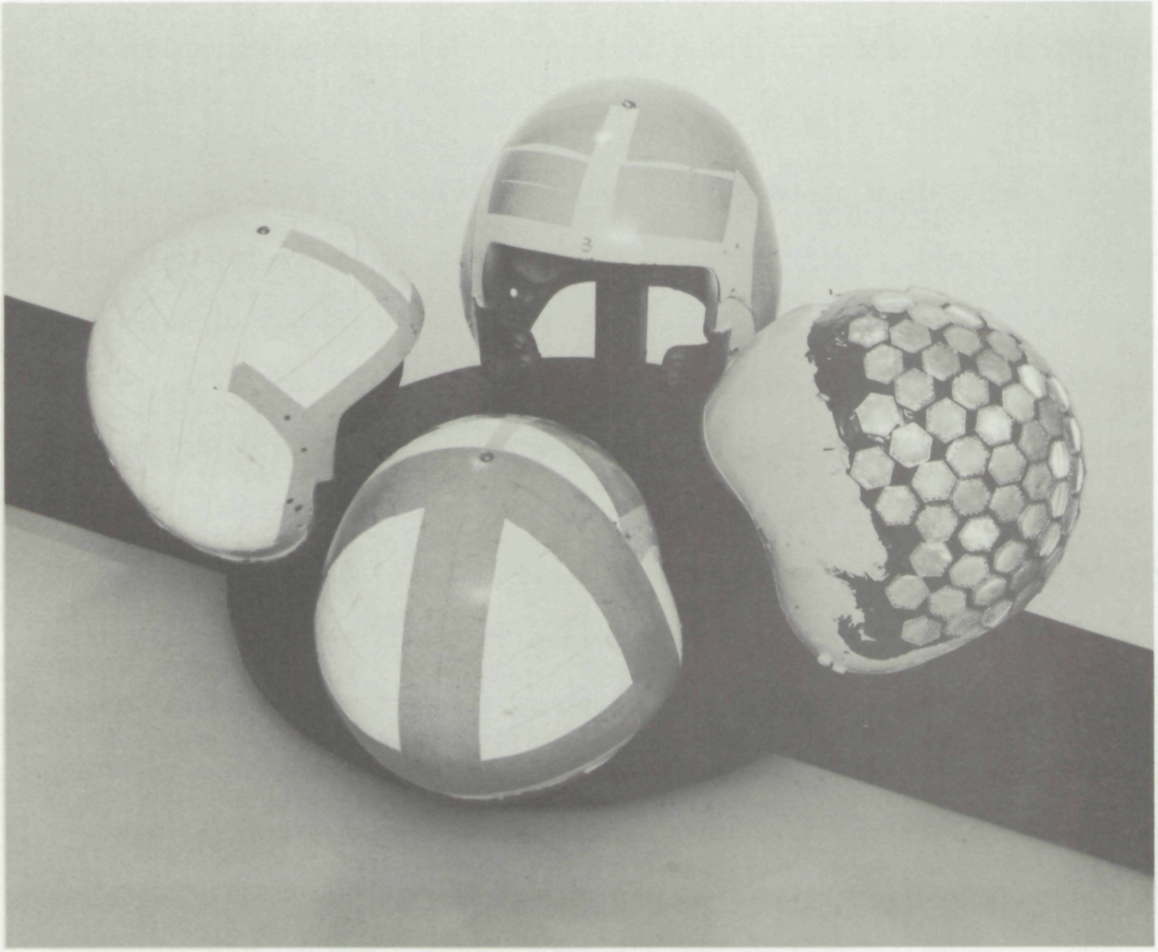


Figure 5. Helmets.

The spectral reflectance characteristics of the two tapes (red and white) were measured on a Hardy recording spectrophotometer; the resulting spectrophotometric data are shown in Fig. 6.

Instructions from the Bureau of Naval Weapons for applying the tapes specified the pattern illustrated in Fig. 5. It provides 14 square inches of red tape and 6 square inches of white tape. In the case of the all-white helmet, 20 square inches of white tape were used in the same way, and similarly in the case of the red helmet, 20 square inches of red tape were applied. The specific brightness of the taped helmets was measured by a technique which is described in Appendix A of this report. The results are shown in Fig. 7. It will be noted that the specific brightness of the back of any given helmet is roughly three times the specific brightness of the front. This is due, of course, to the aperture for the face of the pilot. It is unfortunate that the reflecting characteristics of the helmets are not omni-directional, inasmuch as there is no way to be certain how the aviator being searched for will be faced with respect to the helicopter. It has been assumed, however, that he will probably turn his face toward the rescue vehicle, thereby presenting his least favorable aspect to his rescuers. Although this assumption has been built into the calculations contained in the main body of this report, duplicate calculations using the reverse assumption (i.e., the assumption that the aviator will present the rear of his helmet to his rescuers) have also been carried through and are presented in Appendix B of the report in order to illustrate the gain in area search-rate that could be achieved under this circumstance. No way has been seen for giving the front view of a taped helmet a specific brightness equal to that of the rear view of the same helmet.*

*It will be noted that the red and white helmet has predominantly red tape when seen from the front and more white tape when seen from the rear. This is the reason for a larger spread in the data between the two helmet positions for the red and white helmet than occurs for the helmets which employ only one kind of tape.

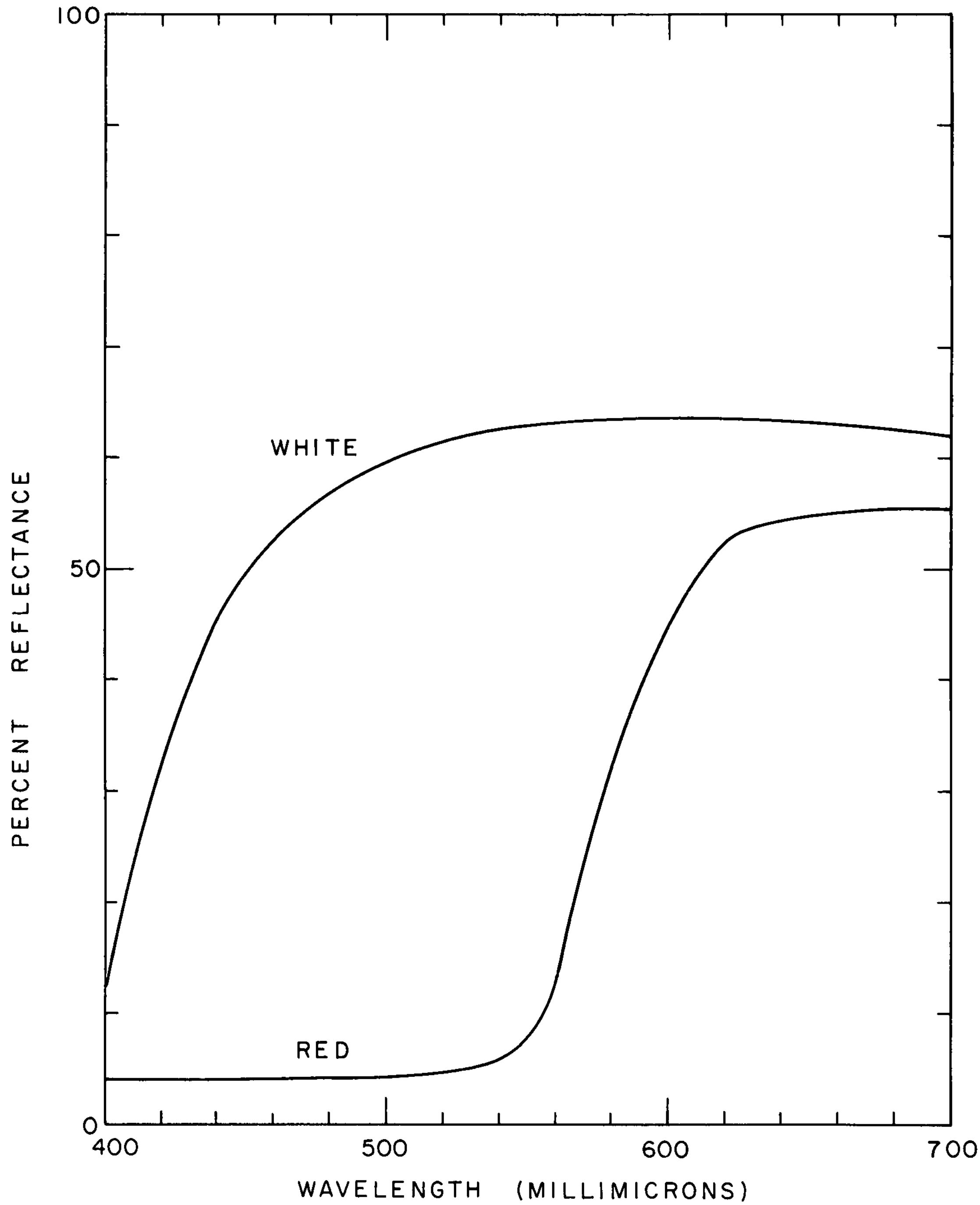


FIGURE 6 - SPECTRAL REFLECTANCE OF SCOTCHLITE REFLECTIVE TAPES

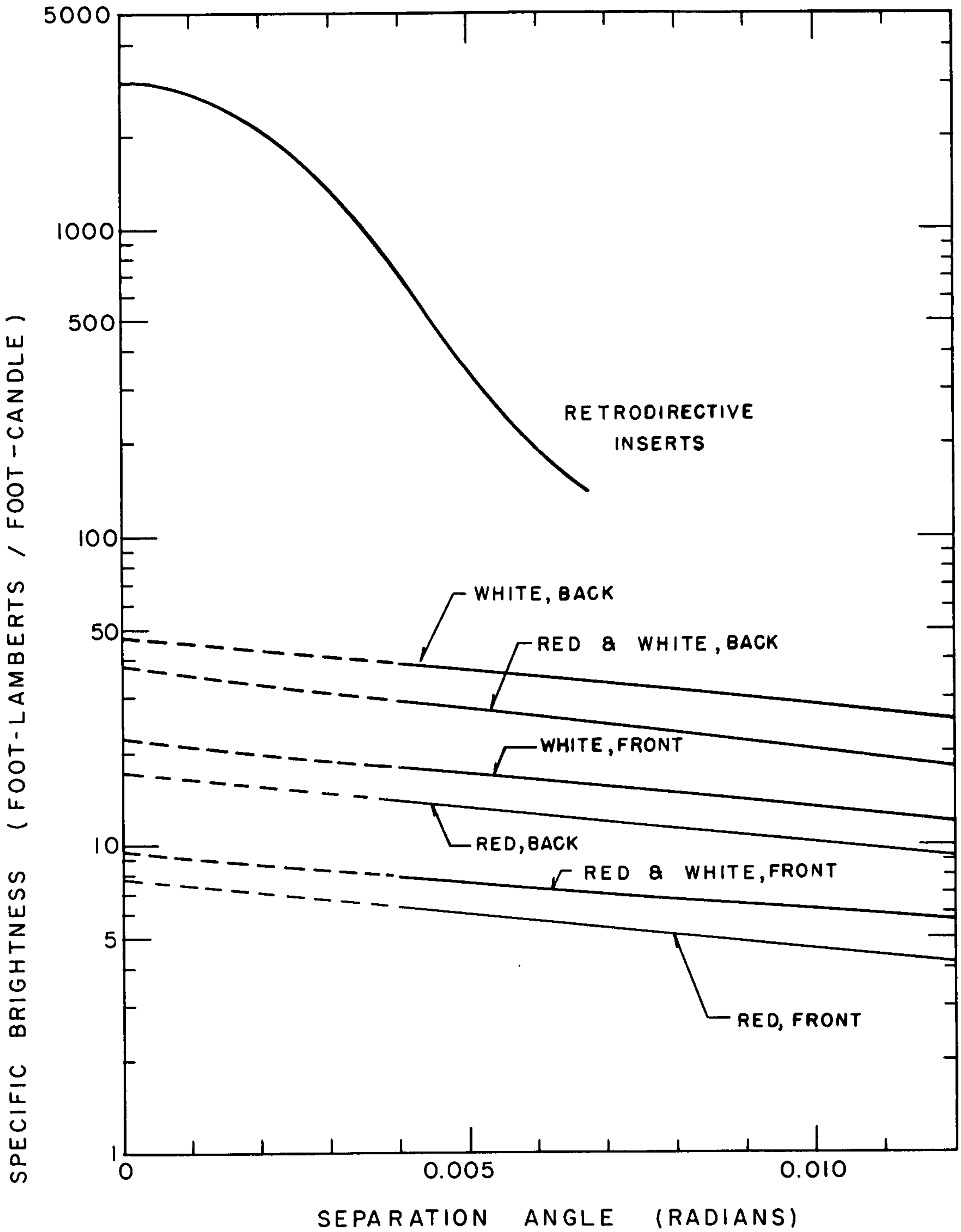


FIGURE 7 - SPECIFIC BRIGHTNESS OF HELMETS

Retrodirective Reflector Inserts

All retrodirective plastic tapes return the light toward the observer in a rather broad cone. Although this return is vastly more efficient than the hemispherical return provided by most ordinary surfaces, it is true, nevertheless, that retrodirective reflector materials which concentrate the returned light in a narrower cone more tightly fitted to the separation between the spotlight and the observer in the helicopter, are more efficient as reflectors and thus have greater specific brightness. The mechanical properties of plastic tape materials are such that a truly narrow-beam return is not possible. There have recently been placed upon the market, however, some high-precision plastic retrodirective reflector inserts which concentrate the reflected light in so narrow a cone that when applied to a helmet in the manner shown on the right in Fig. 5, they produce a specific brightness which is up to 400 times greater than that of the taped helmets. (See Fig. 7.) The enormous increase in reflective efficiency translates into:

(1) vastly greater area search-rates, and

(2) helmets having omnidirectional reflection characteristics.*

The gain possible by the use of plastic inserts instead of plastic tape is so dramatic that any costs associated with their use should be carefully weighed against the great advantage afforded by these materials.

Whereas the adhesive plastic tape can be applied to existing helmets either by the aviator or at the factory, this advantage is not shared by the retrodirective inserts. They must be incorporated in the helmet during manufacture. When suitably cast into the helmet, the individual

*Achieved by slight change in the shape of the forehead of the helmet.

plastic inserts will lose their mechanical identity and become an integral part of the helmet structure. They would, in fact, constitute an outer transparent layer fused to the reinforced Fiberglas shell of the helmet. The helmet exterior would then be completely smooth, just as at present.

For the purposes of the Visibility Laboratory's field test, the inserts were simply attached to an existing helmet by means of an adhesive, but it is not suggested that this be done in the case of head gear for flight use.

Comparison between Helmets

The maximum area search-rates for each of the four helmets shown in Fig. 5 under each of the three selected atmospheric conditions (dense haze, haze, and clear) are depicted graphically in Fig. 8. The crosshatched bars in this figure show the area search-rates which can be achieved with the retractable sealed beam spotlight, Type 4580, which is presently installed on the H2 helicopter. The increase in area search-rate possible by means of the AN/AVQ-4(XN-1) experimental searchlight is indicated by the taller, open addition to the bar. The dramatic improvement afforded by the retrodirective inserts, particularly in clear weather, is obvious.

Figure 8 does not reveal, however, a major additional advantage of the inserts. Their specific brightness is so high that the helmet, when caught in the searchlight beam, has the appearance of a searchlight itself. Because it is vastly more intense than any whitecap, the probability of detection does not diminish with sea state within the range of wind velocities in which the H2 can operate. In the case of

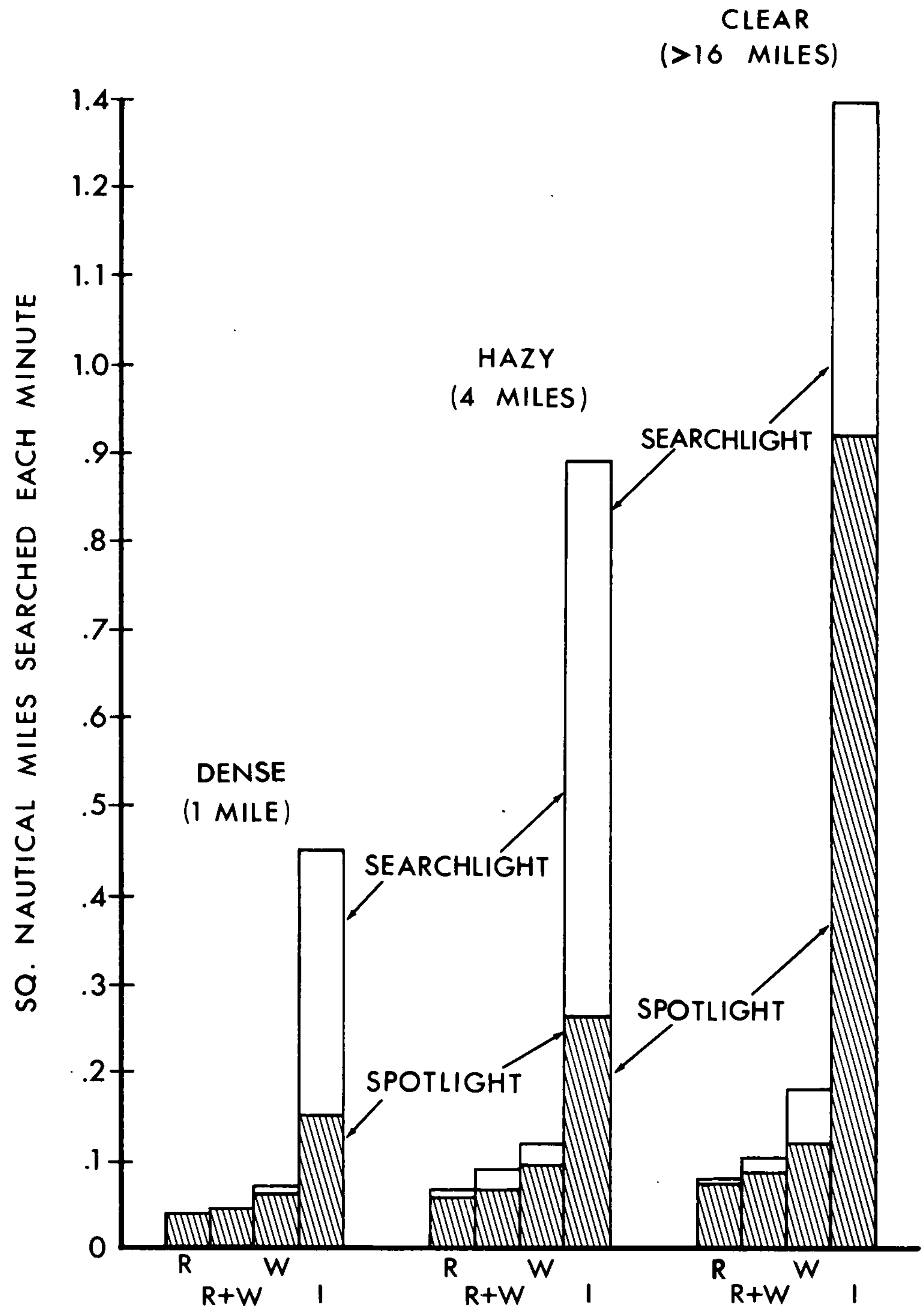


FIG. 8 COMPARISON BETWEEN HELMETS AND COMPARISON BETWEEN SPOTLIGHT AND SEARCHLIGHT

helmets treated with plastic tape, however, detection probability declines whenever wind velocities are sufficient to produce white water. Moreover, the noticeability of the insert-bearing helmet at all ranges is vastly greater than that of the taped helmets; this provides a large factor of safety that is important under conditions of fatigue and distraction on the part of the helicopter crew. The Visibility Laboratory feels, on the basis of its trial of these helmets in the field, that no decision to reject the insert-bearing helmet should be made until those responsible for the decision have witnessed a field test of this very remarkable aid to the location of downed aviators.

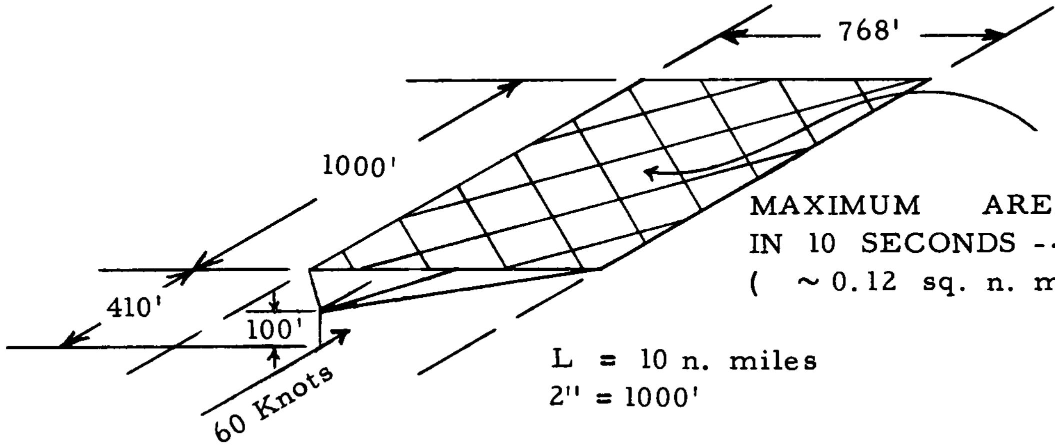
4. OPTIMUM SEARCH PROCEDURES

The recommended optimum search procedures based upon the study described by this report are presented graphically by the following fifty perspective drawings. The same recommendations are also summarized by tables (Tables 1, 2, and 3). The graphical presentations comprise five groups of figures. The first group (Figs. 9-1, 9-2, and 9-3) illustrates the optimum use of the G.E. No. 4580 spotlight presently carried by the H2 helicopter. Clear weather conditions (visibility $>$ 16 miles) are depicted in Fig. 9-1; hazy weather conditions (visibility = 4 miles) are shown in Fig. 9-2; and dense weather (visibility = 1 mile) is represented in Fig. 9-3. Each figure provides a comparison of the area search-rate achievable with the four-helmet treatments described in the preceding section of this report. In Figs. 9-1, 9-2, and 9-3 it is assumed that the aviator is facing the rescue helicopter and is, therefore, presenting the least favorable aspect of his helmet to his rescuers. In Appendix B this assumption is reversed in a second group of graphical presentations (Figs. B1-1, B1-2, and B1-3) wherein it is assumed that the rear of the helmet is presented to the rescue helicopter. It is believed that search operations should not be based upon this second assumption.

Helmets bearing the retrodirective reflector inserts have omnidirectional characteristics so that the orientation of the floating aviator is of no importance; i.e., Fig. 9-1 and Fig. B1-1 are identical for the helmets having retrodirective inserts. The same is true of Figs. 9-2 and B1-2 as well as the pair of Figs. 9-3 and B1-3. This is an important advantage of the retrodirective reflector inserts.

HELMET WITH WHITE TAPE (FRONT)

SPOTLIGHT SWEEP TIME = 5.1 sec.
SPOTLIGHT SWEEP ANGLE = $\pm 70.5^{\circ}$
SPOTLIGHT DEPRESSION ANGLE = 13.7°



MAXIMUM AREA SEARCHED IN 10 SECONDS -- 768,000 sq. ft.
(~ 0.12 sq. n. miles per min.)

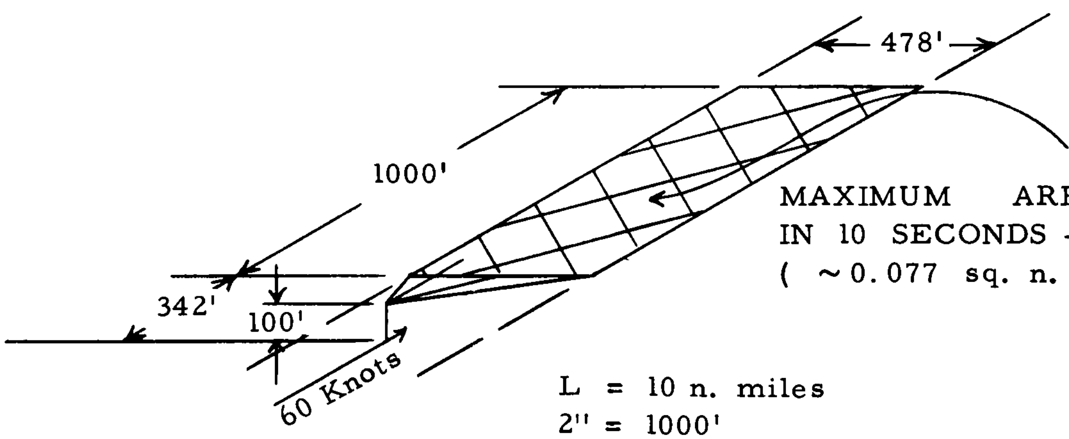
L = 10 n. miles
2" = 1000'

WEATHER CLEAR

Fig. 9-1

HELMET WITH RED TAPE (FRONT)

SPOTLIGHT SWEEP TIME = 3.2 sec.
SPOTLIGHT SWEEP ANGLE = $\pm 44.5^{\circ}$
SPOTLIGHT DEPRESSION ANGLE = 16.3°

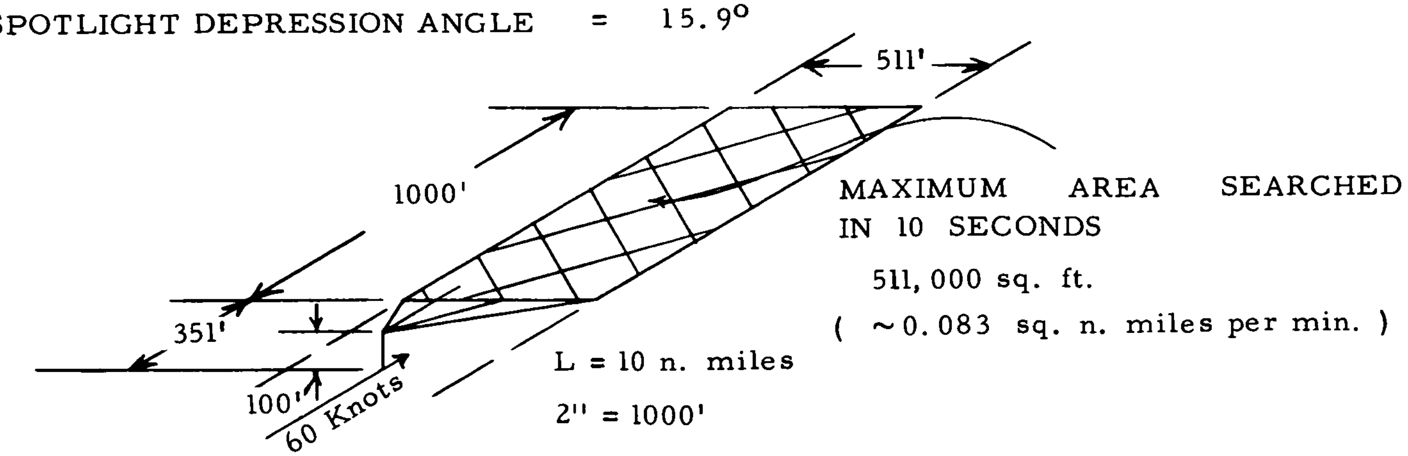


MAXIMUM AREA SEARCHED IN 10 SECONDS -- 478,000 sq. ft.
(~ 0.077 sq. n. miles per min.)

L = 10 n. miles
2" = 1000'

HELMET WITH RED AND WHITE TAPE (FRONT)

SPOTLIGHT SWEEP TIME = 3.4 sec.
SPOTLIGHT SWEEP ANGLE = ±47°
SPOTLIGHT DEPRESSION ANGLE = 15.9°

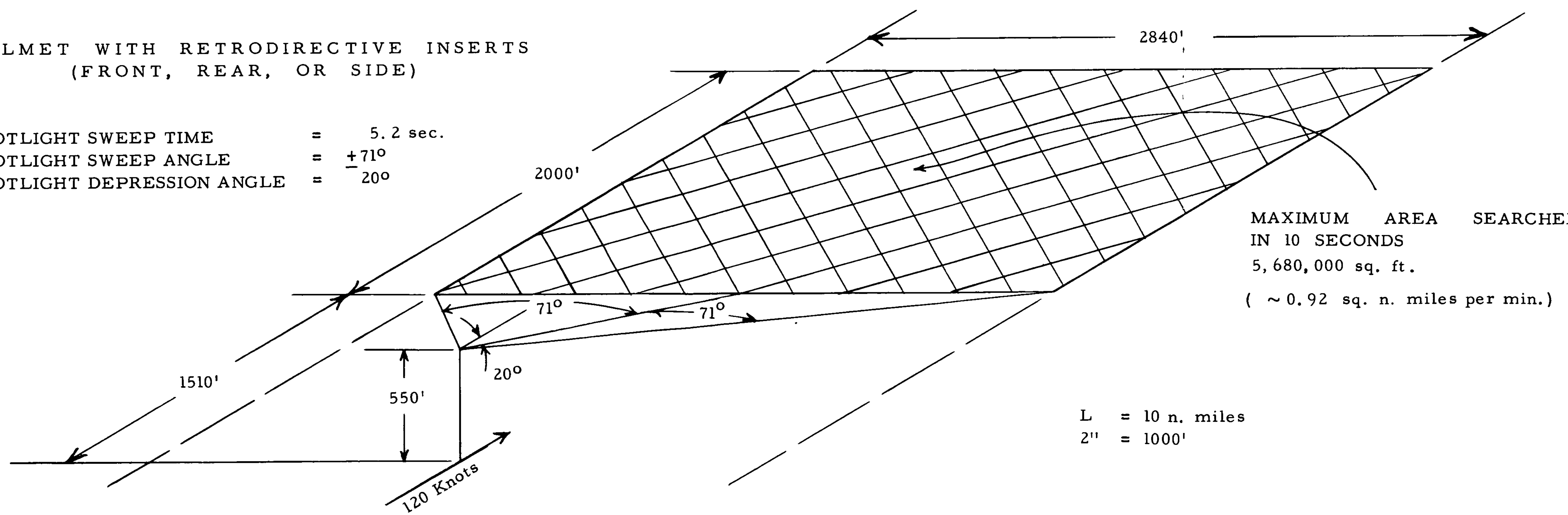


WEATHER CLEAR

Fig. 9-1 (con't)

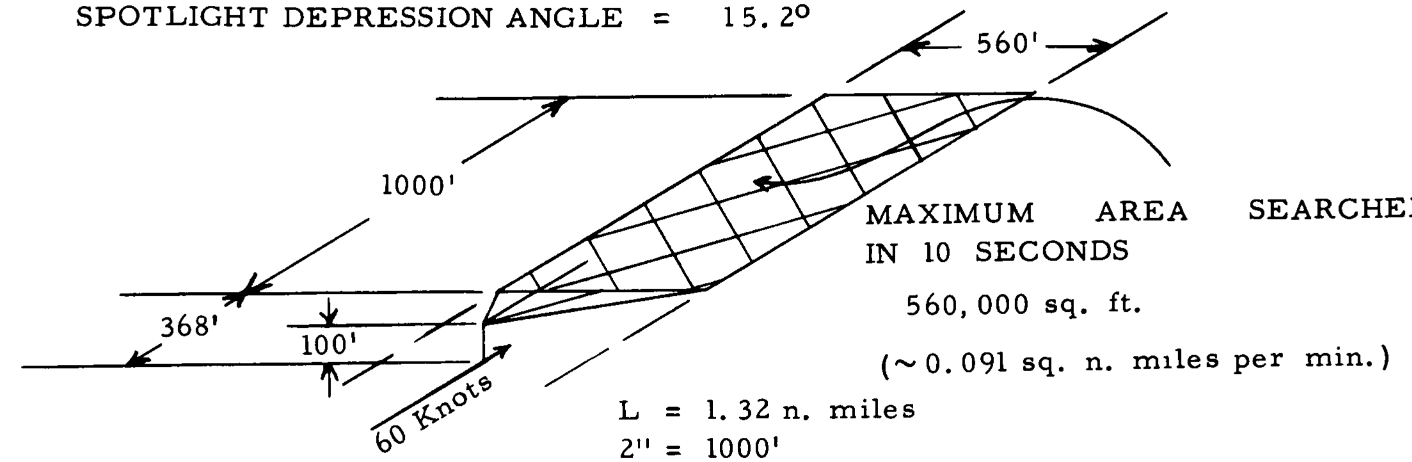
HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, REAR, OR SIDE)

SPOTLIGHT SWEEP TIME = 5.2 sec.
SPOTLIGHT SWEEP ANGLE = ±71°
SPOTLIGHT DEPRESSION ANGLE = 20°



HELMET WITH WHITE TAPE (FRONT)

SPOTLIGHT SWEEP TIME = 3.7 sec.
SPOTLIGHT SWEEP ANGLE = ± 50 5°
SPOTLIGHT DEPRESSION ANGLE = 15.2°

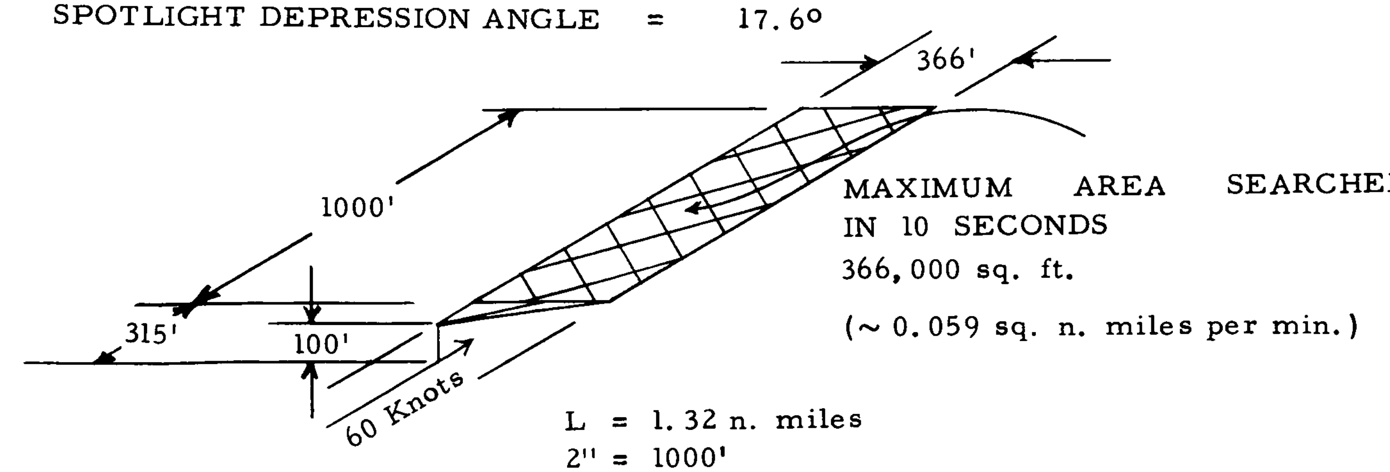


WEATHER HAZE

Fig. 9-2

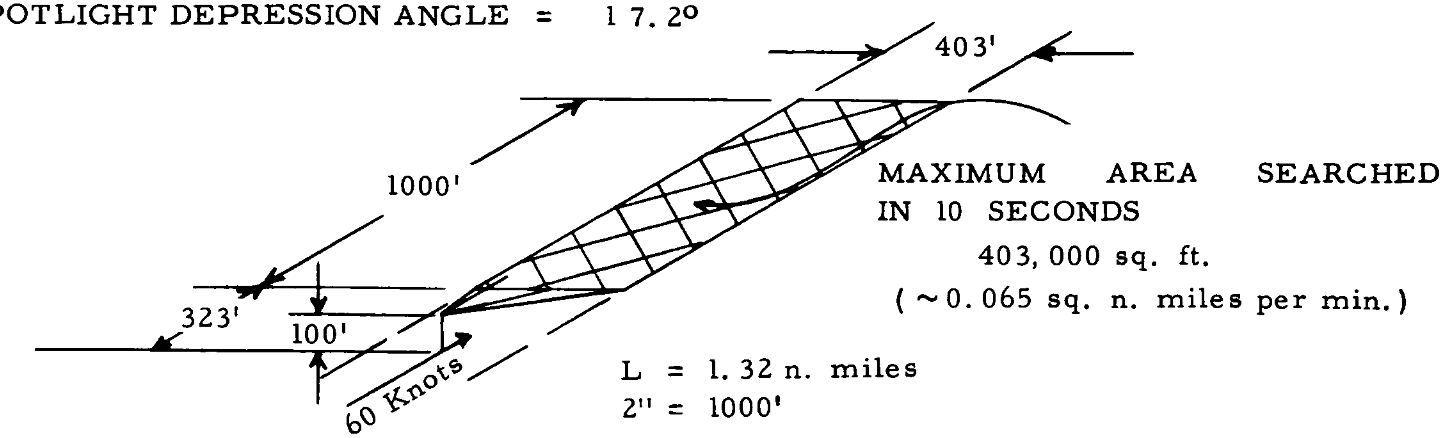
HELMET WITH RED TAPE (FRONT)

SPOTLIGHT SWEEP TIME = 2.6 sec.
SPOTLIGHT SWEEP ANGLE = ±36.5°
SPOTLIGHT DEPRESSION ANGLE = 17.6°



HELMET WITH RED AND WHITE TAPE (FRONT)

SPOTLIGHT SWEEP TIME = 2.8 sec.
SPOTLIGHT SWEEP ANGLE = ±38.5°
SPOTLIGHT DEPRESSION ANGLE = 17.2°

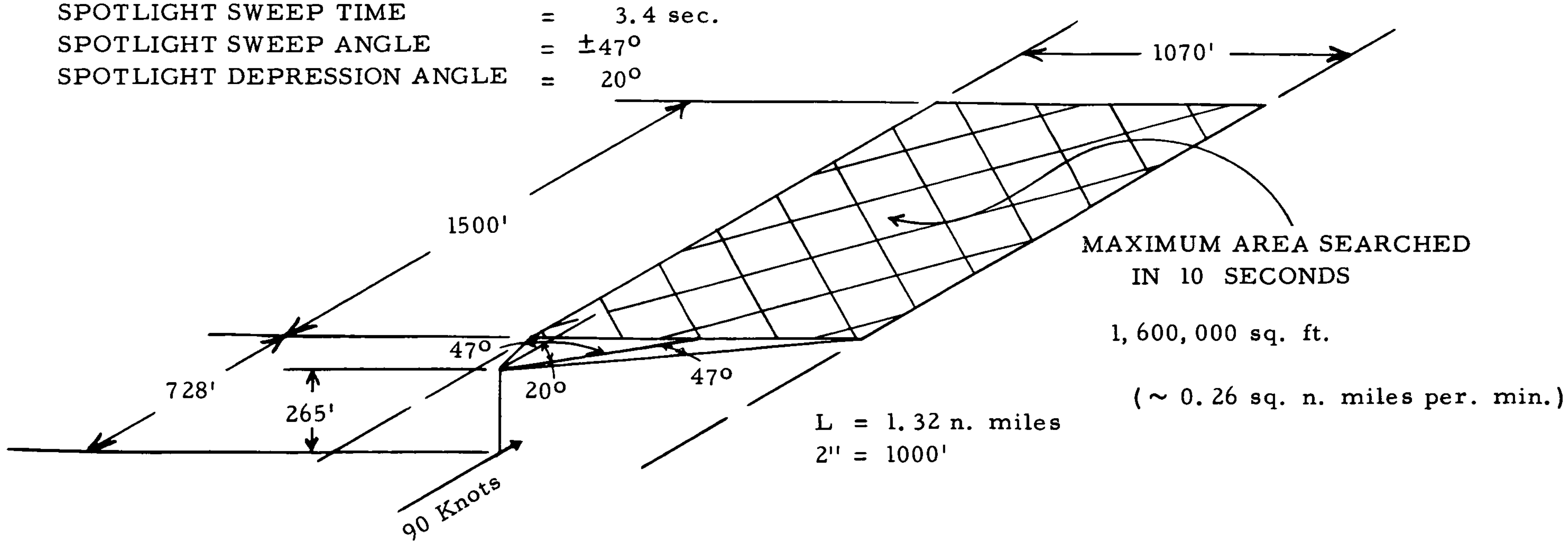


WEATHER HAZE

Fig. 9-2 (con't)

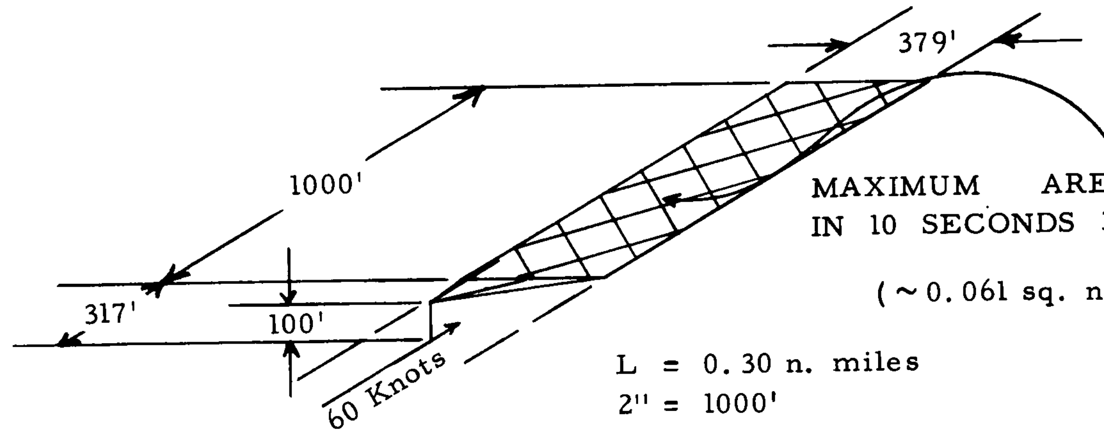
HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, REAR, OR SIDE)

SPOTLIGHT SWEEP TIME = 3.4 sec.
SPOTLIGHT SWEEP ANGLE = ±47°
SPOTLIGHT DEPRESSION ANGLE = 20°



HELMET WITH WHITE TAPE (FRONT)

SPOTLIGHT SWEEP TIME = 2.7 sec.
SPOTLIGHT SWEEP ANGLE = ±36.5°
SPOTLIGHT DEPRESSION ANGLE = 17.5°



MAXIMUM AREA SEARCHED IN 10 SECONDS 379,000 sq. ft.

(~ 0.061 sq. n. miles per min.)

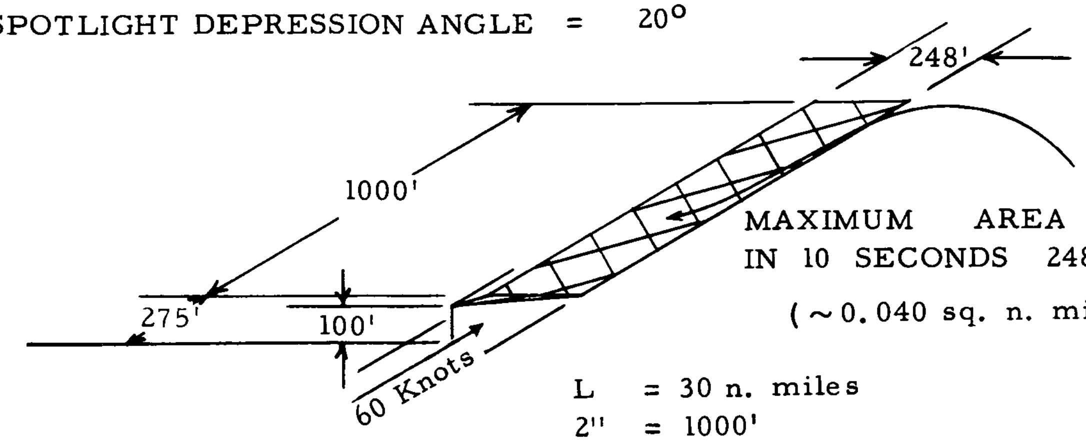
L = 0.30 n. miles
2" = 1000'

WEATHER DENSE

Fig. 9-3

HELMET WITH RED TAPE (FRONT)

SPOTLIGHT SWEEP TIME = 1.9 sec.
SPOTLIGHT SWEEP ANGLE = ± 27°
SPOTLIGHT DEPRESSION ANGLE = 20°



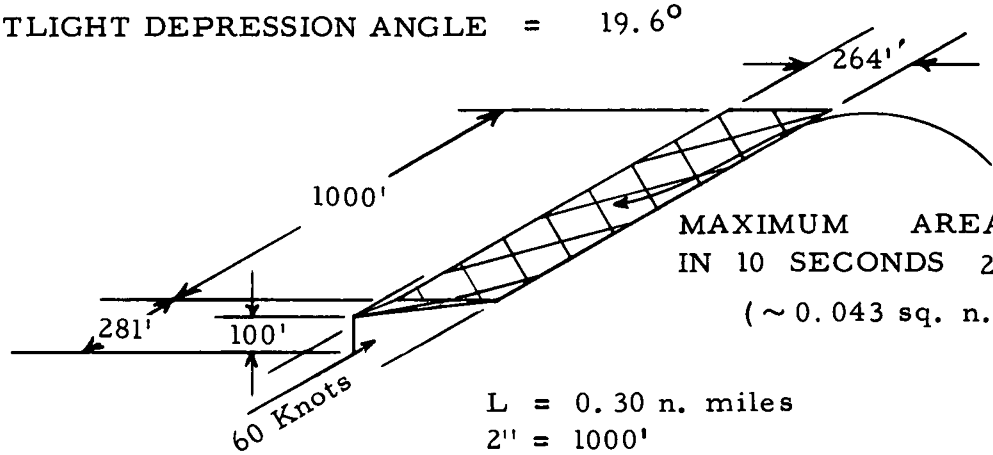
MAXIMUM AREA SEARCHED IN 10 SECONDS 248,000 sq. ft.

(~ 0.040 sq. n. miles per min.)

L = 30 n. miles
2" = 1000'

HELMET WITH RED AND WHITE TAPE (FRONT)

SPOTLIGHT SWEEP TIME = 2.1 sec.
SPOTLIGHT SWEEP ANGLE = ± 28.5°
SPOTLIGHT DEPRESSION ANGLE = 19.6°



MAXIMUM AREA SEARCHED IN 10 SECONDS 264,000 sq. ft.
(~ 0.043 sq. n. miles per min.)

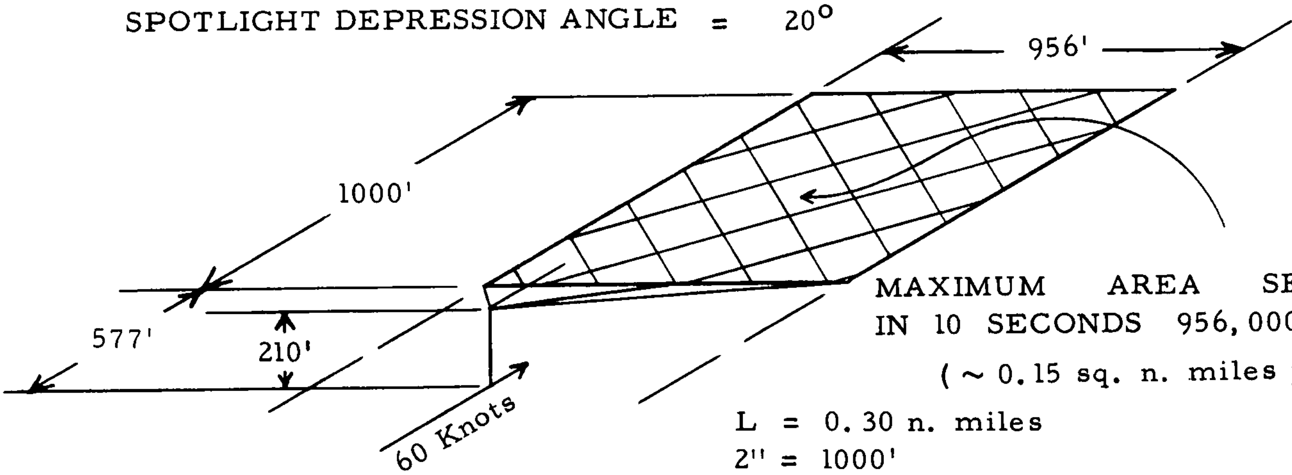
L = 0.30 n. miles
2" = 1000'

WEATHER DENSE

Fig. 9-3 (con't)

HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, REAR, OR SIDE)

SPOTLIGHT SWEEP TIME = 4.3 sec.
SPOTLIGHT SWEEP ANGLE = ± 56°
SPOTLIGHT DEPRESSION ANGLE = 20°



MAXIMUM AREA SEARCHED IN 10 SECONDS 956,000 sq. ft.
(~ 0.15 sq. n. miles per min.)

L = 0.30 n. miles
2" = 1000'

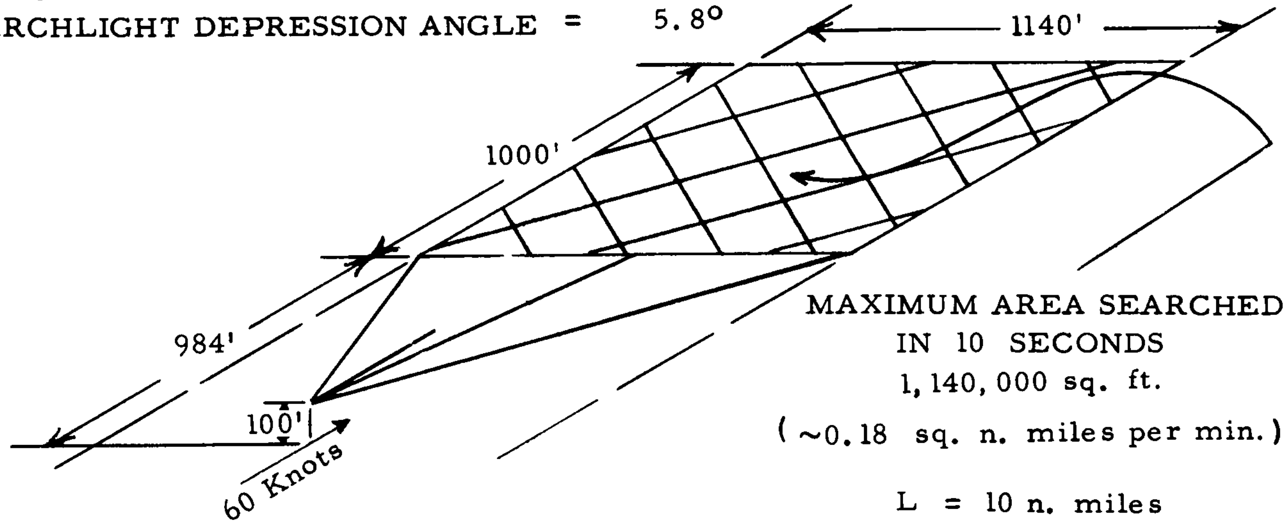
Table 1. Maximum Area Search-Rate for Spotlight on Starlight Night.

Helmet	Attenuation Length (Nautical Miles)	Area Search-Rate (Square Feet per Second)	Helicopter Altitude (Feet)	Helicopter Velocity (Knots)	Beam Depression Angle	Beam Azimuthal Coverage	Sweep Width (Feet)	Sweep Time (Seconds)
Retrodirective Inserts	10.0	568 000	550	120	20.0°	142°	2 840	5.2
	1.32	160 000	265	90	20.0°	94°	1 070	3.4
	0.30	95 600	210	60	20.0°	112°	956	4.3
White Tape (Front)	10.0	76 800	100	60	13.7°	141°	768	5.1
	1.32	56 000	100	60	15.2°	101°	560	3.7
	0.30	37 900	100	60	17.5°	73°	379	2.7
Red and White Tape (Front)	10.0	51 100	100	60	15.9°	94°	511	3.4
	1.32	40 300	100	60	17.2°	77°	403	2.8
	0.30	26 400	100	60	19.6°	57°	264	2.1
Red Tape (Front)	10.0	47 800	100	60	16.3°	89°	478	3.2
	1.32	36 600	100	60	17.6°	73°	366	2.6
	0.30	24 800	100	60	20.0°	54°	248	1.9

The third and fourth groups of graphical presentations (Figs. 10-1, 10-2, 10-3 and in Appendix B, Figs. B2-1, B2-2, and B2-3) correspond in every respect with the first and second groups except that they relate to the use of the new AN/AVQ-4(XN-1) four-million candlepower airborne searchlight.

HELMET WITH WHITE TAPE (FRONT)

SEARCHLIGHT SWEEP TIME = 4.2 sec.
SEARCHLIGHT SWEEP ANGLE = ±35.5°
SEARCHLIGHT DEPRESSION ANGLE = 5.8°

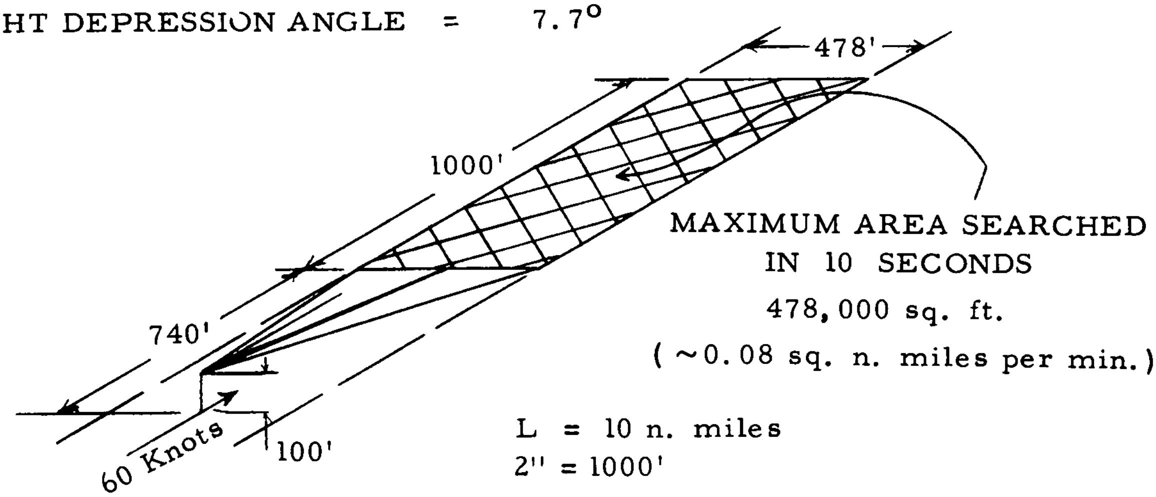


WEATHER CLEAR

Fig. 10-1

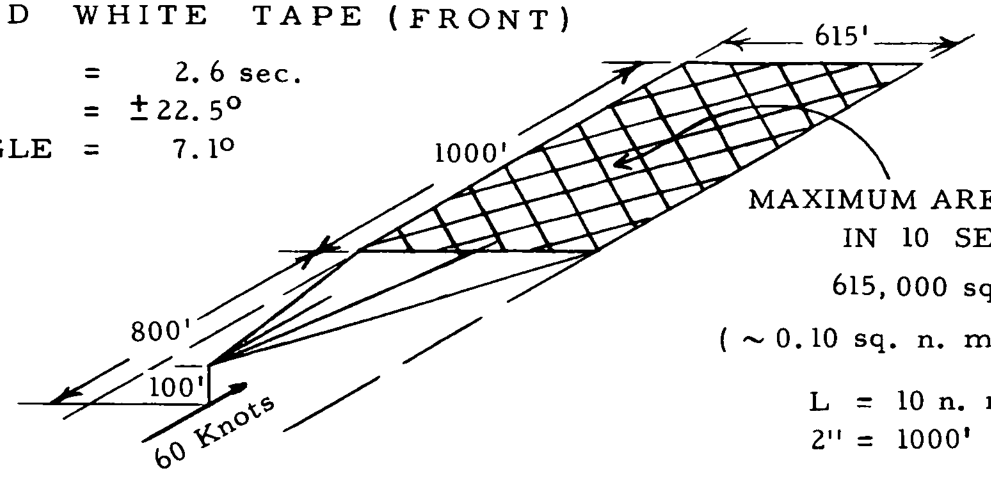
HELMET WITH RED TAPE (FRONT)

SEARCHLIGHT SWEEP TIME = 2.2 sec.
SEARCHLIGHT SWEEP ANGLE = ±19°
SEARCHLIGHT DEPRESSION ANGLE = 7.7°



HELMET WITH RED AND WHITE TAPE (FRONT)

SEARCHLIGHT SWEEP TIME = 2.6 sec.
SEARCHLIGHT SWEEP ANGLE = ±22.5°
SEARCHLIGHT DEPRESSION ANGLE = 7.1°



MAXIMUM AREA SEARCHED
IN 10 SECONDS
615,000 sq. ft.
(~ 0.10 sq. n. miles per min.)

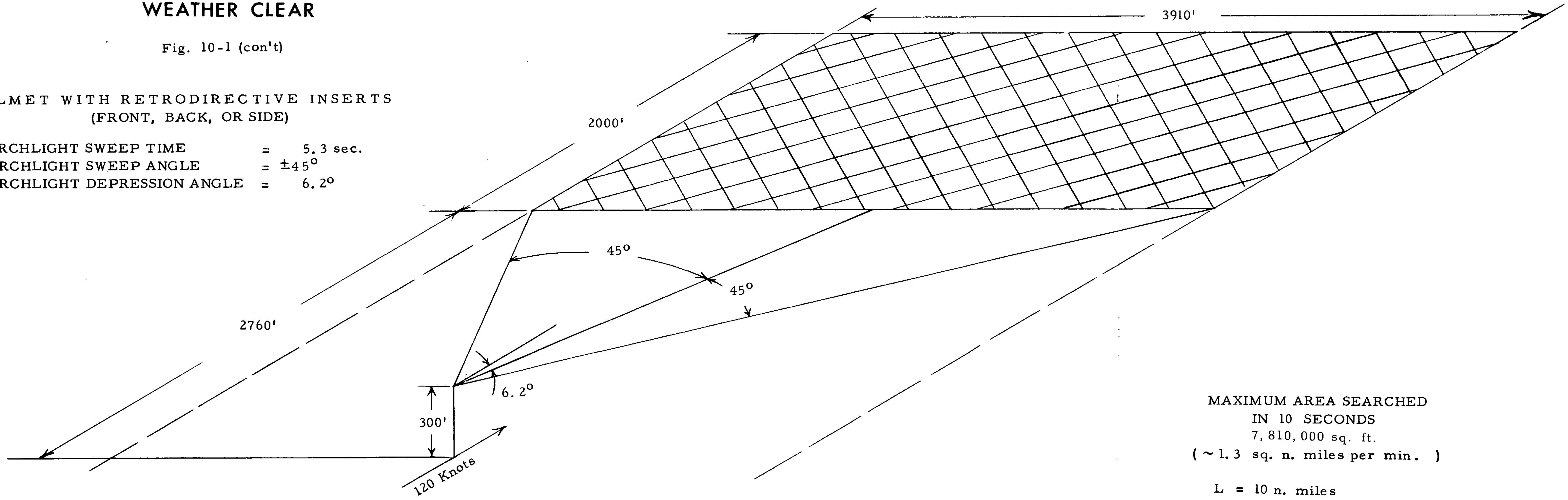
L = 10 n. miles
2" = 1000'

WEATHER CLEAR

Fig. 10-1 (con't)

HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, BACK, OR SIDE)

SEARCHLIGHT SWEEP TIME = 5.3 sec.
SEARCHLIGHT SWEEP ANGLE = ±45°
SEARCHLIGHT DEPRESSION ANGLE = 6.2°

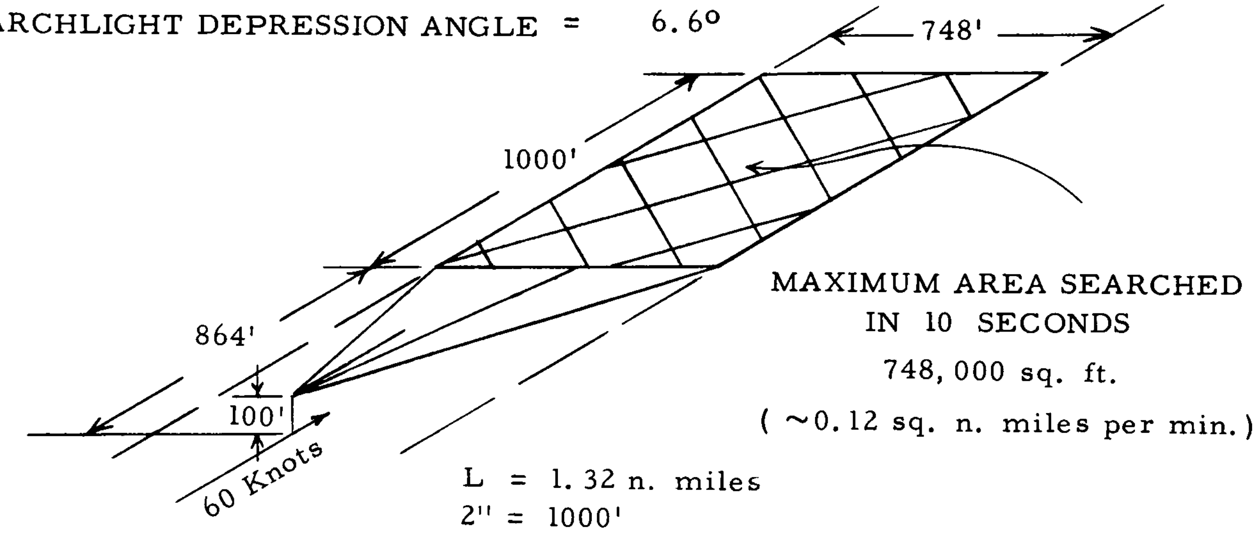


MAXIMUM AREA SEARCHED
IN 10 SECONDS
7,810,000 sq. ft.
(~ 1.3 sq. n. miles per min.)

L = 10 n. miles
2" = 1000'

HELMET WITH WHITE TAPE (FRONT)

SEARCHLIGHT SWEEP TIME = 3.0 sec.
SEARCHLIGHT SWEEP ANGLE = ±26°
SEARCHLIGHT DEPRESSION ANGLE = 6.6°

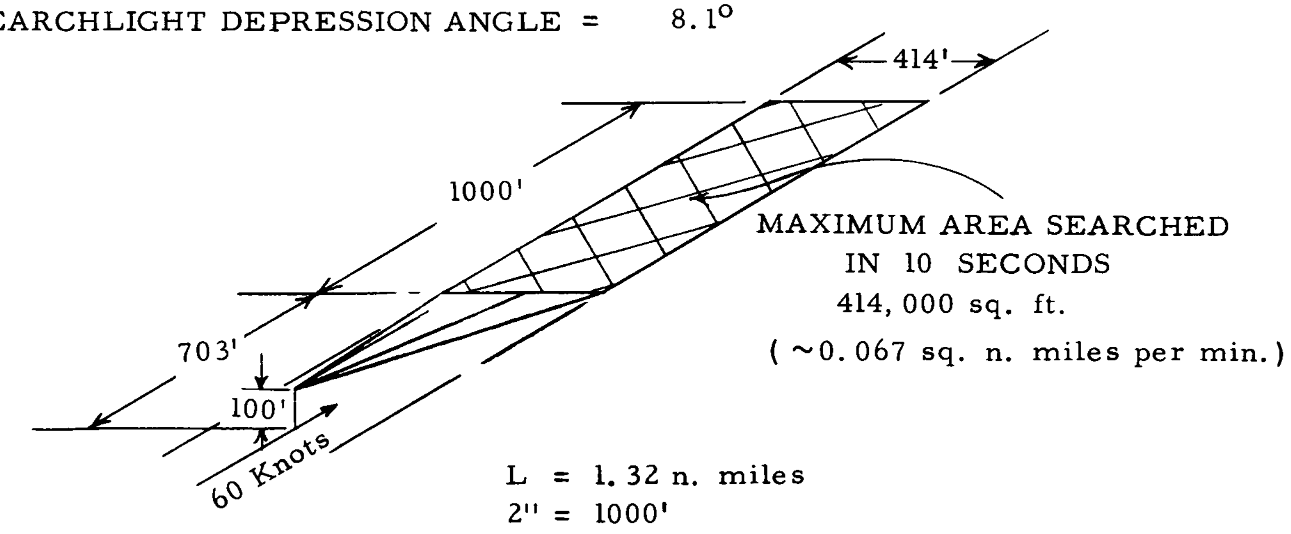


WEATHER HAZE

Fig. 10-2

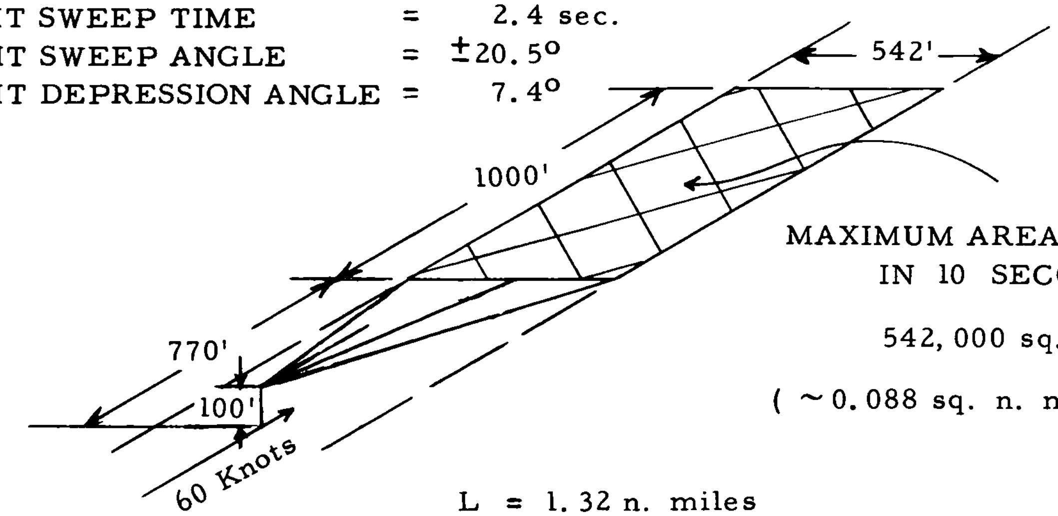
HELMET WITH RED TAPE (FRONT)

SEARCHLIGHT SWEEP TIME = 2.0 sec.
SEARCHLIGHT SWEEP ANGLE = ±17°
SEARCHLIGHT DEPRESSION ANGLE = 8.1°



HELMET WITH RED AND WHITE TAPE (FRONT)

SEARCHLIGHT SWEEP TIME = 2.4 sec.
SEARCHLIGHT SWEEP ANGLE = ±20.5°
SEARCHLIGHT DEPRESSION ANGLE = 7.4°



MAXIMUM AREA SEARCHED
IN 10 SECONDS

542,000 sq. ft.

(~0.088 sq. n. miles per min.)

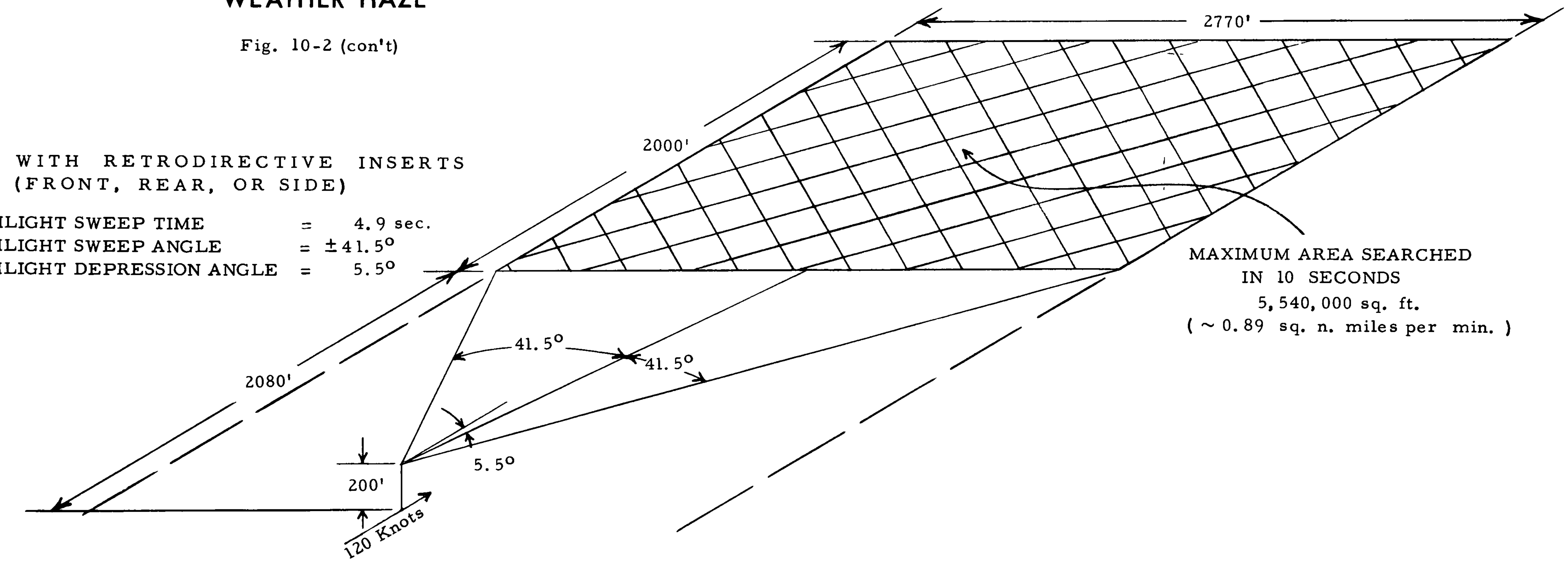
L = 1.32 n. miles
2" = 1000'

WEATHER HAZE

Fig. 10-2 (con't)

HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, REAR, OR SIDE)

SEARCHLIGHT SWEEP TIME = 4.9 sec.
SEARCHLIGHT SWEEP ANGLE = ±41.5°
SEARCHLIGHT DEPRESSION ANGLE = 5.5°

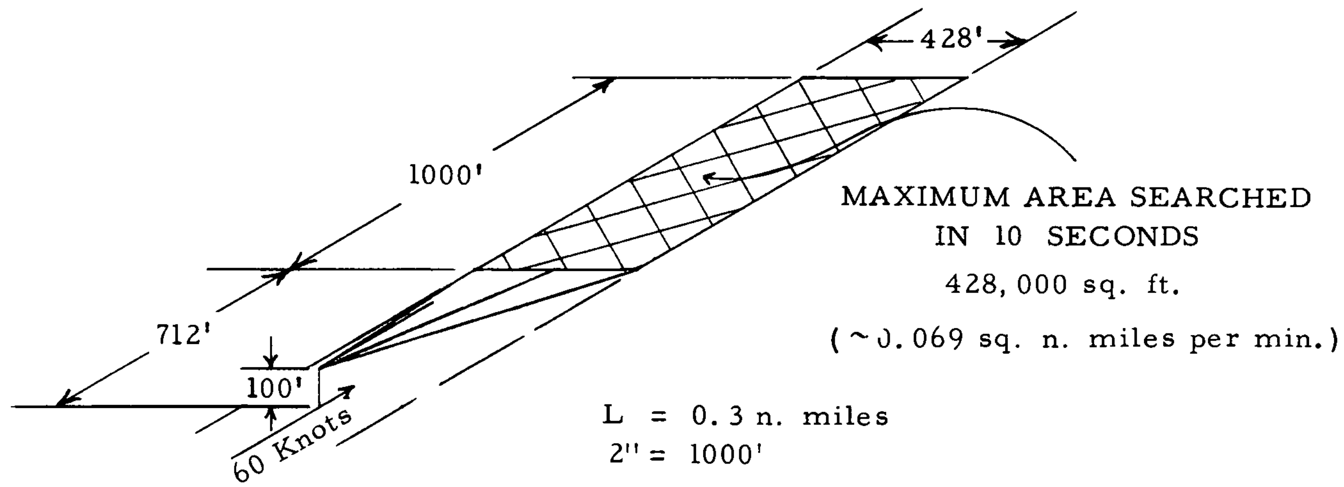


MAXIMUM AREA SEARCHED
IN 10 SECONDS
5,540,000 sq. ft.
(~ 0.89 sq. n. miles per min.)

L = 1.32 n. miles
2" = 1000'

HELMET WITH WHITE TAPE (FRONT)

SEARCHLIGHT SWEEP TIME = 2.0 sec
SEARCHLIGHT SWEEP ANGLE = ±17.5°
SEARCHLIGHT DEPRESSION ANGLE = 8.0°

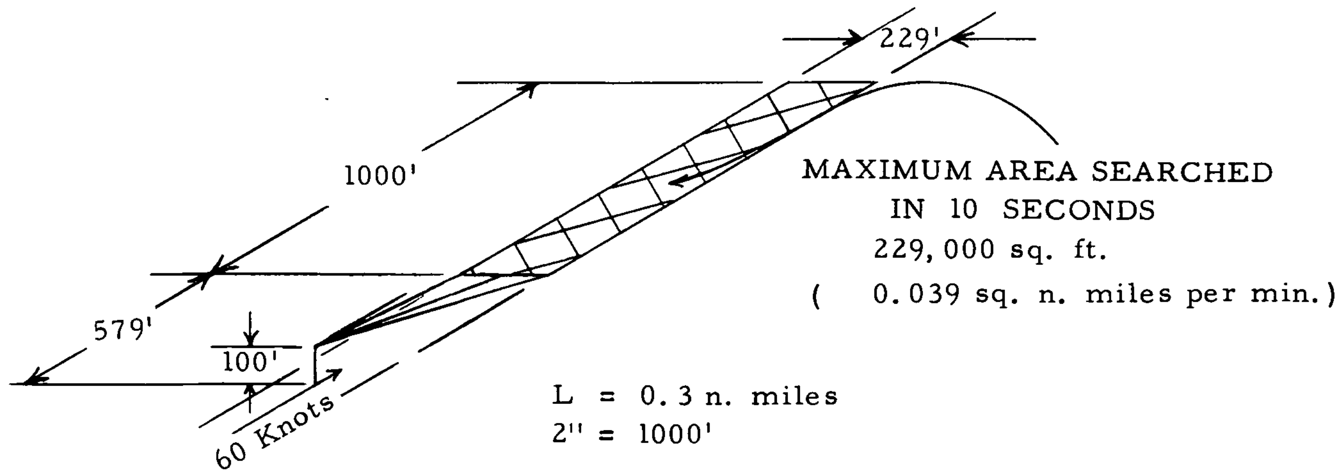


WEATHER DENSE

Fig. 10-3

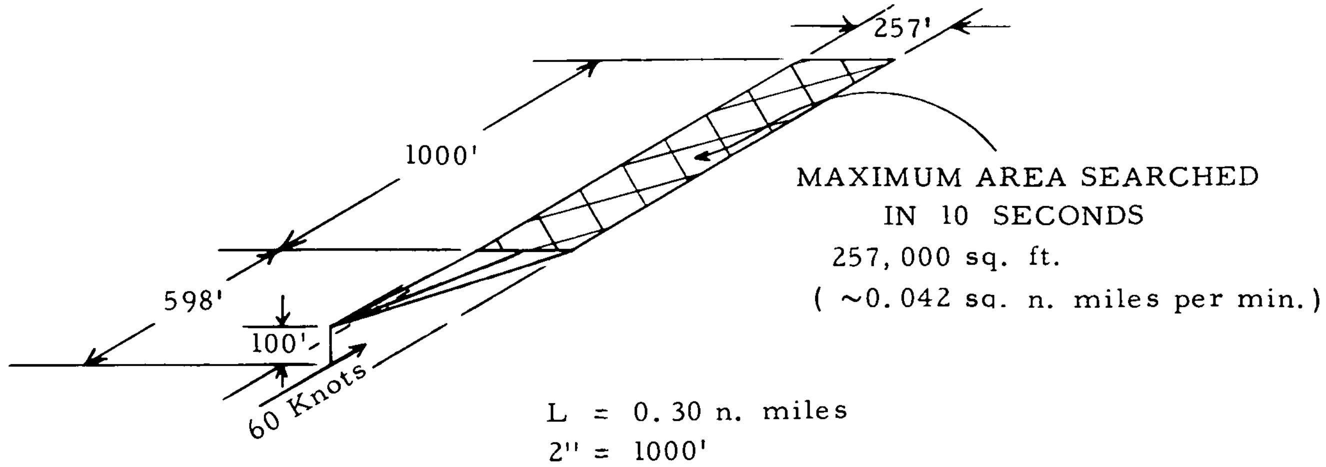
HELMET WITH RED TAPE (FRONT)

SEARCHLIGHT SWEEP TIME = 1.4 sec.
SEARCHLIGHT SWEEP ANGLE = ±11.5°
SEARCHLIGHT DEPRESSION ANGLE = 9.8°



HELMET WITH RED AND WHITE TAPE (FRONT)

SEARCHLIGHT SWEEP TIME = 1.5 sec.
SEARCHLIGHT SWEEP ANGLE = ±12.5°
SEARCHLIGHT DEPRESSION ANGLE = 9.5°



WEATHER DENSE

Fig. 10-3 (con't)

HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, BACK, OR SIDE)

SEARCHLIGHT SWEEP TIME = 3.9 sec.
SEARCHLIGHT SWEEP ANGLE = ±33°
SEARCHLIGHT DEPRESSION ANGLE = 4.5°

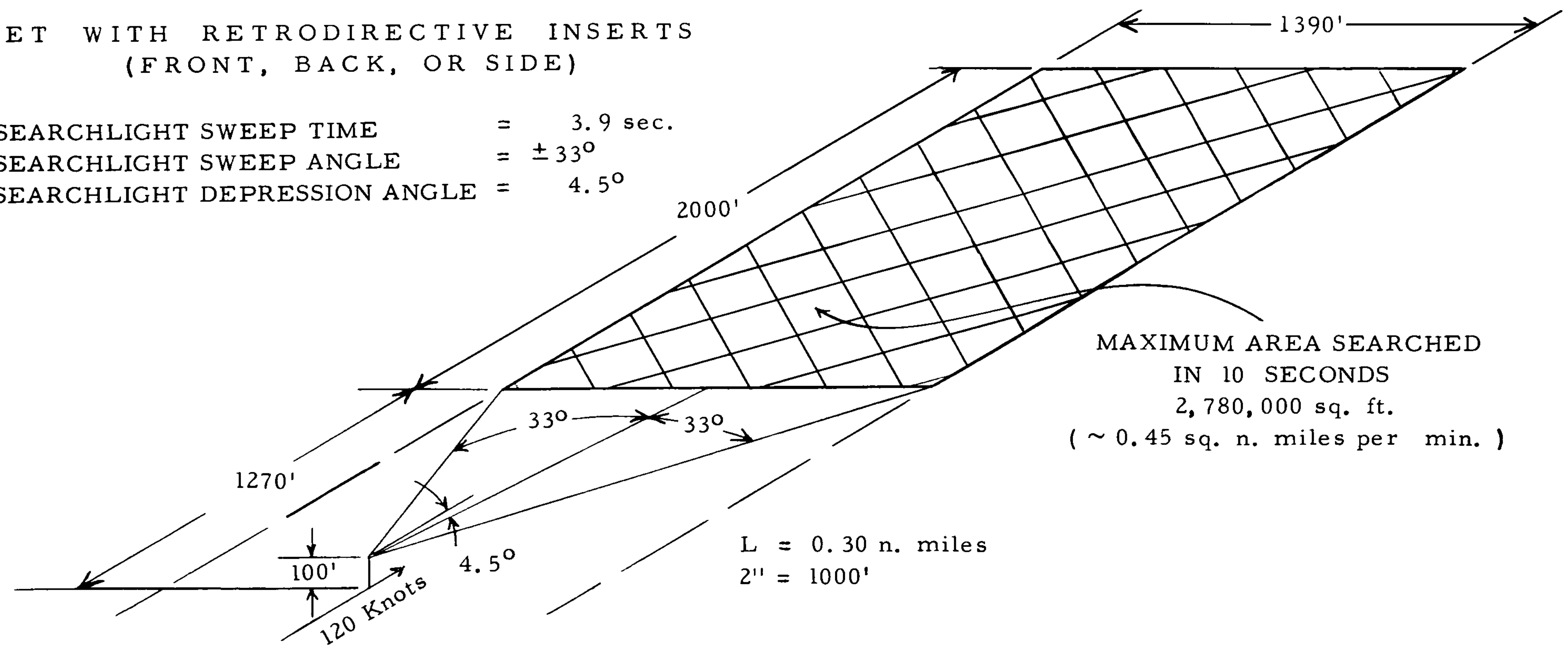


Table 2. Maximum Area Search-Rate for Searchlight on Starlight Night.

Helmet	Attenuation Length (Nautical Miles)	Area Search-Rate (Square Feet per Second)	Helicopter Altitude (Feet)	Helicopter Velocity (Knots)	Beam Depression Angle	Beam Azimuthal Coverage	Sweep Width (Feet)	Sweep Time (Seconds)
Retrodirective Inserts	10.0	781 000	300	120	6.2°	90°	3 910	5.3
	1.32	554 000	200	120	5.5°	83°	2 770	4.9
	0.30	278 000	100	120	4.5°	66°	1 390	3.9
White Tape (Front)	10.0	114 000	100	60	5.8°	71°	1 140	4.2
	1.32	74 800	100	60	6.6°	52°	748	3.0
	0.30	42 800	100	60	8.0°	35°	428	2.0
Red and White Tape (Front)	10.0	61 500	100	60	7.1°	45°	615	2.6
	1.32	54 200	100	60	7.4°	41°	542	2.4
	0.30	25 700	100	60	9.5°	25°	257	1.5
Red (Front)	10.0	47 800	100	60	7.7°	38°	478	2.2
	1.32	41 400	100	60	8.1°	34°	414	2.0
	0.30	22 900	100	60	9.8°	23°	229	1.4

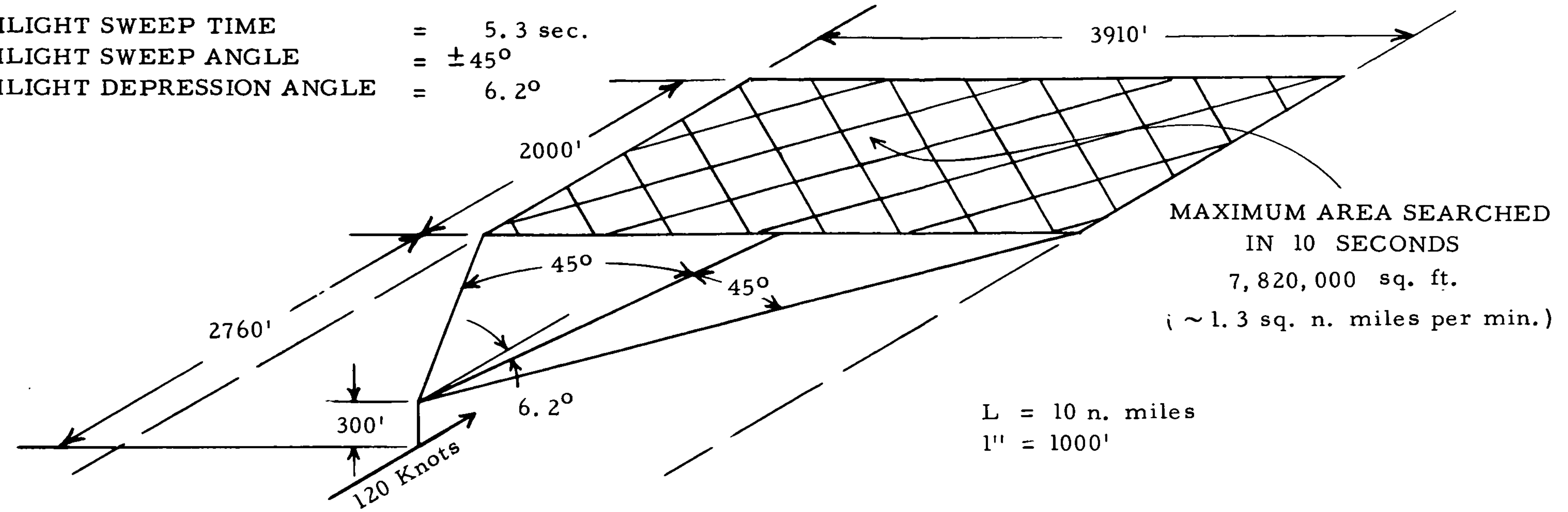
A dramatic increase in area search-rate can be achieved by means of magnification. This is illustrated by Fig. 11, which compares the area which can be searched with 7 X 50 binoculars to that which can be searched by naked eye with the same probability of detection. The scale of Fig. 11 is only half as great as that of the preceding graphical presentations. The AN/AVQ-4(XN-1) searchlight, the helmet with retro-directive reflecting inserts, and clear weather have been assumed in this comparison. The binoculars should be bore-sighted with the search-light and slaved to it so that the aviator neither holds the binoculars nor directs them. The search procedure is fully automatic and requires only that the observer look through the binoculars as they scan the field ahead. The presence of a floating aviator will be evidenced by a blazing white star hundreds of times more intense than any whitecap.

Table 3. Maximum Area Search Rate for Searchlight on Starlight Night, Optical Aid 7 X 50 X 7.1 Binoculars.

Helmet	Attenuation Length (Nautical Miles)	Area Search-Rate (Square Feet per Second)	Helicopter Altitude (Feet)	Helicopter Velocity (Knots)	Beam Depression Angle	Beam Azimuthal Coverage	Sweep Width (Feet)	Sweep Time (Seconds)
Retrodirective Inserts	10	1 860 000	750	120	6.5°	90°	9 310	5.3

HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, REAR, OR SIDE)

SEARCHLIGHT SWEEP TIME = 5.3 sec.
SEARCHLIGHT SWEEP ANGLE = ±45°
SEARCHLIGHT DEPRESSION ANGLE = 6.2°

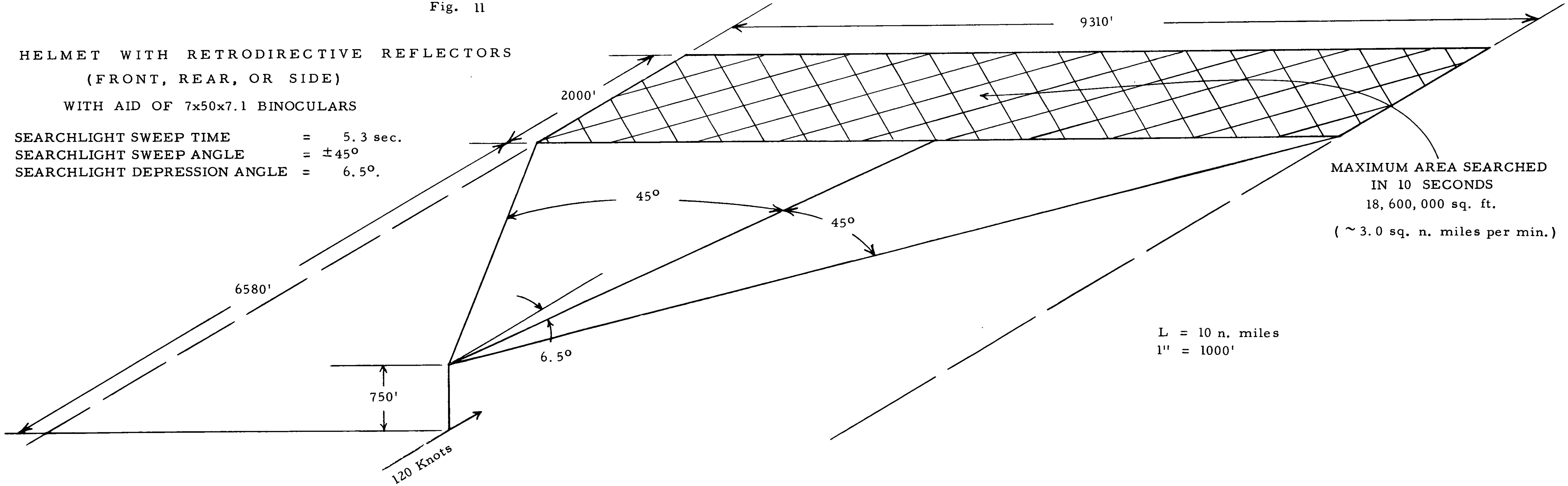


WEATHER CLEAR

Fig. 11

HELMET WITH RETRODIRECTIVE REFLECTORS
(FRONT, REAR, OR SIDE)
WITH AID OF 7x50x7.1 BINOCULARS

SEARCHLIGHT SWEEP TIME = 5.3 sec.
SEARCHLIGHT SWEEP ANGLE = ±45°
SEARCHLIGHT DEPRESSION ANGLE = 6.5°.



5. A FIELD TEST

Flight testing of the results of the study described by this report was not contemplated in the level of funding requested and received for the project. Moreover, no mounting for the experimental AN/AVQ-4(XN-1) searchlight had been engineered for the H2 helicopter, so that flight testing of that equipment at sea was not possible. The location of the Visibility Laboratory on Point Loma in San Diego provided, however, a convenient opportunity for a static field test, and one was conducted in the manner described in this section of the report.

Point Loma is a mountainous peninsula extending 3 miles south into the Pacific Ocean and providing a western barrier and protection for San Diego harbor. At the southernmost tip of the Point sheer cliffs rise more than 300 feet above the sea. The observers, the spotlight, and the searchlight were stationed atop one of these cliffs, and the helmets, mounted astern of a powered work boat, were moved about in the sea beneath the cliffs. Slant ranges to the helmets were measured by means of an optical theodolite and atmospheric transmission for the path of sight was determined by means of a telephotometer at the observation site and a large incandescent lamp of controlled intensity carried by the work boat. Detection ranges were predicted and compared with those observed. The role of helmet color in aiding detection was explored during these experiments. Figure 12 is a sketch of the experimental arrangement.

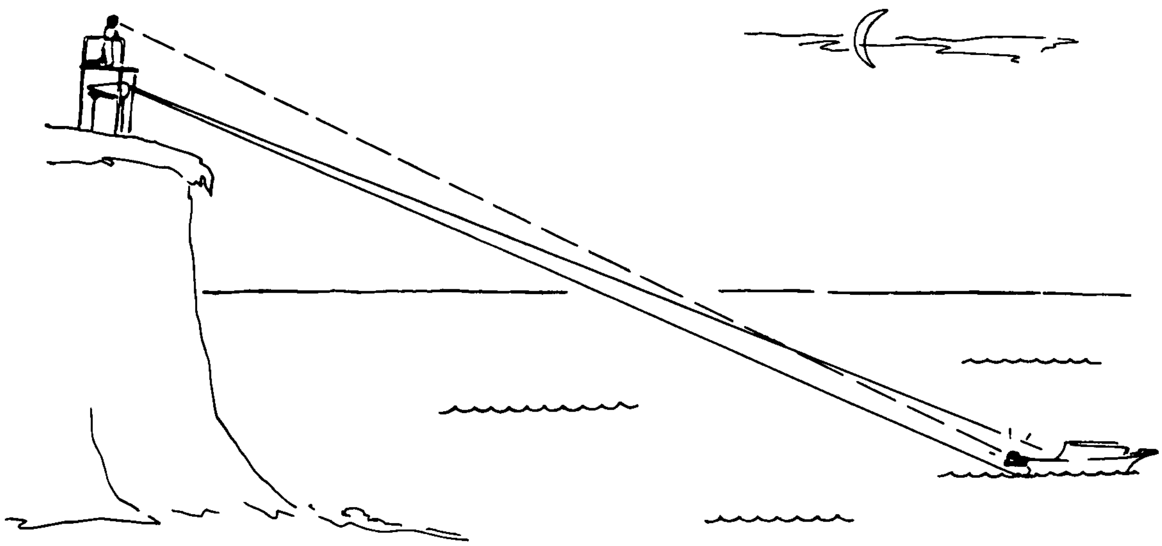


FIGURE 12 - SKETCH OF TEST SITE (NOT TO SCALE)

5.1 Observer and Searchlight Station

The observers and the light sources were installed on a level area of ground 296 feet above the sea surface. At this location, which afforded a sweeping view of the ocean, a scaffold was erected beneath which the searchlight was mounted. Two observers were stationed atop the scaffold in a position similar to that occupied by the two pilots of the H2 helicopter. An additional two pairs of observers took up positions to the side of the searchlight during the field tests. Figure 13 shows the arrangement of the searchlight and the primary two observers, while Fig. 15 shows schematically the relative positions of all six observers as actually used.

Light Sources

Two lights were used. The first, the AN/AVQ-4(XN-1) searchlight described in Sect. 3.2, was mounted under the scaffold with its control stick on the observers' platform above (Fig. 13). The second, a sealed beam spotlight as described in Sect. 3.2 was tripod mounted together with its aiming reticle and was positioned in front of the scaffold when in use. Plywood sheets were used to shield the observers from glare from the lights.

Telephotometer

A telephotometer, designed and built by the Visibility Laboratory, was used in conjunction with a calibrated lamp having a uniform candlepower distribution on board the boat as a transmissometer. In addition to its use in obtaining a measure of attenuation length, the telephotometer was also used to measure the backscatter in the center of the beams from the two searchlights. The telephotometer had a field of view of 2°. The telephotometer data were recorded on the Brown strip-chart recorder shown to the left rear of the scaffold in Fig. 13.

Power Supply

The main power supply for the searchlights and telephotometer was a 115 or 220-volt, three-phase, 60 cps., gasoline-driven auxiliary power unit (motor-generator unit). In conjunction with this unit a Christy 28 volt D.C. 200-amp power supply and a General Electric 115-volt, 400 cps. rotary inverter were used.

Theodolite

A Wild T2 Model 56 Universal Theodolite (Fig. 14) was used to measure the depression angle of the boat position. The theodolite is accurate within two minutes of arc. Slant range was calculated from this depression angle and height of the theodolite above sea level.

Observers

Six observers were used. In addition to the two on the scaffold, two were placed on each side of the scaffold. The positions of the observers and equipment are shown in Fig. 15. The average separation distance from the center of the searchlight to the observers' eyes was approximately 4.5 feet. Thus with the telephotometer placed as shown, the backscatter measurements were comparable to the backscatter affecting the observers on either side.

All six observers, five males and one female, were trained in psychophysical vision experiments, but they had not observed with searchlights prior to the nights of the field test. The observers were instructed to respond when they were reasonably sure they saw the target.

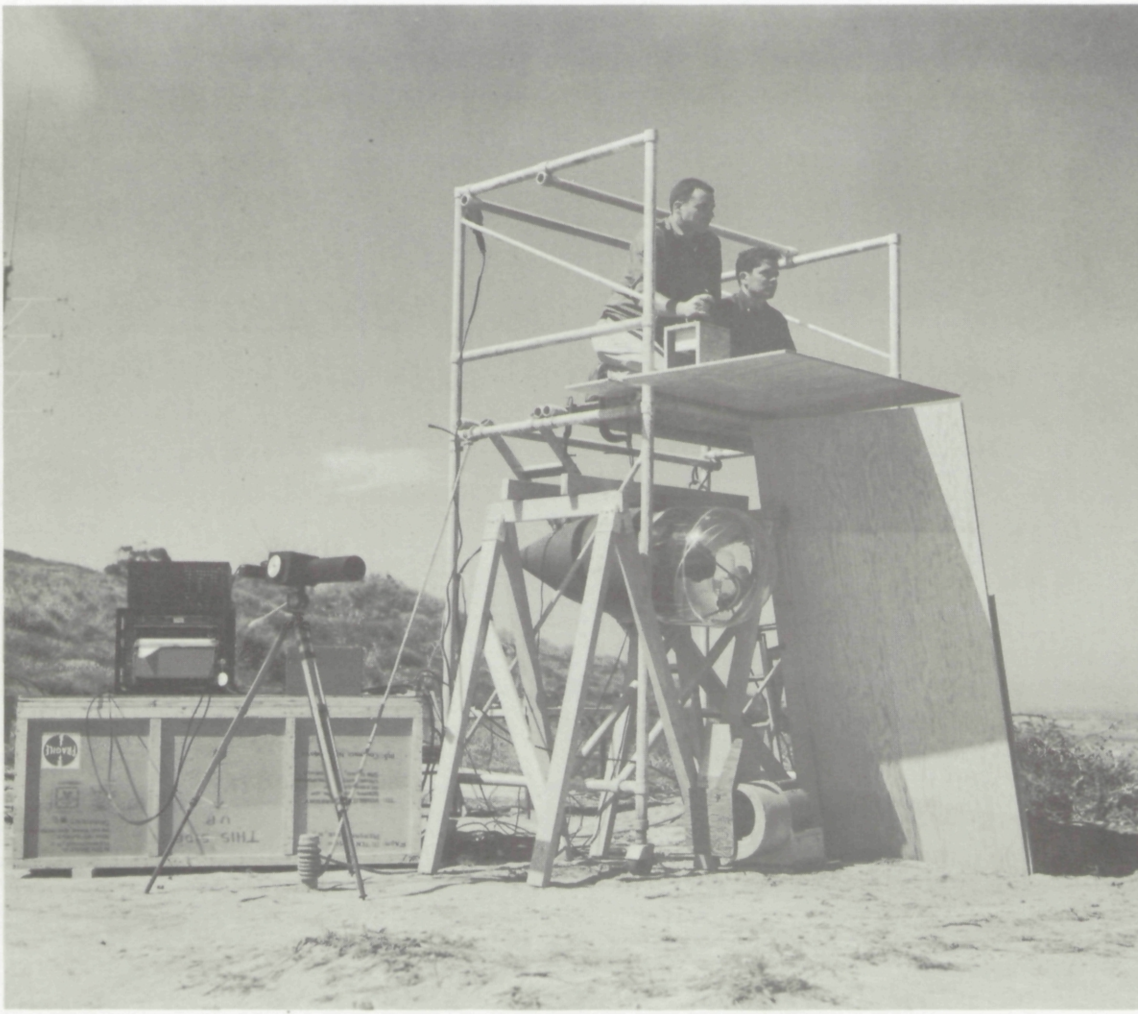


Figure 13. Searchlight mounted under scaffold, with two observers in position.

Figure 14. Theodolite.

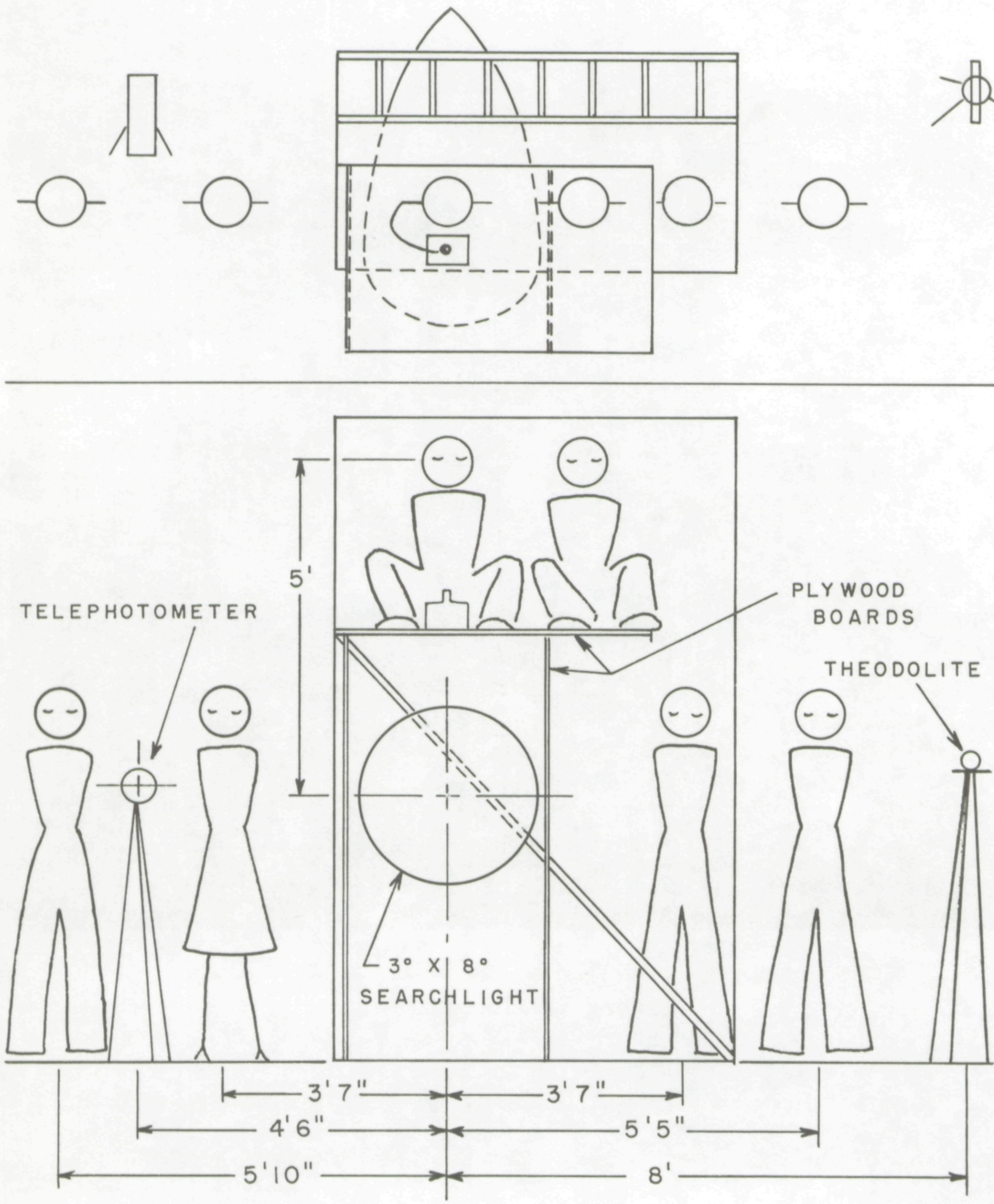


FIGURE 15 - DIAGRAM OF POSITIONS OF EQUIPMENT AND OBSERVERS

Recorders

Two people recorded the observers' responses. The recorders were in constant radio communication with the personnel on the boat so that the latter could inform the observers when a target was being presented. Each observer had a button in his hand, connected electrically to a small light on the recorders' table, which he pushed if he saw the target, then pushed again if he saw color. The recorders had a button on their table connected electrically to a bell mounted on the scaffold. The bell was rung once at the beginning of the presentation, rung twice at the end of 10 seconds which was also the beginning of the interval for indication of response to color, and rung three times at the end of the presentation.

5.2 Target Area

The helmets used as targets were suspended behind a 32-foot, diesel-powered, utility boat belonging to the Scripps Institution of Oceanography. As shown in Fig. 16, water was the background beneath, but not to the sides or above the helmets. It is believed that this did not affect the results, however, since the boat itself was not visible at the distances used during the field test.

Targets

The four helmets described in Sect. 3.3 were used as targets. Three had reflective tapes: one, all white; the second, part white, part red; the third, all red. The fourth helmet had Stimsonite retrodirective hexagonal inserts mounted on it. The helmets were mounted on a round, rotatable platform and were separated by wooden

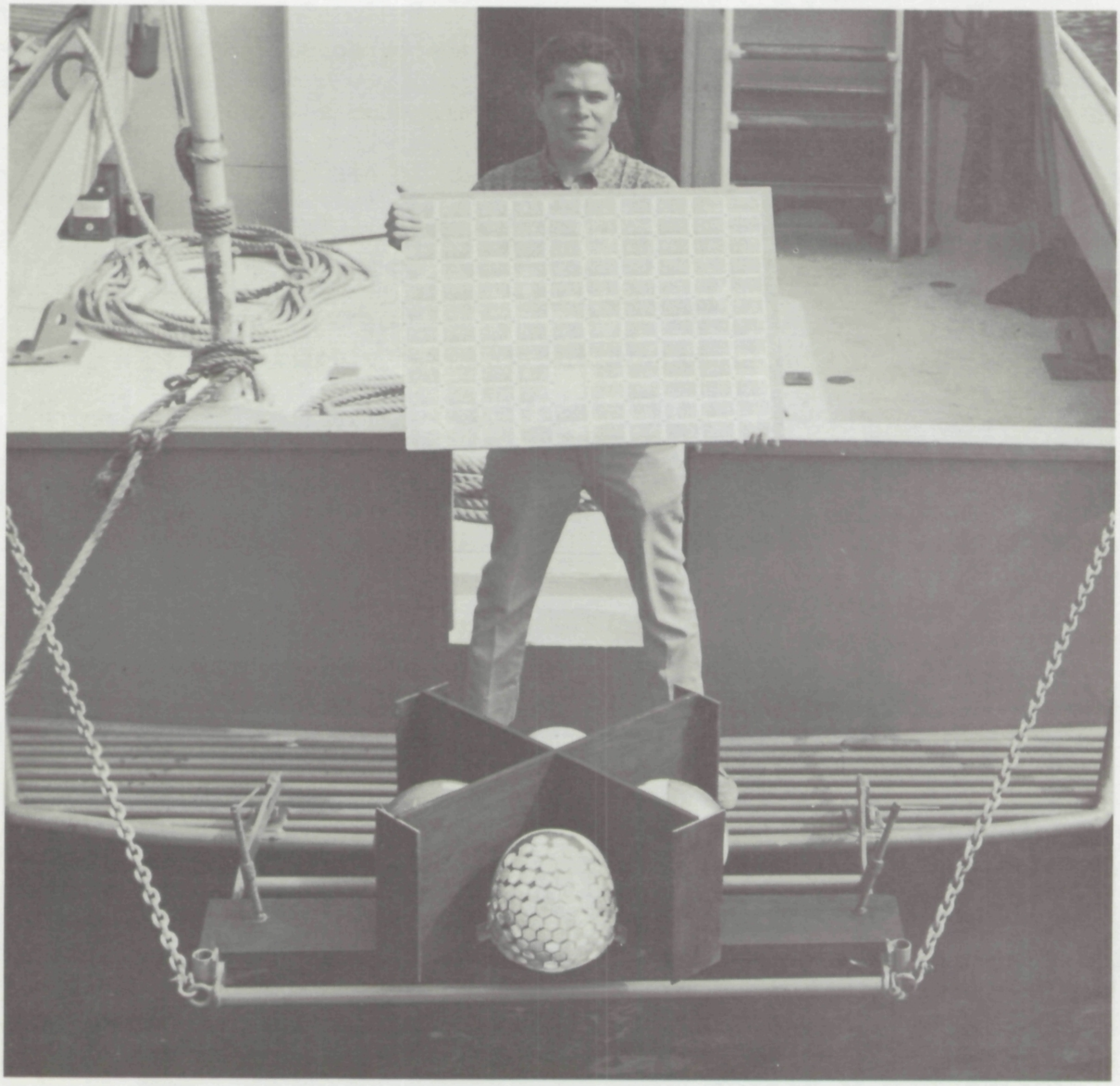


Figure 16. Rear of utility boat showing targets and searchlight orientation board.

dividers painted black. At the low angles of sight used for the test, the dividers effectively blocked all but the rearward helmet from view. The helmets were all mounted so that they would be seen from the rear, in their most advantageous position.

Searchlight Orientation Board

Since the boat itself was not visible without running lights at the distances used for the experiment, it was necessary to devise a means for orienting the searchlight or spotlight on the target area. A 2.5 by 2.0-foot plywood board covered with rectangular Stimsonite No. 21 retroreflectors was used for this purpose (see Fig. 16). Although the individual retroreflectors were less efficient than those mounted on the helmet, the greatly increased area, held normal to the beam from the light, insured a bright target for orienting the center of the light beam. As the light beam was moved to an off-center position the intensity of the reflection noticeably diminished. In this manner the proper positioning of the light source was ensured prior to each data session. The reflector-covered board was, of course, removed from view before the helmets were displayed.

Calibrated Lamp

The calibrated lamp used in conjunction with the telephotometer had an intensity of 139 candles in the direction of observation. It was turned on only during the transmission measurements.

Test Area

Figure 17 is a map of the area used for the test, showing the observers' position with respect to the three pre-arranged boat positions at ranges of 1450, 2600, and 3600 yards. These positions were

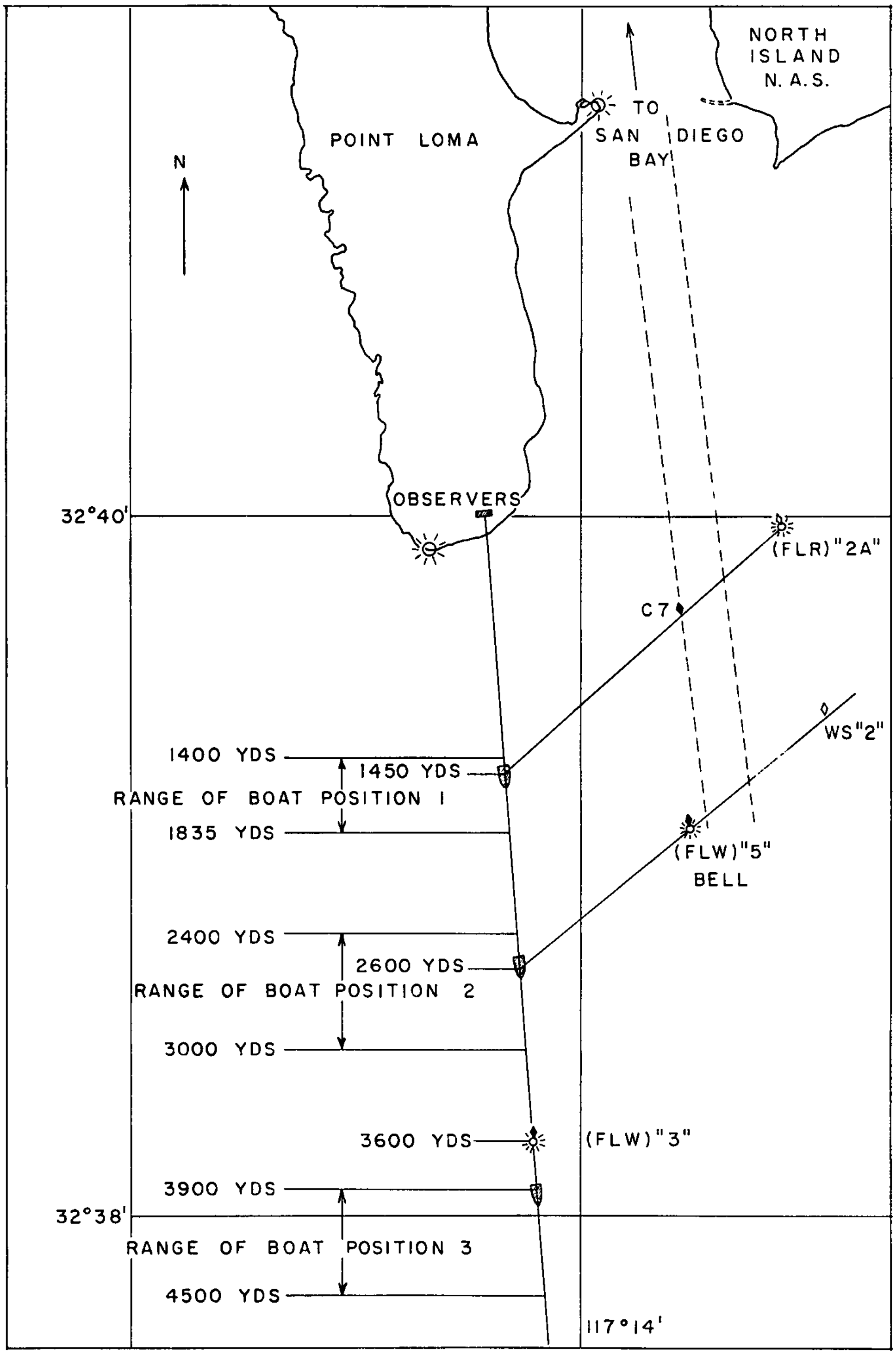


FIGURE 17 - MAP OF EXPERIMENT AREA

on the line determined by a buoy at 3600 yards and the observers' position. The first two positions were with the boat in line with specified pairs of channel buoys, and the third was just beyond the 3600-yard buoy. These three positions are indicated on the map. A continual check of the range was kept with the theodolite to get the variation of the boat location due to drift with the current from these positions; this variation is shown on the map.

5.3 Procedure

A trial run was made on the night of Tuesday, May 8, 1962, to check out equipment, personnel, and procedures. The actual experiment was on the night of Wednesday, May 9, 1962, which had a one-quarter moon hidden by clouds. The first observation was at 2130 and the final one at 0030.

With the boat at the first position, 1400 yards, the running lights were turned off and the calibrated lamp turned on. On land, a telephotometer reading on the lamp was taken and a reading of position made with the theodolite. The lamp was then turned off, and the orientation board held up just above the target helmets. The spotlight was turned on and centered on the target area by means of the reticle. The orientation board was removed. Each helmet was then presented five times in a predetermined random order, and the observers were given a ten-second time interval to respond to each presentation. At the end of the ten seconds the observers were told by means of the bell to respond again if they had seen color. During these presentations the backscatter of the spotlight was monitored with the telephotometer, and the position of the boat as it drifted was monitored by means of the theodolite. Between the 10th and 11th presentations of the helmet the orientation board was held up for checking the position of the spotlight. After the 20th or final presentation was made, the calibrated lamp was turned on and a transmissometer reading made.

At 2205 the running lights were turned back on and the boat repositioned at the first position. The same general procedure was repeated for the searchlight. An observer on the scaffolding positioned the searchlight by means of the control stick.

At 2230 the boat was moved to the second position, 2600 yards, and the same procedure repeated for both lights, first the spotlight, then the searchlight.

At 2315 the boat moved toward the third position. This time the boat was depending on radio communication to indicate proper positioning. The position was monitored with the theodolite, but radio contact was lost and the boat reached 7000 yards before contact was re-established. A spot check was made at this point. The searchlight was positioned on the target area by means of the orientation board. Then upon request from land the retrodirective helmet was presented. None of the observers reported seeing the helmet. The boat was then instructed to return to the 3600-yard buoy which was the third prearranged position.

At 0010 the boat took up position three. The basic procedure was repeated for the searchlight only. The field test was terminated at 0030.

5.4 Results

Introduction

The personnel aboard the utility boat estimated the local windspeed to be eight to ten knots and the swells to be three to four feet in height.

In addition to this information, standard weather observations were obtained for the test period from the U. S. Fleet Weather Facility, NAS North Island. The reported wind direction was northwest to north with windspeeds varying from a maximum of eight knots to calm. (Differences in local windspeed could be expected between the boat position and the North Island weather post.) Cloud cover was 8/10 to 10/10, and cloud height was above 15 000 feet. Swell was northwesterly. The Navy estimated visibility was 15 plus to 15 statute miles, or very clear. This is roughly equivalent to an attenuation length of 4.4 nautical miles.

From the transmissometer data the average measured attenuation length for the observer's path of sight was 6.5 nautical miles.

The average backscatter from the center of the searchlight beam was 9.5×10^{-2} foot-lamberts, and from the spotlight was 1.6×10^{-2} foot-lamberts. These values are in close agreement with the center approximation equation in Appendix C2 using a 6.5 nautical mile attenuation length.

Data

Table 4 shows the observed data for the searchlight. The results are reported separately for the observers above the light and beside the light since the backscatter is different for these two groups due to the elliptical shape of the searchlight beam. The column labeled N is the number of possible observations, that is, the product of the number of observers times the number of presentations of each helmet.

Table 5 shows the same information for the spotlight. Since this light has an almost circular beam spread, the backscatter was about the same for all the observers and their data are grouped together. The slant ranges are slightly different than in the case of the searchlight since the boat was repositioned while the lights were being exchanged.

Depression Angle

It will be noted that the depression angle of the beam is much smaller than those recommended in the previous section for the best area search-rates. The minimum range, 1400 yards, corresponds to a depression angle of $4^{\circ}2'$ and the maximum range, 4400 yards, corresponds to a depression angle of $1^{\circ}17'$. This difference is to be expected since, in the field test, the most sensitive portion of the eye, the fovea, is used to view the target in the best position in the beam, the center. On the other hand, the maximum area search-rates are obtained when the target can be seen anywhere in the beam, center or edge, when the eye is fixated on the center of the beam. Also, in the latter case less time is available for the target to be on one point on the retina since the situation is dynamic.

Comparison between Targets

In all cases the helmet with the Stimsonite retrodirective inserts was much superior to the helmets with the Scotchlite tape. At the greater ranges with the searchlight and at both ranges with the spotlight, the retrodirective insert helmet was always seen more often than the

Table 4 Comparison of Predicted to Observed Slant Ranges for 50 Per Cent Probability of Detection

Helmet	Observers Above Searchlight		Observers at Side of Searchlight	
	Predicted Range (Yards)	Observed Range (Yards)	Predicted Range (Yards)	Observed Range (Yards)
Retrodirective Inserts	4346	4040 - 4400	4007	2900 - 4040
White Tape	3340	2900 - 4040	3010	2420 - 2900
Red and White Tape	3140	2900 - 4040	2830	2900 - 4040
Red Tape	2690	<2420 -<2900	2420	2420 - 2900

Table 5

Helmet	All Observers for Spotlight	
	Predicted Range (Yards)	Observed Range (Yards)
Retrodirective Inserts	2897	>2650 ->3000
White Tape	2130	1750 - 2650
Red and White Tape	2010	>1450 ->1750
Red Tape	1605	>1450 ->1750

taped helmets. At the closest range with the searchlight, where all helmets were seen all of the time, the retrodirective insert helmet was always very noticeably brighter than the other helmets.

The differences between the three helmets with the Scotchlite is less clear cut. The red helmet was seen less well than the red and white or white helmets, but there is little difference between the latter two. This is reasonable since they differed by only a factor of approximately 1.2 in specific brightness. On the other hand, the specific brightness of the red helmet was less by a factor of 2.5 to 3.0 than that of the other two helmets. The variability resulting from the relatively small number of observations possible in the field test tends to obscure small differences.

Color

All color judgments, correct or false, were made when the helmets could be detected with a probability of 40 per cent or greater. When the spotlight was used, false color was reported as often as color was reported correctly. It is interesting to note that there were no false color judgments with the searchlight as the light source. At ranges such that the helmets were seen 100 per cent of the time, color was seen more often for the red helmet than for the red and white helmet.

The results indicate that it requires a shorter distance to discriminate color than to detect the target at the same degree of probability. Thus, color functions as a recognition clue rather than a detection clue. The target is first detected as the presence of something bright in a relatively dark surround. Then if that target is about at threshold luminance (has a 50 per cent probability of being detected under non-forced choice conditions), there is about a 10 per cent probability that color can be seen. At ranges such that the target has about a 90 per cent probability of being seen, there is roughly a 50 per cent probability that a red target will appear to be red.

The maximum possible area search-rate for the red helmet is less than for any of the other three helmets (see Sect. 4). If, because of the presence of white caps, it is necessary to see that the target is red before judgment is made that it is a helmet, the area search-rate would be considerably diminished. It is much better to use the retrodirective inserts on the helmet and achieve both an increased area search-rate and, in addition, a bright target that is always easily discriminable from white caps.

6. REFERENCES

1. J. W. Lane, Jr., T. H. Projector, W. A. Hall, and L. R. Noffsinger, "Evaluation Field Tests of Searchlight and Reflective Materials in Search and Rescue Operations," National Bureau of Standards Report 4606 (1956).

2. Report on Tests Performed on Searchlight Set, AN/AVQ-4(XN-1), Serial No. 1, 2, 3, M. Ten Bosch, Inc., Pleasantville, New York, (1960), TD 6 and 7.

3. Bureau of Naval Weapons Aviation Clothing and Survival Equipment Bulletin No. 1-60, p. 2, Washington 25, D. C. (1960).

APPENDICES

The main body of the report has presented all of the results and recommendations that were produced by the study. A description of a static field test has been given and a comparison has been made between the predicted and observed detection ranges. Several technical details concerning the methods of measurement employed and the techniques used for predicting detection ranges, optimum sweep width, ground speed, altitude, etc. are described in the Appendices which follow.

APPENDIX A

SPECIFIC BRIGHTNESS MEASUREMENTS OF TAPED HELMETS

Specific brightness measurements were made on the three helmets at night. Each helmet (white, red and white, and red) was measured for two positions. One position was chosen to simulate the downed aviator facing toward the searchlight. If the pilot is conscious he is most likely to be looking toward his potential rescuers. The second position, the rear of the helmet, was chosen to maximize the area of the reflective tape. This case might occur if the aviator were unconscious in the water.

A 500-watt, tungsten filament, projection lamp was placed 200 feet from the helmet. A logarithmic recording telephotometer was first placed at the position of the helmet to provide a luminance measurement of the source. Second, the photometer was placed near the light source and measurements made of the helmets at various separation distances from the source. The ratio of the readings of the helmet and the source was multiplied by π and divided by the angular subtense of the helmet in steradians to obtain the specific brightness in units of foot-lamberts per foot-candle. This procedure obviates the necessity for a calibration standard.

Measurements of each helmet were made at separation angles of 0.004, 0.0245, and 0.045 radians. The data for the smaller separation angles were shown in Fig. 7. Data were extrapolated for the on-axis position. It will be noted that the red and white helmet has predominantly red tape when seen from the front and more white tape when seen from the rear. This is the reason for the larger spread in the data between the two helmet positions for the red and white helmet than occurs for the helmets with only one kind of tape.

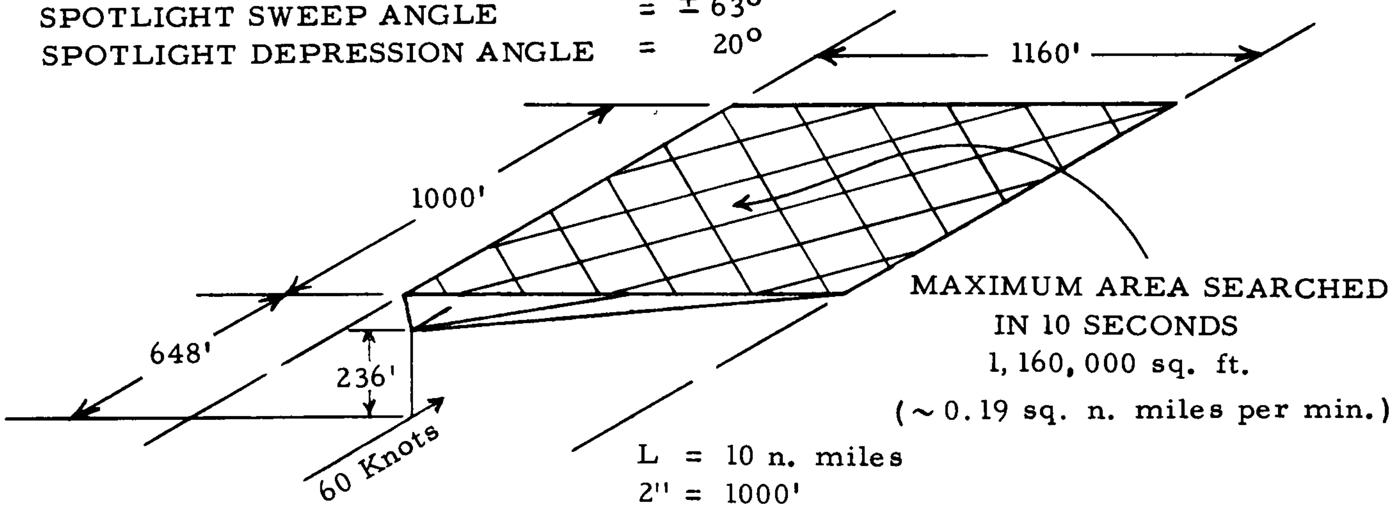
APPENDIX B

SEARCH PROCEDURES FOR REAR OF HELMET

The optimum search procedures based upon the assumption that the rear of the helmet is presented to the rescue helicopter are presented graphically in two groups of perspective drawings, B1-1, B1-2, B1-3 and B2-1, B2-2, and B2-3. These same recommendations are also summarized in Tables B1 and B2. It is believed that search operations should not be based upon the assumption that the rear of the helmet is presented to the helicopter: preferably use Figs. 9-1, 9-2, 9-3 and 10-1, 10-2, and 10-3 or Tables 1 and 2 in Sect. 4.

HELMET WITH WHITE TAPE (REAR)

SPOTLIGHT SWEEP TIME = 4.5 sec.
SPOTLIGHT SWEEP ANGLE = ± 63°
SPOTLIGHT DEPRESSION ANGLE = 20°

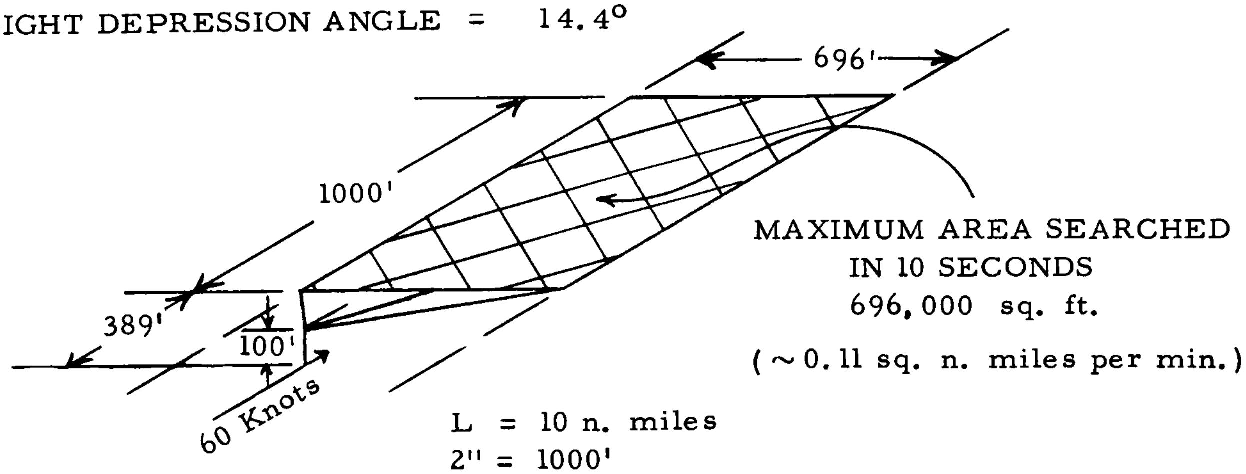


WEATHER CLEAR

Fig. B1-1

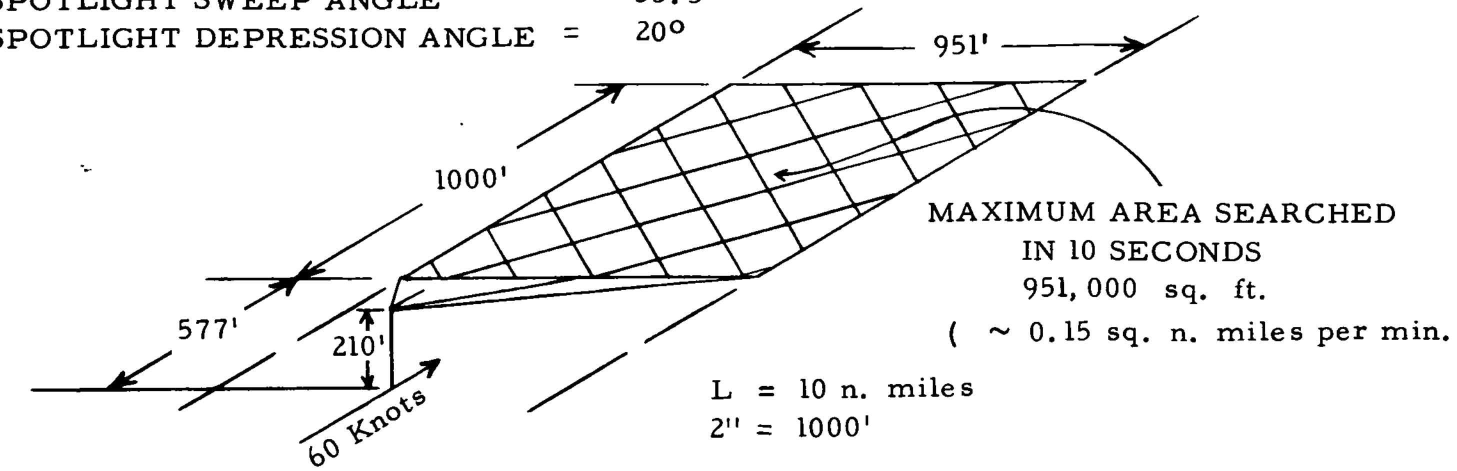
HELMET WITH RED TAPE (REAR)

SPOTLIGHT SWEEP TIME = 4.6 sec.
SPOTLIGHT SWEEP ANGLE = ± 63°
SPOTLIGHT DEPRESSION ANGLE = 14.4°



HELMET WITH RED AND WHITE TAPE (REAR)

SPOTLIGHT SWEEP TIME = 4.0 sec
SPOTLIGHT SWEEP ANGLE = ± 55.5°
SPOTLIGHT DEPRESSION ANGLE = 20°

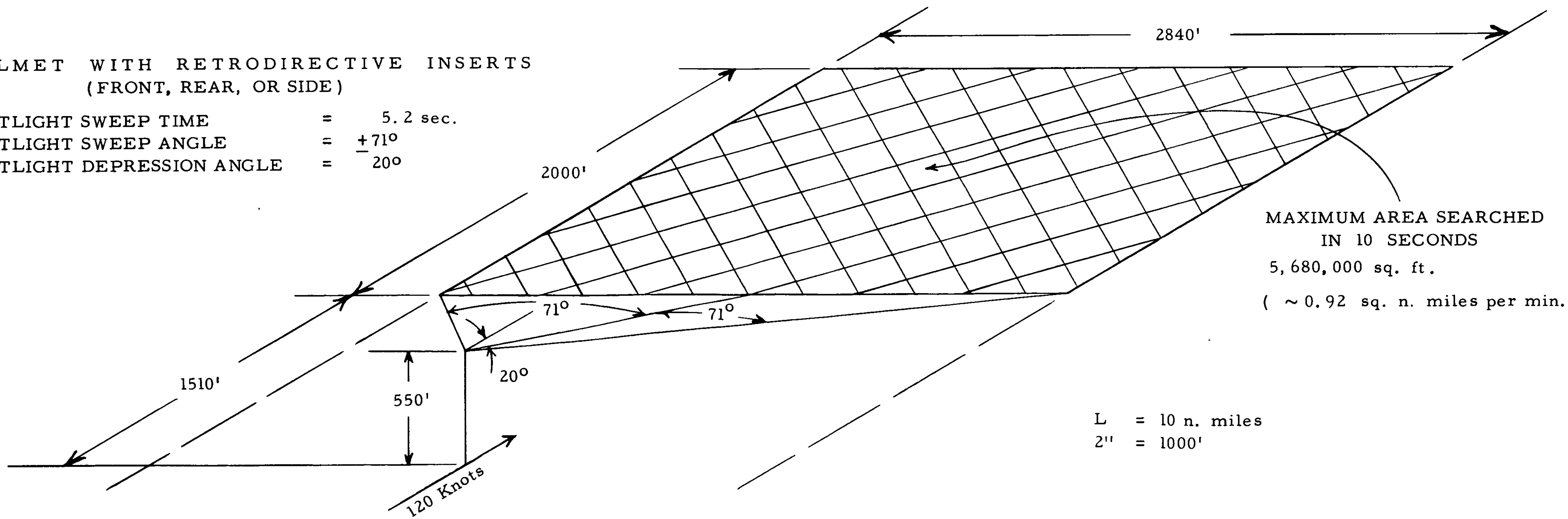


WEATHER CLEAR

Fig. B1-1 (con't)

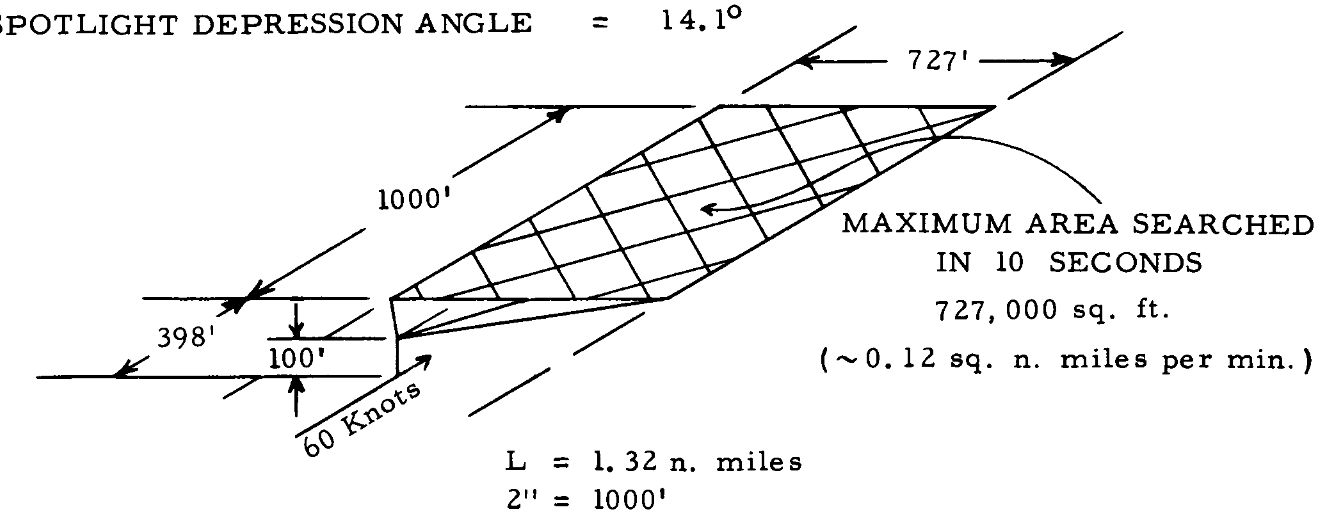
HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, REAR, OR SIDE)

SPOTLIGHT SWEEP TIME = 5.2 sec.
SPOTLIGHT SWEEP ANGLE = ± 71°
SPOTLIGHT DEPRESSION ANGLE = 20°



HELMET WITH WHITE TAPE (REAR)

SPOTLIGHT SWEEP TIME	=	4.8 sec.
SPOTLIGHT SWEEP ANGLE	=	±66°
SPOTLIGHT DEPRESSION ANGLE	=	14.1°

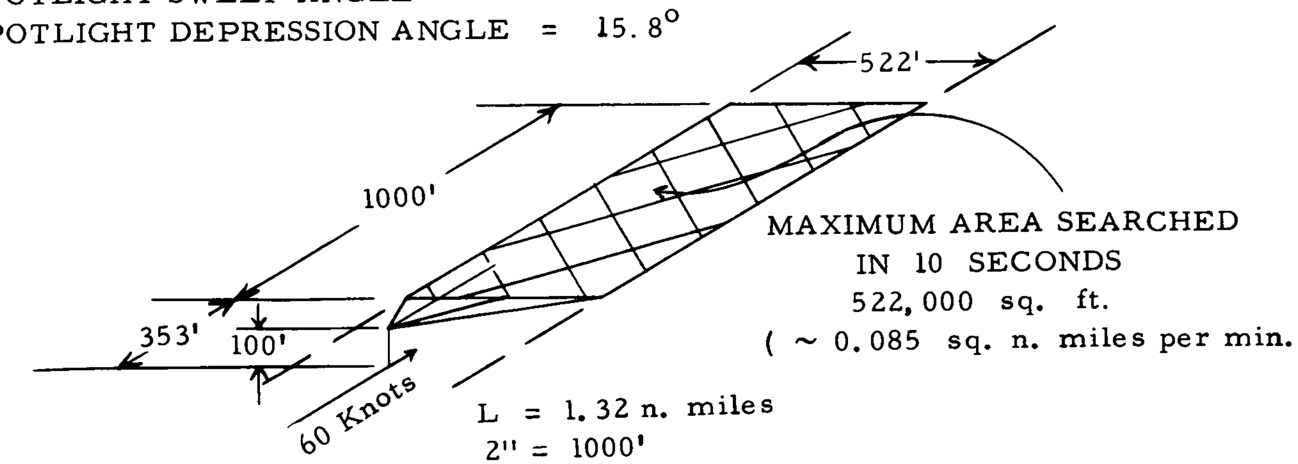


WEATHER HAZE

Fig. B1-2

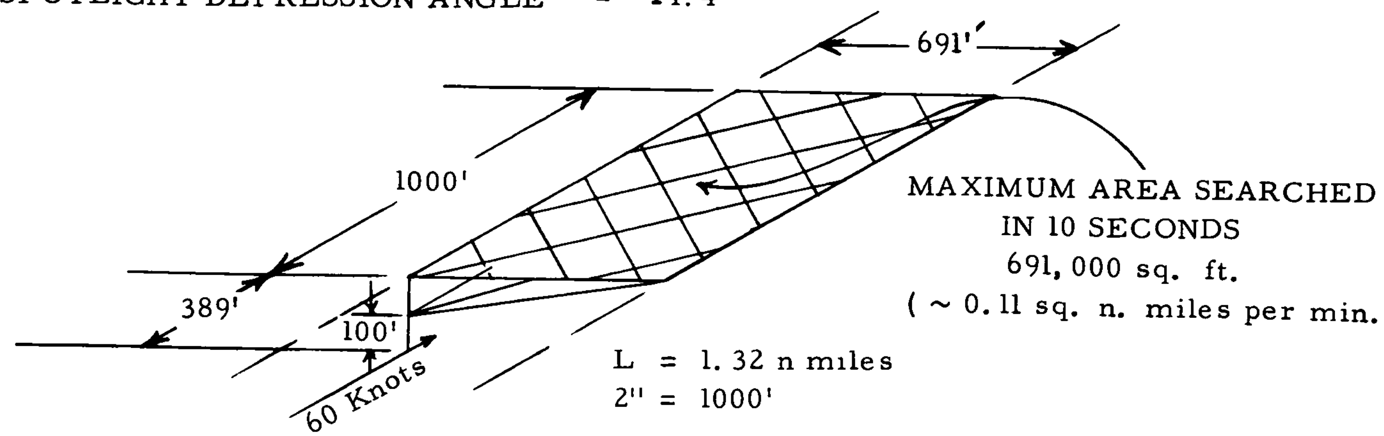
HELMET WITH RED TAPE (REAR)

SPOTLIGHT SWEEP TIME	=	3.5 sec.
SPOTLIGHT SWEEP ANGLE	=	±47.5°
SPOTLIGHT DEPRESSION ANGLE	=	15.8°



HELMET WITH RED AND WHITE TAPE (REAR)

SPOTLIGHT SWEEP TIME = 4.5 sec.
SPOTLIGHT SWEEP ANGLE = ±62.5°
SPOTLIGHT DEPRESSION ANGLE = 14.4°

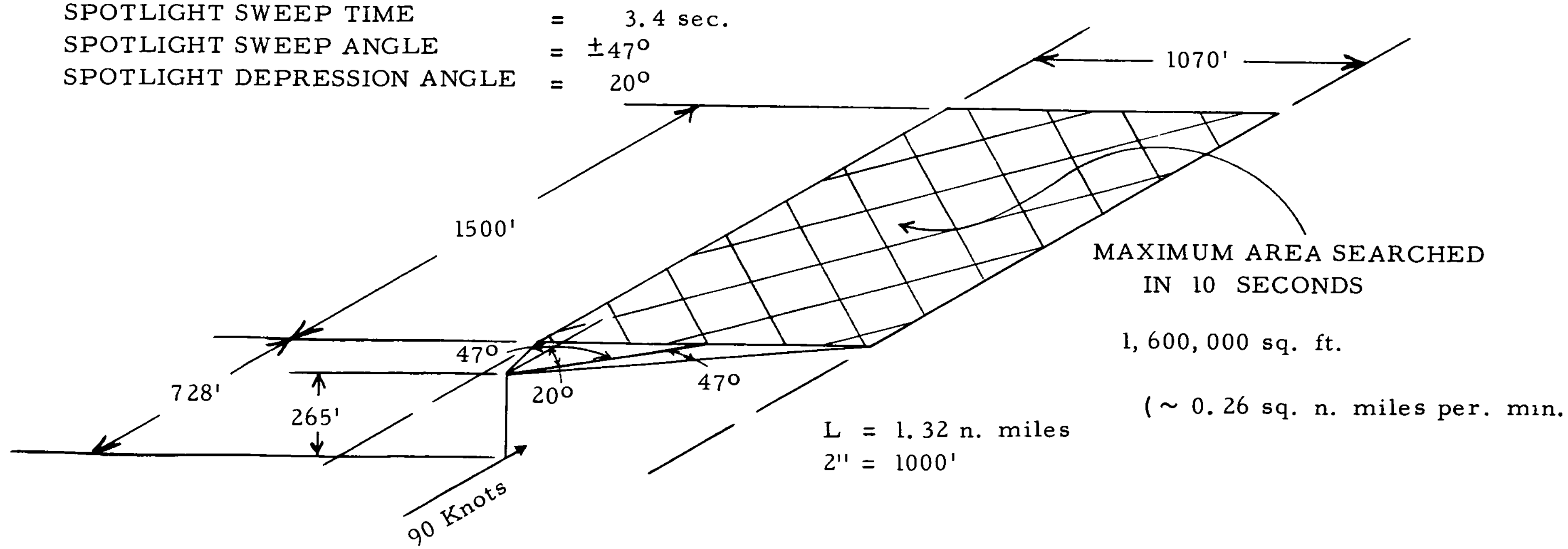


WEATHER HAZE

Fig. B1-2 (con't)

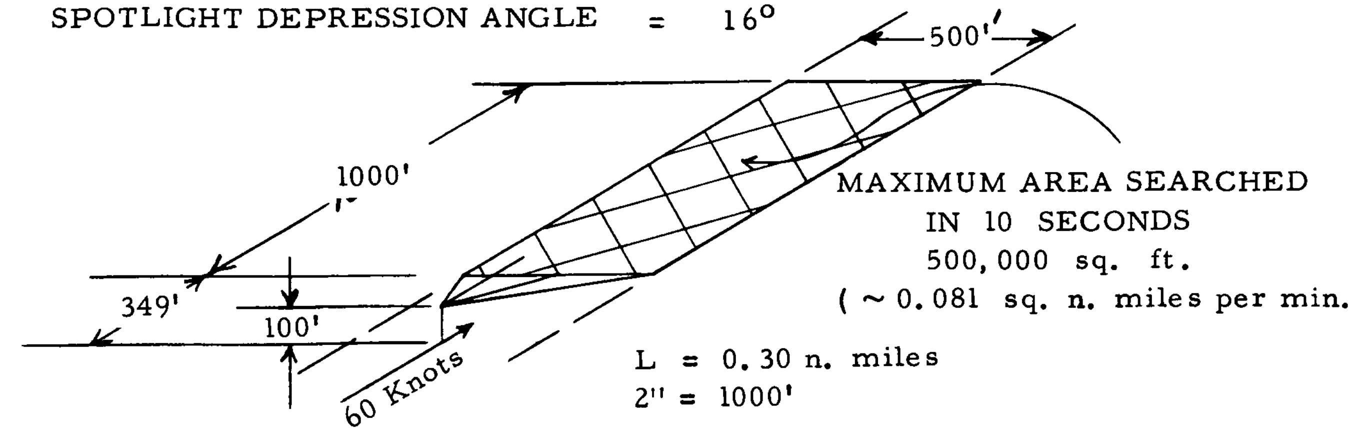
HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, REAR, OR SIDE)

SPOTLIGHT SWEEP TIME = 3.4 sec.
SPOTLIGHT SWEEP ANGLE = ±47°
SPOTLIGHT DEPRESSION ANGLE = 20°



HELMET WITH WHITE TAPE (REAR)

SPOTLIGHT SWEEP TIME = 3.3 sec.
SPOTLIGHT SWEEP ANGLE = $\pm 46^{\circ}$
SPOTLIGHT DEPRESSION ANGLE = 16°

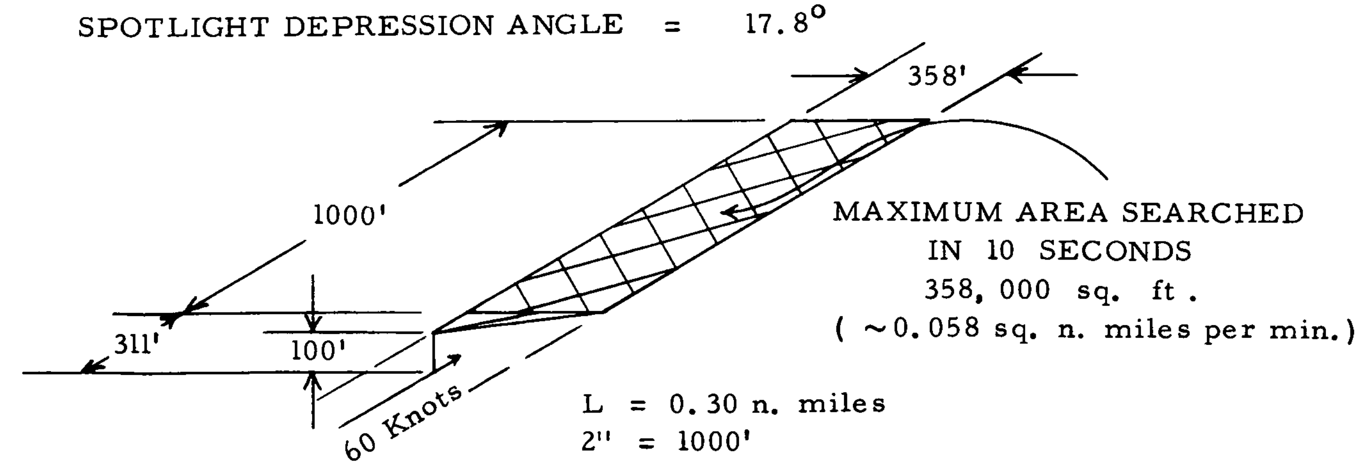


WEATHER DENSE

Fig. B 1-3

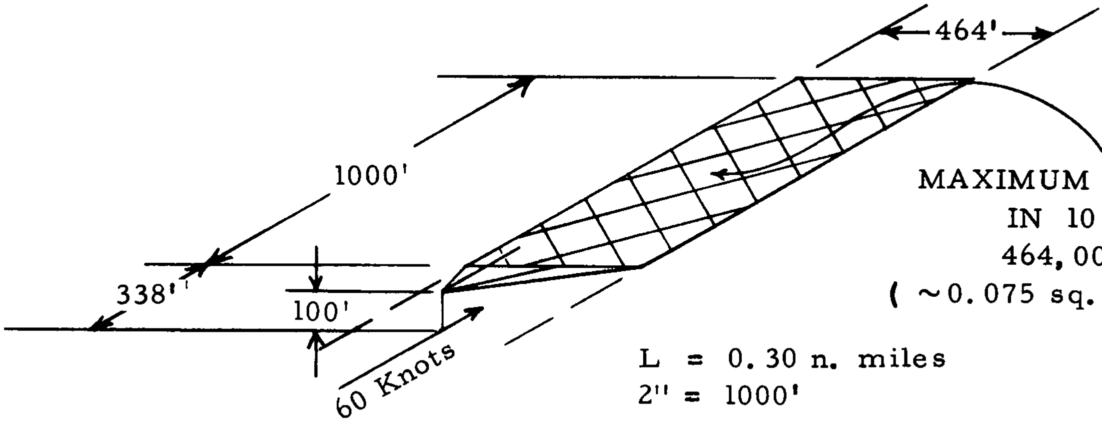
HELMET WITH RED TAPE (REAR)

SPOTLIGHT SWEEP TIME = 2.6 sec.
SPOTLIGHT SWEEP ANGLE = $\pm 35^{\circ}$
SPOTLIGHT DEPRESSION ANGLE = 17.8°



HELMET WITH RED AND WHITE TAPE (REAR)

SPOTLIGHT SWEEP TIME = 3.2 sec.
SPOTLIGHT SWEEP ANGLE = ±43.5°
SPOTLIGHT DEPRESSION ANGLE = 16.5°



MAXIMUM AREA SEARCHED
IN 10 SECONDS
464,000 sq. ft.
(~0.075 sq. n. miles per min.)

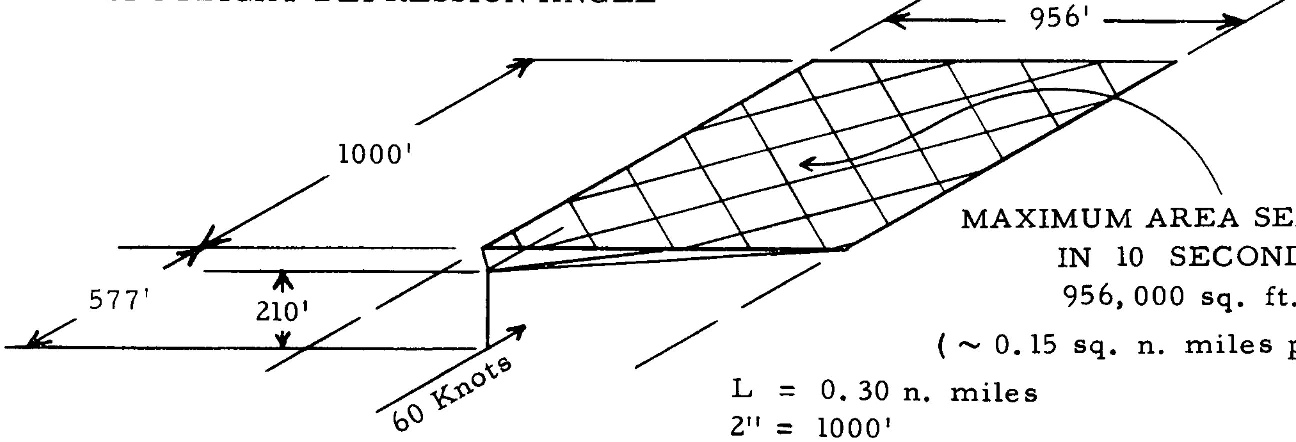
L = 0.30 n. miles
2" = 1000'

WEATHER DENSE

Fig. B1-3 (con't)

HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, REAR, OR SIDE)

SPOTLIGHT SWEEP TIME = 4.3 sec.
SPOTLIGHT SWEEP ANGLE = ±56°
SPOTLIGHT DEPRESSION ANGLE = 20°



MAXIMUM AREA SEARCHED
IN 10 SECONDS
956,000 sq. ft.
(~ 0.15 sq. n. miles per min.)

L = 0.30 n. miles
2" = 1000'

Table B1. Maximum Area Search-Rate for Spotlight on Starlight Night.

Helmet	Attenuation Length (Nautical Miles)	Area Search-Rate (Square Feet per Second)	Helicopter Altitude (Feet)	Helicopter Velocity (Knots)	Beam Depression Angle	Beam Azimuthal Coverage	Sweep Width (Feet)	Sweep Time (Seconds)
White Tape (Rear)	10.0	116 000	236	60	20.0°	126°	1 160	4.5
	1.32	72 700	100	60	14.1°	132°	727	4.8
	0.30	50 000	100	60	16.0°	92°	500	3.3
Red and White Tape (Rear)	10.0	95 100	210	60	20.0°	111°	951	4.0
	1.32	69 100	100	60	14.4°	125°	691	4.5
	0.30	46 400	100	60	16.5°	87°	464	3.2
Red Tape (Rear)	10.0	69 600	100	60	14.4°	126°	696	4.6
	1.32	52 200	100	60	15.8°	95°	522	3.5
	0.30	35 800	100	60	17.8°	70°	358	2.6

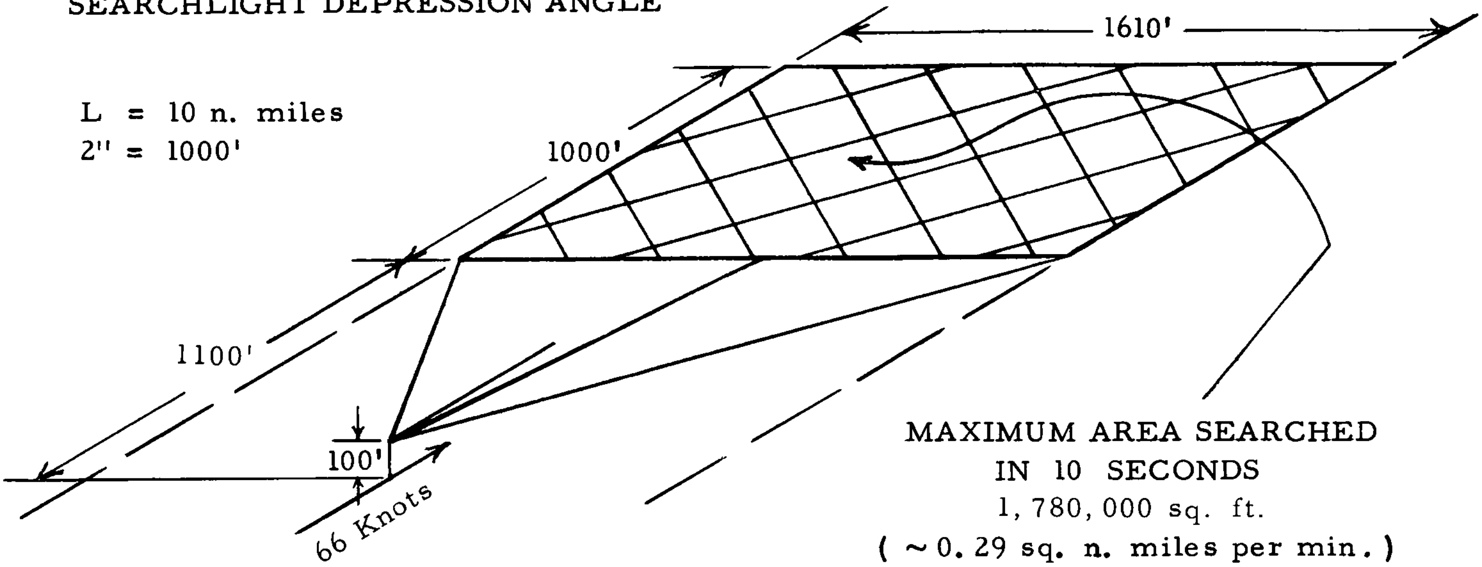
Table B2. Maximum Area Search-Rate for Searchlight on Starlight Night.

Helmet	Attenuation Length (Nautical Miles)	Area Search-Rate (Square Feet per Second)	Helicopter Altitude (Feet)	Helicopter Velocity (Knots)	Beam Depression Angle	Beam Azimuthal Coverage	Sweep Width (Feet)	Sweep Time (Seconds)
White Tape (Rear)	10.0	178 000	100	66	5.0°	90°	1 610	5.3
	1.32	121 000	100	60	5.7°	74°	1 210	4.3
	0.30	66 700	100	60	6.7°	46°	667	2.7
Red and White Tape (Rear)	10.0	134 000	100	60	5.5°	80°	1 340	4.7
	1.32	103 000	100	60	6.0°	65°	1 030	3.8
	0.30	52 000	100	60	7.5°	40°	520	2.3
Red Tape (Rear)	10.0	84 300	100	60	6.4°	56°	843	3.3
	1.32	69 700	100	60	7.0°	46°	697	2.7
	0.30	37 300	100	60	8.4°	32°	373	1.9

HELMET WITH WHITE TAPE (REAR)

SEARCHLIGHT SWEEP TIME = 5.3 sec.
SEARCHLIGHT SWEEP ANGLE = ±45°
SEARCHLIGHT DEPRESSION ANGLE = 5.0°

L = 10 n. miles
2'' = 1000'



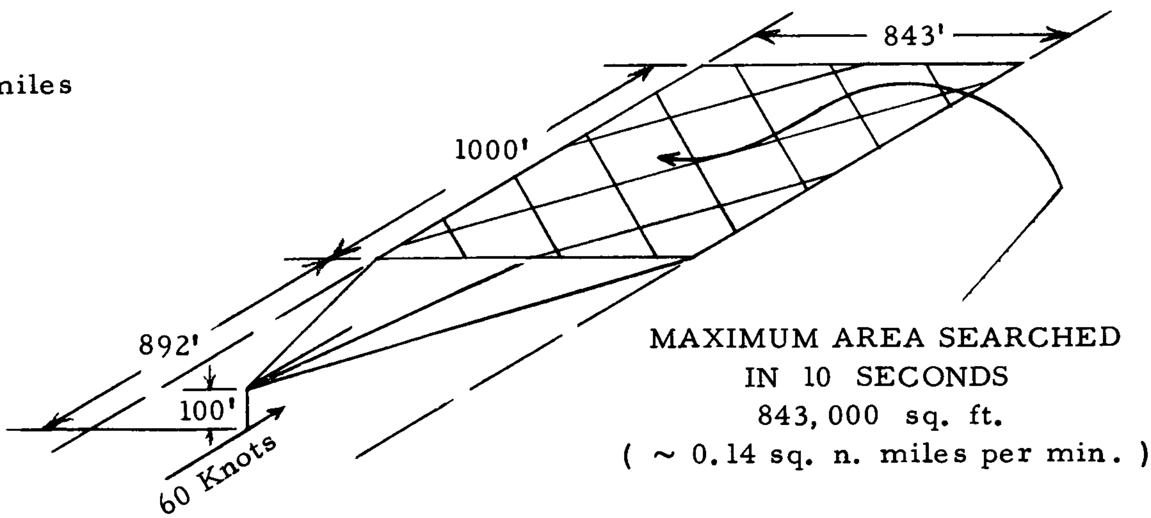
WEATHER CLEAR

Fig. B 2-1

HELMET WITH RED TAPE (REAR)

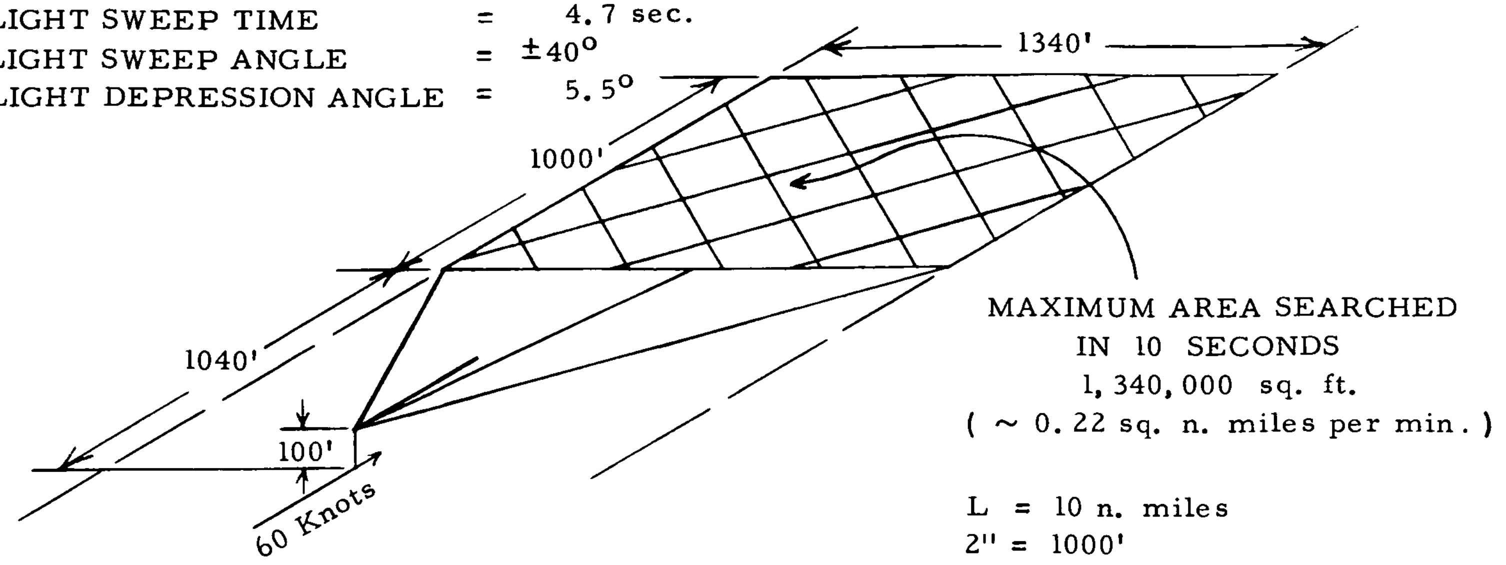
SEARCHLIGHT SWEEP TIME = 3.3 sec.
SEARCHLIGHT SWEEP ANGLE = ±28°
SEARCHLIGHT DEPRESSION ANGLE = 6.4°

L = 10 n miles
2'' = 1000'



HELMET WITH RED AND WHITE TAPE (REAR)

SEARCHLIGHT SWEEP TIME = 4.7 sec.
SEARCHLIGHT SWEEP ANGLE = ±40°
SEARCHLIGHT DEPRESSION ANGLE = 5.5°

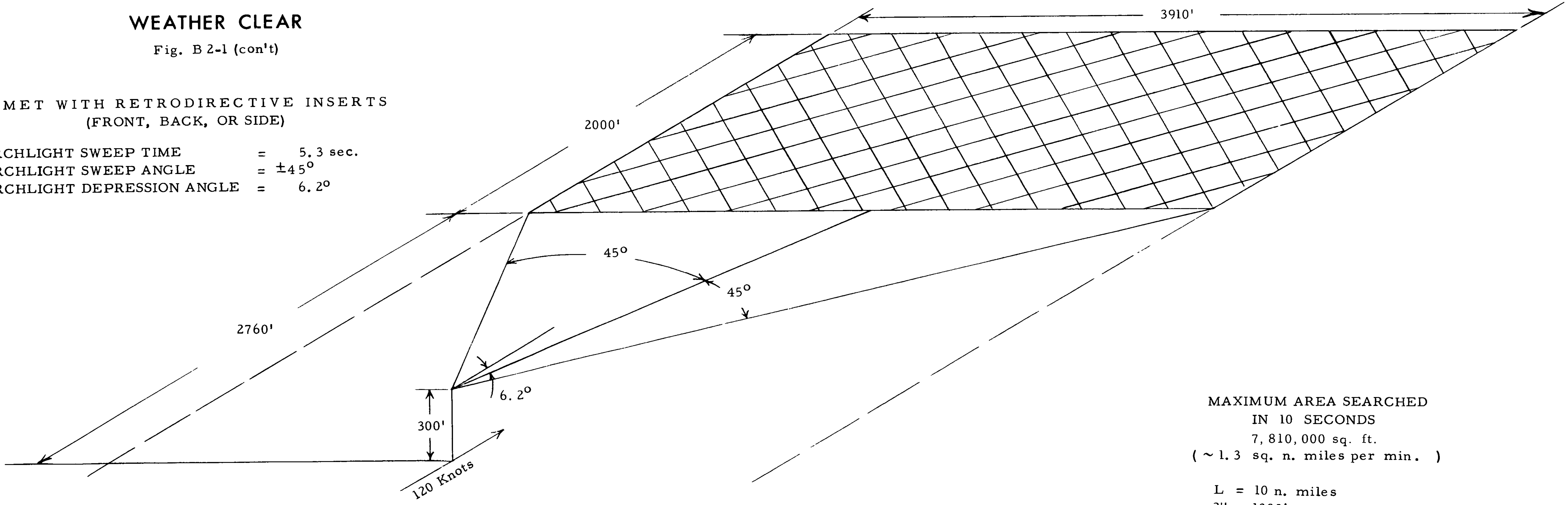


WEATHER CLEAR

Fig. B 2-1 (con't)

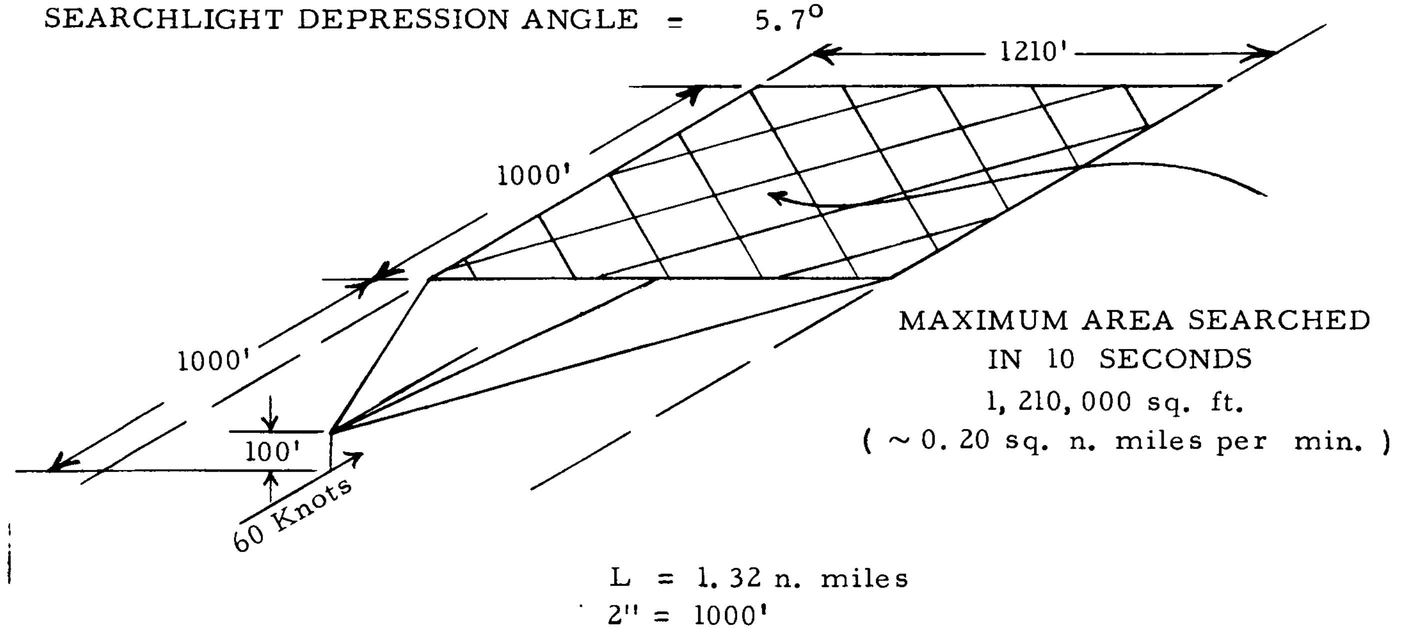
HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, BACK, OR SIDE)

SEARCHLIGHT SWEEP TIME = 5.3 sec.
SEARCHLIGHT SWEEP ANGLE = ±45°
SEARCHLIGHT DEPRESSION ANGLE = 6.2°



HELMET WITH WHITE TAPE (REAR)

SEARCHLIGHT SWEEP TIME = 4.3 sec.
SEARCHLIGHT SWEEP ANGLE = ± 37°
SEARCHLIGHT DEPRESSION ANGLE = 5.7°

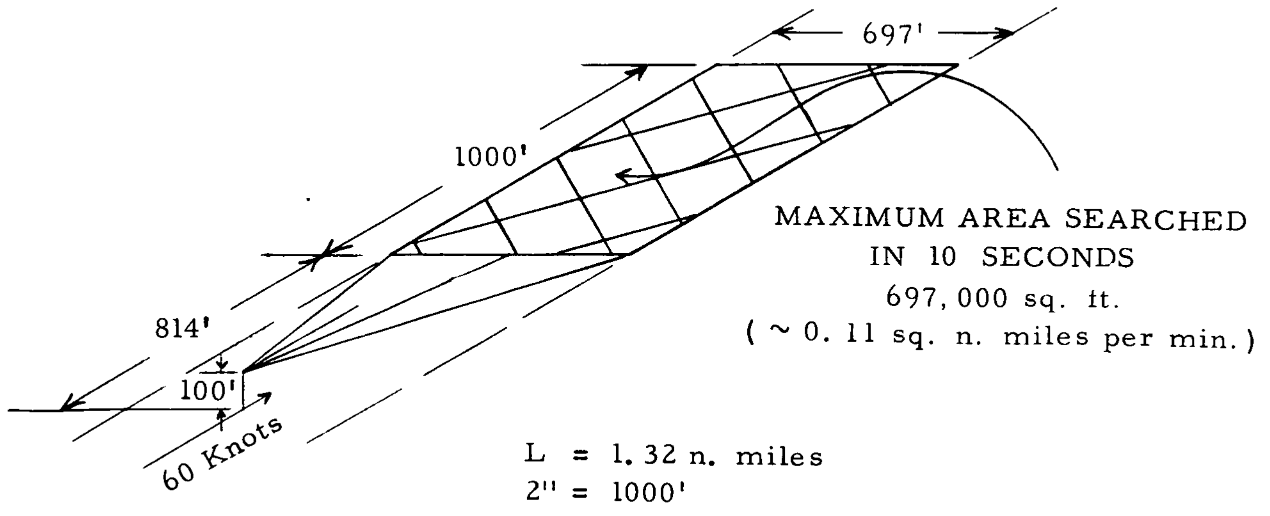


WEATHER HAZE

Fig. B 2-2

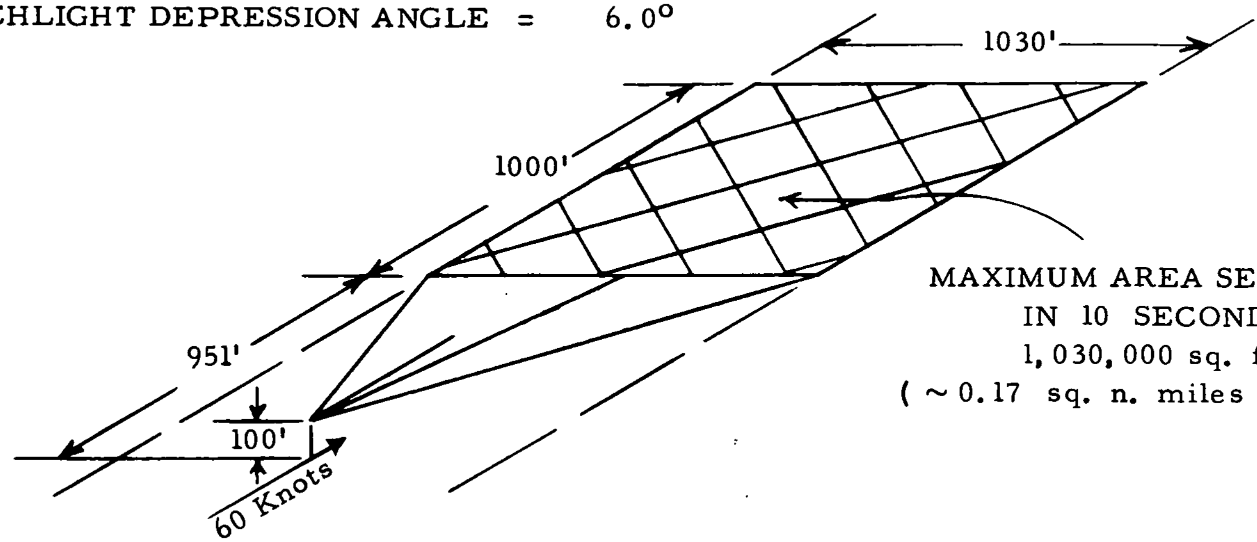
HELMET WITH RED TAPE (REAR)

SEARCHLIGHT SWEEP TIME = 2.7 sec.
SEARCHLIGHT SWEEP ANGLE = ± 23°
SEARCHLIGHT DEPRESSION ANGLE = 7.0°



HELMET WITH RED AND WHITE TAPE (REAR)

SEARCHLIGHT SWEEP TIME = 3.8 sec.
SEARCHLIGHT SWEEP ANGLE = ± 32.5°
SEARCHLIGHT DEPRESSION ANGLE = 6.0°



MAXIMUM AREA SEARCHED
IN 10 SECONDS
1,030,000 sq. ft.
(~ 0.17 sq. n. miles per min.)

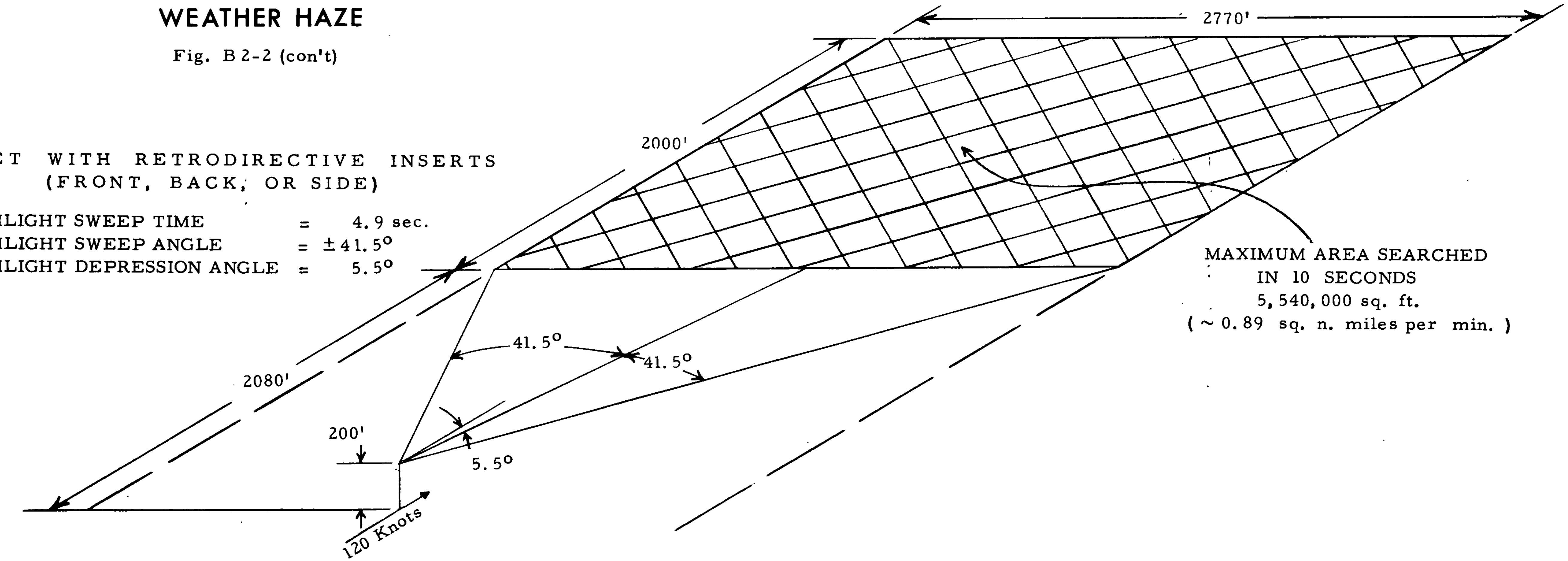
L = 1.32 n. miles
2" = 1000'

WEATHER HAZE

Fig. B 2-2 (con't)

HELMET WITH RETRODIRECTIVE INSERTS (FRONT, BACK, OR SIDE)

SEARCHLIGHT SWEEP TIME = 4.9 sec.
SEARCHLIGHT SWEEP ANGLE = ± 41.5°
SEARCHLIGHT DEPRESSION ANGLE = 5.5°

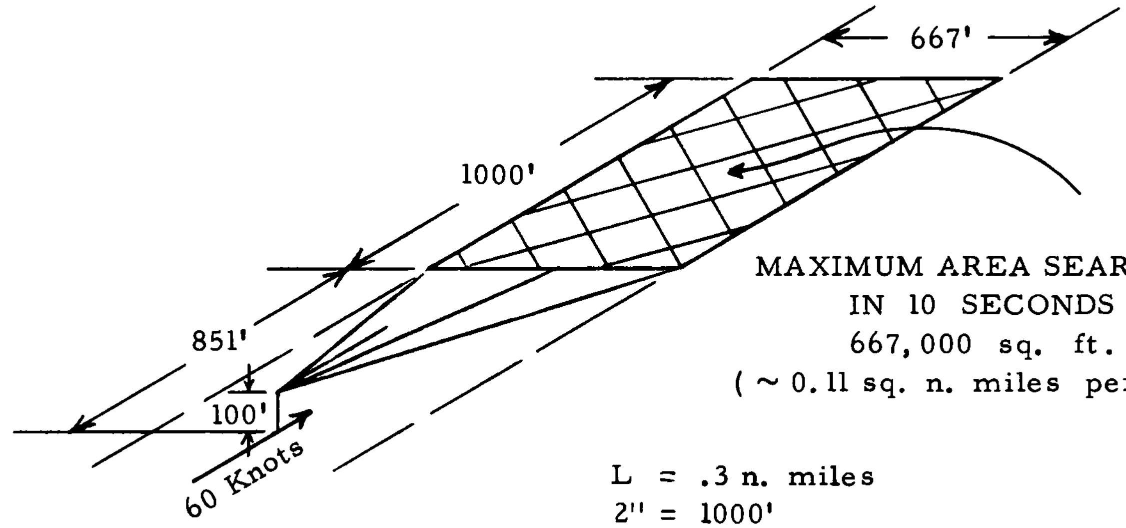


MAXIMUM AREA SEARCHED
IN 10 SECONDS
5,540,000 sq. ft.
(~ 0.89 sq. n. miles per min.)

L = 1.32 n. miles
2" = 1000'

HELMET WITH WHITE TAPE (REAR)

SEARCHLIGHT SWEEP TIME = 2.7 sec.
SEARCHLIGHT SWEEP ANGLE = $\pm 23^{o}$
SEARCHLIGHT DEPRESSION ANGLE = 6.7^{o}



MAXIMUM AREA SEARCHED
IN 10 SECONDS
667,000 sq. ft.
(~ 0.11 sq. n. miles per min.)

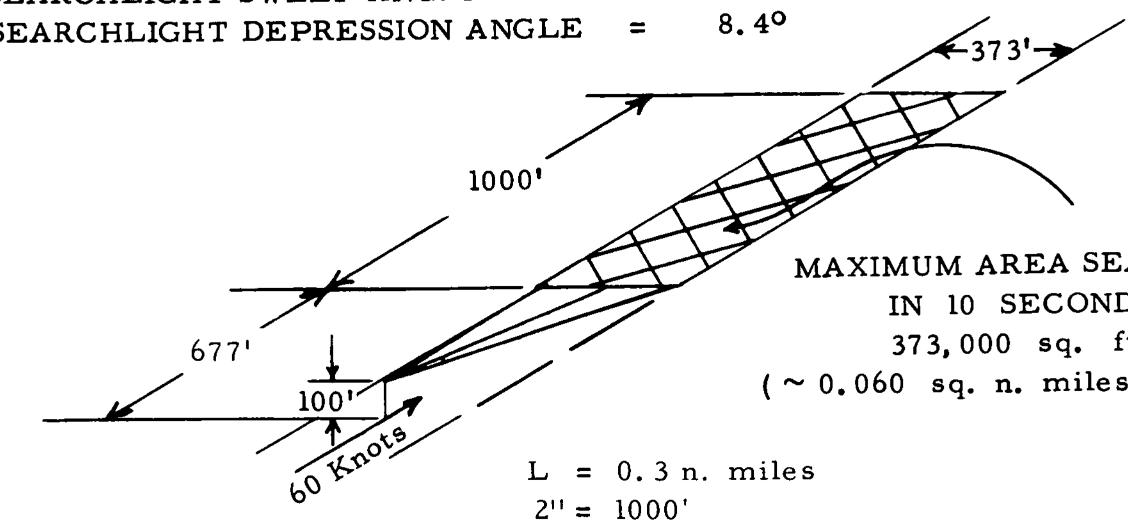
L = .3 n. miles
2" = 1000'

WEATHER DENSE

Fig. B 2-3

HELMET WITH RED TAPE (REAR)

SEARCHLIGHT SWEEP TIME = 1.9 sec.
SEARCHLIGHT SWEEP ANGLE = $\pm 16^{o}$
SEARCHLIGHT DEPRESSION ANGLE = 8.4^{o}

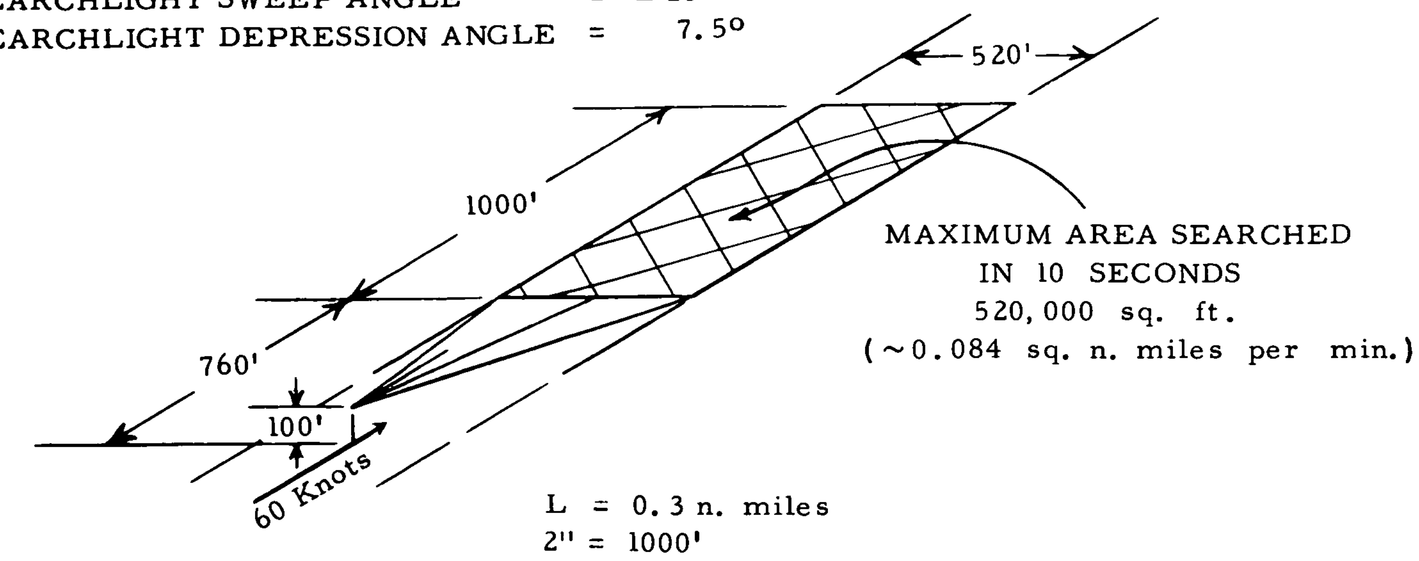


MAXIMUM AREA SEARCHED
IN 10 SECONDS
373,000 sq. ft.
(~ 0.060 sq. n. miles per min.)

L = 0.3 n. miles
2" = 1000'

HELMET WITH RED AND WHITE TAPE (REAR)

SEARCHLIGHT SWEEP TIME = 2.3 sec.
SEARCHLIGHT SWEEP ANGLE = ± 20°
SEARCHLIGHT DEPRESSION ANGLE = 7.5°

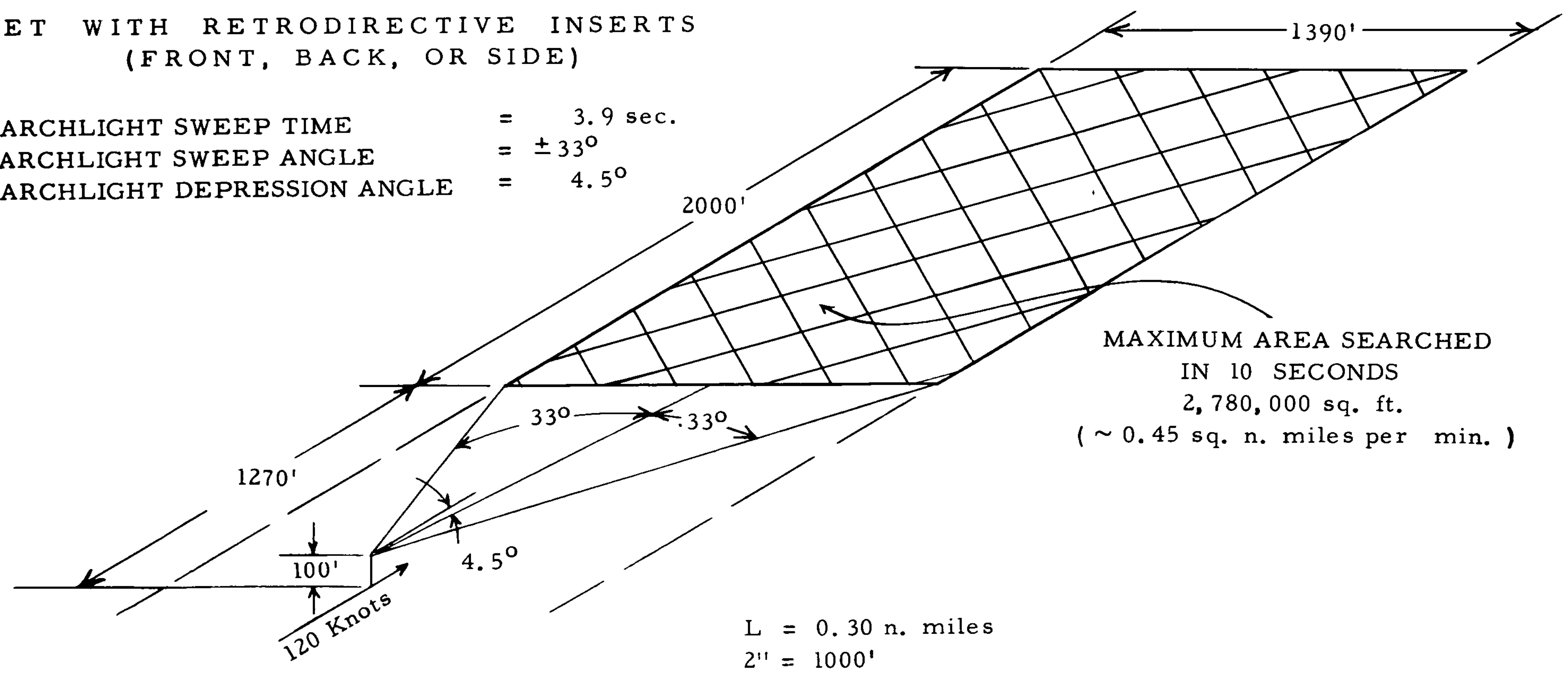


WEATHER DENSE

Fig. B 2-3 (con't)

HELMET WITH RETRODIRECTIVE INSERTS
(FRONT, BACK, OR SIDE)

SEARCHLIGHT SWEEP TIME = 3.9 sec.
SEARCHLIGHT SWEEP ANGLE = ± 33°
SEARCHLIGHT DEPRESSION ANGLE = 4.5°



APPENDIX C

PHOTOMETRIC APPEARANCE OF THE AVIATOR'S FIELD OF VIEW

This Appendix describes the methods used to compute the photometric appearance of the aviator's field of view during a night aerial search for aviators downed at sea. The visual thresholds of the aviator are also discussed.

C1 SEA SURFACE LUMINANCE

Introduction

The luminance of the wind-ruffled sea surface is governed by the slope characteristics of the capillary waves and by white water. Both are caused by local wind. Swell is caused by non-local wind and while not affecting the luminance of the sea surface, would affect the search problem from the standpoint of occultation of the target during a certain percentage of the time at low angles of sight, unless the search could be conducted in the direction of the troughs of the swells. Seasonal surveys on various ocean areas of both sea (local wind) and swell (non-local wind) with wave height, wind direction, etc., are available in the literature and can be used as an aid to the planner of rescue missions.

The relative contribution of the small capillary waves and the white water to the total sea luminance is a function of the wind speed* as measured at an anemometer height of 41 feet. There are no white caps up to and including the 11-knot wind speed; then the percentage appears to increase linearly until, at 20 knots (the maximum wind speed for use of helicopters), white caps constitute approximately 15 percent of the sea surface. A good approximation for finding the percentage of white caps, P, from the wind speed in knots, S, is:

$$P = \frac{13}{8}(S-11)$$

*R. L. Ensminger, CONFIDENTIAL Report, Univ. of Calif., Visibility Laboratory, SIO Ref. 57-24, p. 115 (1957).

In the night search problem there are two sources of illumination: (1) the natural source, which is the sky with or without a moon, and (2) the artificial source, the searchlight. The total inherent luminance is the sum of the sea luminances from the two sources.

Natural Illumination

Luminance due to Small Capillary Waves

The inherent luminance due to small capillary waves of the wind-ruffled sea surface is the sum of the inherent reflected luminance and the inherent upwelling luminance at each given path of sight.* A method, described below, was devised to obtain these two components of the inherent luminance computationally. The results of these computations, using two nighttime illumination conditions are shown in Fig. C1.

The sky luminance distribution for the starlight sky was taken from the literature.** The starlight sky shows no change in luminance with azimuth; hence the sea luminance is not a function of azimuth.

The sky luminance distribution for the moonlight case was taken from the Visibility Laboratory files of measurements made with a hemispherical scanning photometer mounted on a B-29 aircraft. These data were selected so as to have a full moon at a low altitude angle of 25° and thus provide the maximum glitter path at the small depression angles of sight appropriate to this study.

*S. Q. Duntley, "Visibility of Submerged Objects," Mass. Inst. of Tech., Visibility Laboratory, Final Report, Eq. 1.9, p. 9 and Eq. 1.24, p. 12, (1952).

**E. O. Hulburt, "Survey of Brightness of the Night Sky," Naval Research Laboratory Report No. N-3263, p. 5 (1948).

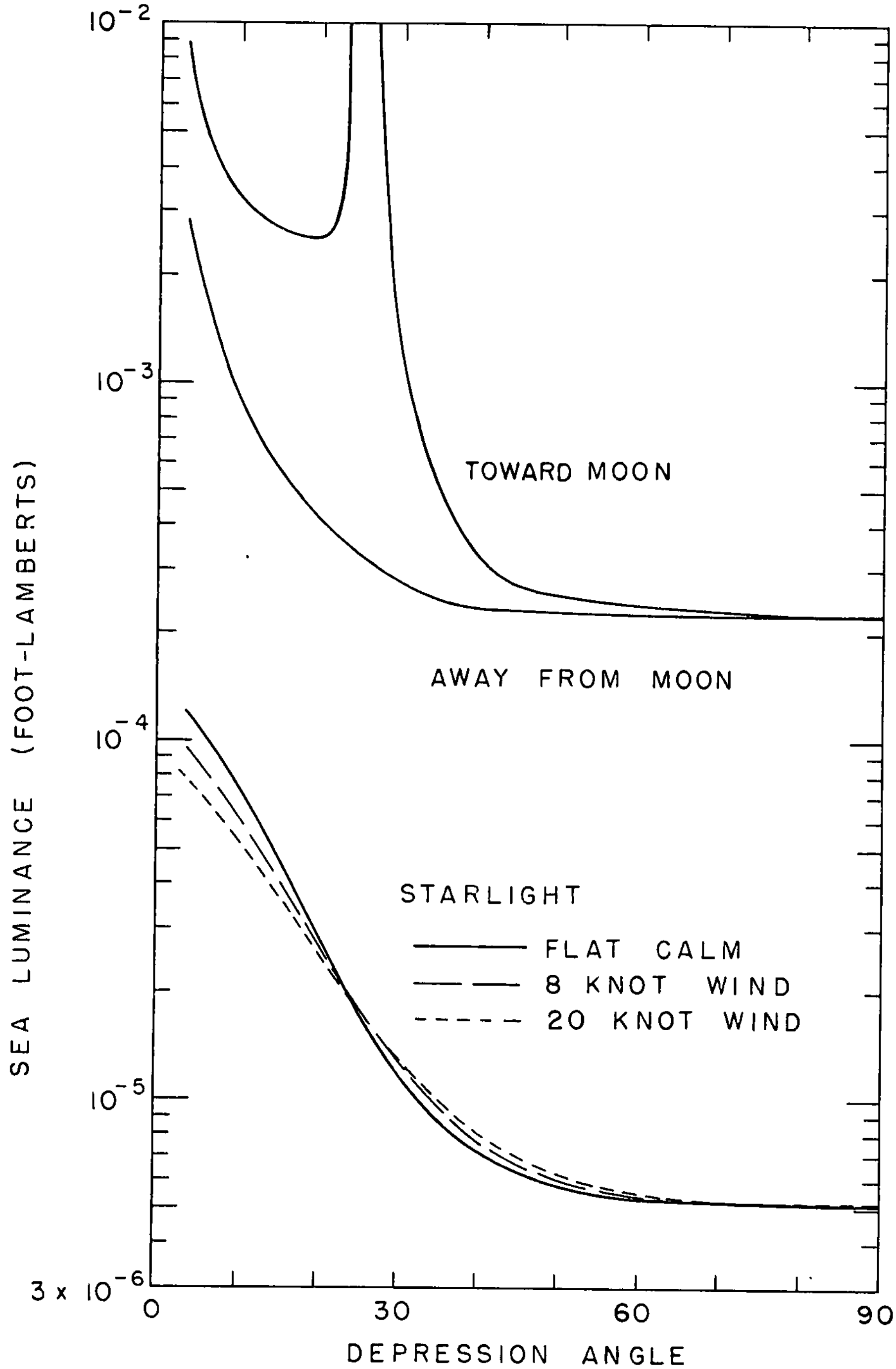


FIGURE CI- LUMINANCE OF THE SEA SURFACE DUE TO NATURAL ILLUMINATION

Luminance of White Water

White water is a nearly diffuse reflector; i.e., the luminance of white water is nearly the same when viewed from any direction. A reflectance of 75 per cent was found to be appropriate for white water under overcast skies.* Assuming this to be reasonably appropriate for clear skies as well, typical luminance of white water under starlight might be 1.1×10^{-4} foot-lamberts and under moonlight with the full moon at an altitude of 25° would be 9.1×10^{-3} foot-lamberts.

Illumination by Searchlight

Luminance due to Small Capillary Waves

The luminance of the water surface due to the searchlight also depends on the slope characteristics of the small capillary waves. In this case, however, the small capillary waves do not specularly reflect the searchlight beam back into the direction of the observer, and the sea luminance is due entirely to the inherent upwelling luminance contributed by the searchlight.

The maximum slope of the small capillary waves when the local wind speed is 20 knots is such that the normal from the maximum slope wavelet is 32.2° from the zenith. Thus, at the small depression angles of sight possible over the nose of the helicopter (and indeed at all of the angles of sight available out the side for use with the $3^{\circ} \times 8^{\circ}$ searchlight, 0° to 45° depression angle), the sea surface cannot specularly reflect the searchlight beam back in the direction of the observer.

*R. L. Ensminger, CONFIDENTIAL Report, Univ. of Calif., Visibility Laboratory, SIO Ref. 57-24, p. 34 (1957).

The upwelling luminance is due to the light from the searchlight which has penetrated the water surface and has been reflected back upward again by the deep water. For a first approximation, the luminance of a given point on the water surface was assumed to be a direct function of the illumination from the searchlight at that particular point. Thus, the upwelling luminance could be thought of as being the product of the illuminance from the searchlight times a directional reflectance. This directional reflectance is a function of angle of sight and local wind speed. For all wind speeds the directional reflectance is slightly under 2 per cent at a depression angle of 90° and decreases as the depression angle decreases. At 3.5° depression angle the directional reflectance is 0.2 per cent for no wind and 0.7 per cent for a 20-knot wind.

Luminance of White Water

The inherent luminance of white water due to the searchlight is the product of the reflectance of white water (75 per cent) times the illuminance from the searchlight.

C2 BACKSCATTER FROM LIGHT SOURCES

Introduction

The backscatter from the light source beam as it appears at the position of the observer is a function of the intensity distribution in the beam, the separation distance* between the observer and the light source, and the air clarity.**,†,†† Attenuation length is a measure of air clarity and is the distance at which the beam transmittance is 37 per cent.

For purposes of simplifying the analysis, two assumptions were made. One, the intensity of the light was assumed to decrease linearly with angle from the center of the beam to the edge of the beam where the intensity is 10 per cent of the peak, at which point it was assumed to drop abruptly to zero. Two, the observer was assumed to be directly above or above and slightly to the rear of the light source.

These assumptions make it possible to approximate the backscatter in the center of the beam by the following equation:†††

$$B_R^* = \frac{1.84 \times 10^{-7} I_o K}{L\ d} \qquad (1)$$

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*Separation distance is the length of the perpendicular dropped from observer to the axis of the light source.

**E. O. Hulburt, "Optics of Atmospheric Haze," J. Opt. Soc. Am. 31, 467-476 (1941).

† E. O. Hulburt, "Optics of Searchlight Illumination," J. Opt. Soc. Am. 36, 483-491 (1946).

††H. R. Blackwell, S. Q. Duntley, and W. M. Kincaid, "Characteristics of Tank Mounted Searchlights for Detection of Ground Targets," Work Group on Tank Searchlight, Armed Forces-NRC Vision Com., Univ. of Mich. (1953).

†††R. L. Ensminger and J. L. Harris, "Feasibility Study of a Photoelectric System for Detection of Downed Aviators," Univ. of Calif., Vis. Lab., SIO Ref. 60-45, p. 3 (1960).

Backscatter (B_R^*) is given in foot-lamberts, I_o is the peak intensity of the beam in candles, K is one-half the vertical beam spread in degrees, L is attenuation length in nautical miles, and d is the observer-to-source separation distance in feet. The peak intensity used in this study for the searchlight with plastic dome over the projector as in flight was 2 x 10^6 candles.

High Attenuation Length

The center beam backscatter approximation is an excellent one for high attenuation lengths, 10 nautical miles or greater. The angular distribution of the backscatter as related to the center of the searchlight beam is presented at the top of Fig. C2. For a given example, the luminance of the backscatter would be obtained by multiplying the normalized values by the luminance of the backscatter for the center of the beam which depends upon attenuation length and the separation distance, source to observer.

This distribution angularly has been expressed analytically in a form applicable to any light source for high attenuation lengths.

Low Attenuation Length

The approximation for the backscatter for the center of the beam breaks down for lower attenuation lengths. The backscatter luminance approaches but does not reach the value predicted by the approximation. The degree to which the approximation is approached depends upon three factors: attenuation length, distance of observer to target, and distance of observer to light source. The approximation

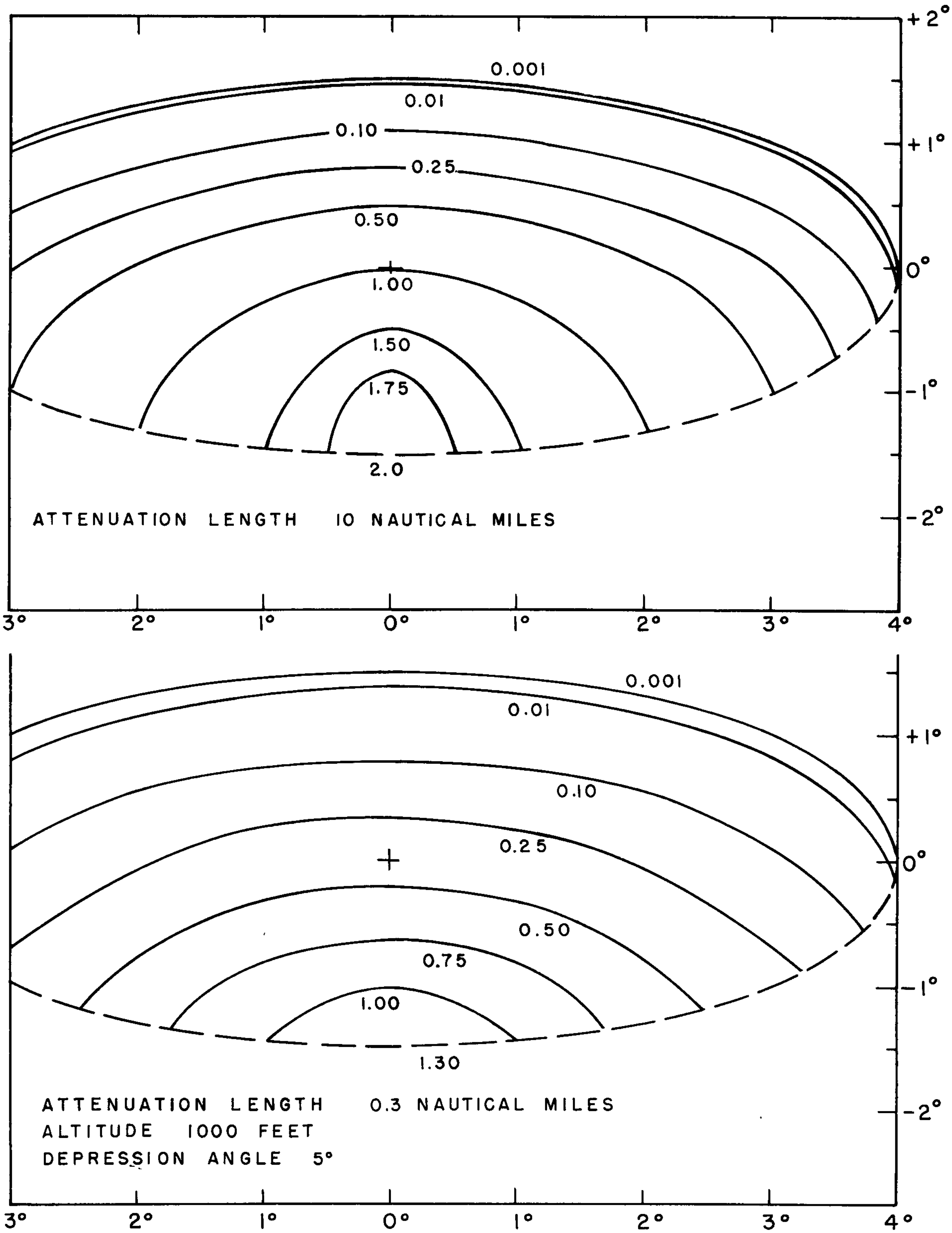

FIGURE C2 - ANGULAR DISTRIBUTION OF BACKSCATTER RELATED TO APPROXIMATION FOR CENTER OF 3° x 8° BEAM is best at high attenuation lengths and small distances of observer to target and light source.

The angular distribution of the backscatter as related to the approximation for the center of the searchlight beam is presented at the bottom of Fig. C2 for an attenuation length of 0.3 nautical miles. The distance of observer-to-target area is long since the observer altitude is 1000 feet and the depression angle of sight is 5°. The separation distance of observer to light source was 5.1 feet. The angular distribution of the backscatter luminance has been expressed analytically for the searchlight, taking into account the dependency on attenuation length and distances of observer to target and light source.

For other light sources there is evidence that at low attenuation lengths the center approximation becomes closer as angular beam spread increases. For instance, for the situation comparable to that depicted at the bottom of Fig. C2, the center luminance is 46 per cent of the approximation for the searchlight, whereas for the spotlight it is 78 per cent and for the floodlight it is 93 per cent of the center approximation.

C3. TOTAL APPARENT BACKGROUND LUMINANCE

Introduction

The apparent background luminance is the total inherent background luminance (see Appendix C1) times the beam transmittance plus the path luminance scattered into the path of sight from either the light source or natural illumination. This constitutes the luminance surrounding the target to which the human observer must fully adapt in order to maximize his ability to see the target.

A complete description of the background luminance in the beam of the light source must include the luminance due to both the capillary waves and the white water at the higher wind speeds. Since the white water occurs randomly in position, it is convenient to discuss it separately.

Absence of White Water

The angular distribution of the apparent background luminance had two limiting patterns. Starlight provides the natural illumination in all samples.

An example of the first limiting pattern is shown in the upper half of Fig. C3. In this case the depression angle of the center of the searchlight beam is 45°. The altitude is 1000 feet and the attenuation length is 0.3 nautical miles (weather: dense). In this first limit the apparent background luminance in the beam is equivalent to the backscatter from the searchlight. In order to complete the description of apparent luminance as it might affect the ability of the observer to adapt to the luminance in the $3^{\circ} \times 8^{\circ}$ angular area, the beam area outside the ellipse is also described. The apparent luminance of the water surface just

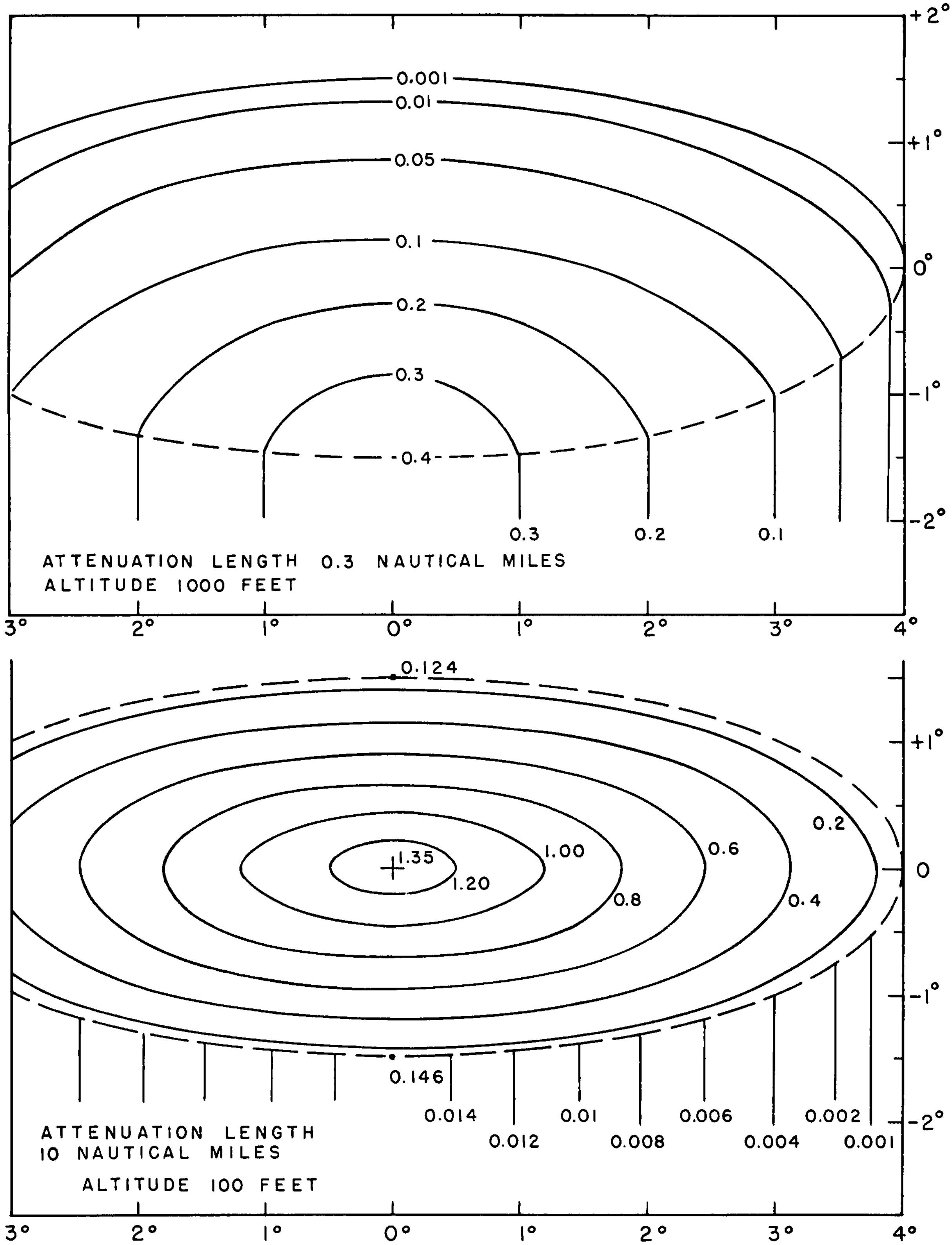

FIGURE C3 - APPARENT BACKGROUND LUMINANCE IN FOOT-LAMBERTS AT A DEPRESSION ANGLE OF 45°

above and outside the beam is very low, 8.4 x 10^{-5} foot-lamberts.

The first pattern, due solely to backscatter from the light source, also occurs at high attenuation lengths but at longer observer-to-target distances for the searchlight.

An example of the second limiting pattern is given in the lower half of Fig. C3. The depression angle is 45°. The altitude is low, 100 feet, and the air very clear; the attenuation length is 10 nautical miles. In this limit the apparent background luminance in the beam is equivalent to the inherent sea luminance due to the searchlight times the beam transmittance. The luminance of the beam below the 3° x 8° angular area is only 1/10 or less of the lowest in the ellipse. The apparent luminance of the water surface just above and outside the beam is still lower than before; 0.9 x 10^{-5} foot-lamberts

The cases in between these two limiting patterns, besides being a combination of the two limits, are also more affected by the natural illumination.

Presence of White Water

When white water does occur at wind speeds 12 knots and greater, the apparent background luminance increases no matter in what part of the beam the white water appears. If the white water happened to occur at the target position, the target would be less easily detected.

There are two ways of handling this problem. One is to treat the case as though all of the area searched were covered with white water. Thus, the target would always be seen whether it were surrounded by white water or not, but the rate of searching a given area would be considerably slowed down. The second is to search as if the white water were not present, and to reduce the probability of detection by the percentage of white caps present. Thus the area searched would be large but the probability of detection in the case of a 20-knot wind would be 85 per cent instead of 100 per cent. This second method of handling the problem was adopted.

C4 APPARENT TARGET LUMINANCE

The visual signal from small targets can be adequately described by the product of the apparent luminance difference of the target from the background and the angular target area. An isoluminance-area graph of this signal for the 3^{o} x 8^{o} angular area in the searchlight beam would show this function to be nearly elliptical in shape, with the center 10 times the value at the edge. This is similar in shape to the graph at the bottom of Fig. C3.

The difference between the apparent target luminance and the apparent background luminance is equal to the difference between the inherent target luminance and the inherent background luminance, times the beam transmittance. The inherent background luminance for the starlight conditions studied was negligible except when white water surrounded either the red helmet or the red and white helmet.

The angular area of the helmets reasonably approximated a point source at the detection distances. The helmets with Scotchlite tape as illuminated by the spotlight, however, were marginal for clear weather. Therefore some additional handicap would be expected at lesser air clarities in comparison to the searchlight since the eye is less efficient in utilizing the available target signal for large targets than for point sources.

C5 VISUAL THRESHOLDS

Introduction

Visual thresholds for point-source targets can be expressed as a relationship among three parameters. One is the apparent background luminance (see Appendix C3). The second is the product of the apparent luminance difference between the target and background times the angular target area (see Appendix C4). The third is the angular position on the retina whereon the signal is received.

Basic Assumptions

The first assumption that was made was that the searchlight would be in a given position for a minimum of 1/3 second. Thus search would be conducted by successive placements of the searchlight beam and the observer would have 1/3 second* for a given fixation at any one beam position.

Static Observer

When the observer was essentially static relative to the target position, as in hover, the target signal would impinge upon some part of the retina for 1/3 second. Detection thresholds for point sources of 1/3-second duration in the fovea and near periphery for mesopic and scotopic background luminances were provided by the Vision Research Branch of the Visibility Laboratory. The data used were preliminary and results of the completed experiment are as yet unpublished.

Moving Observer

When the observer was moving relative to the target as was the case

*C. T. White and A. Ford, "Eye Movements during Simulated Radar Search," J. Opt. Soc. Am. 50, 911 (1960).

for helicopter speeds from 60 to 120 knots, it was not possible for the observer to maintain a fixation on one point of the continuously moving water surface beneath. Therefore the target was in motion relative to the eye. In this case it was assumed that the thresholds were a function of the time the target impinged on any one point of the retina and were equivalent to thresholds for short duration targets of equivalent time duration.*

Detection thresholds for point-source targets of 1/100-second duration in the fovea and near periphery were available in the literature.** Since at low target duration times, 1/100 second or less, the product of the threshold contrast times the duration time is a constant for a given background luminance and target angular area (law of Bunsen-Roscoe or Bloch), these data were applicable to all helicopter speeds between 60 and 120 knots.

Adaptation to a Non-Uniform Field

A vision experiment was performed by the Vision Research Branch of the Visibility Laboratory to determine the proper method of predicting visual detection thresholds in the non-uniform field of view produced by the searchlight beam. The results indicated that the immediate local background of these point-source targets can be used in predicting the detection threshold where the variation in luminance in the field is reasonably smooth and the total luminance change over the field is limited to a factor of 10 to 1.

*A. Morris, "Predicting the Detection Range of a Target in a Moving Field of View," Univ. of Calif., Vis. Lab., SIO Ref. 59-69 (1959).

**H. R. Blackwell and A. B. Moldauer, "Detection Thresholds for Point Sources in the Near Periphery," Univ. of Mich., Engr. Res. Inst. Rept. 2455-14-F (1958).

Since no inhibitory effect from the presence of the higher luminance in the field was found for luminance differences of 10 to 1, it was assumed reasonable that inhibition would be small for differences of 100 to 1. Thus the background used to define the detection thresholds for a given position in the beam was the immediate local background.

Low Background Luminances

At scotopic background luminances, a target can be detected further using the periphery of the eye rather than the fovea. These low background luminances were sometimes present in parts of the beam. It was assumed normal, however, when a target is first seen peripherally to reposition the eye so that the target would then appear on the fovea. This is a normal procedure at photopic and mesopic levels to check whether, indeed, a target is really in view. Since much of the viewing problem utilizing searchlights is in the mesopic background level, it was decided to reject all detections which could only be made peripherally and not checked by shifting to a foveal position.

APPENDIX D

ANALYSIS OF SEARCH TECHNIQUES

The analysis leading to a prescription of the best search pattern for any specified altitude and helicopter speed was essentially threefold. It is presented in the order in which it was developed.

First, how and when the observer is to look within the light beam was established. The question of search within the beam versus a single look was resolved; next, the best fixation point within the beam was determined.

Second, after the fixation position had been selected, the best single placement of the beam was specified. The best position for the beam is that depression angle at which the area wherein the target is detectable is maximized.

Third, with beam placement and observer fixation optimized, front versus side search was evaluated. An optimum search pattern is prescribed.

A fourth section describes the non-analytic methods by which optimum altitude and helicopter speed were specified. Thus, this outlines the method for specifying the altitude, speed, and angle of sight which maximize the area search-rate.

A concluding section compares the results for the three light sources.

D1 FIXATION POINT IN THE BEAM

The observer is looking for the target within the area on the sea surface, which is included in the beam of the light source. It now becomes necessary to specify whether search within the beam should consist of a series of looks, or a single look, and at what position in the beam the observer should fixate for any one look.

Analysis shows that, generally speaking, the area in the beam in which the target is detectable if viewed foveally (with infinite fixations) is not much larger than the area encompassed by a single fixation. Therefore there is little to be gained by making more than one fixation in the beam at a given beam position. The portion of the elliptical beam, depicted in the upper half of Fig. D1, which is not cross-hatched is the area viewed foveally with an infinite number of fixations. The near ellipses inside of this area represent areas covered with various single fixations.

The sample used to illustrate how the best fixation point in the beam is chosen is for an exceptionally clear starlight night with an attenuation length of 10 nautical miles at sea level. The searchlight and the helmet with retrodirective inserts are used. The observer is hovering at 1000 feet above the sea surface and the beam axis is directed 5° below the horizontal.

The upper half of Fig. D1 depicts angularly the $3^{\circ} \times 8^{\circ}$ beam. Within this beam the angular area wherein the target can be detected is shown for five different fixation points.

The lower half of Fig. D1 depicts these same angular areas. The areas have now been drawn ignoring location in the beam. The near

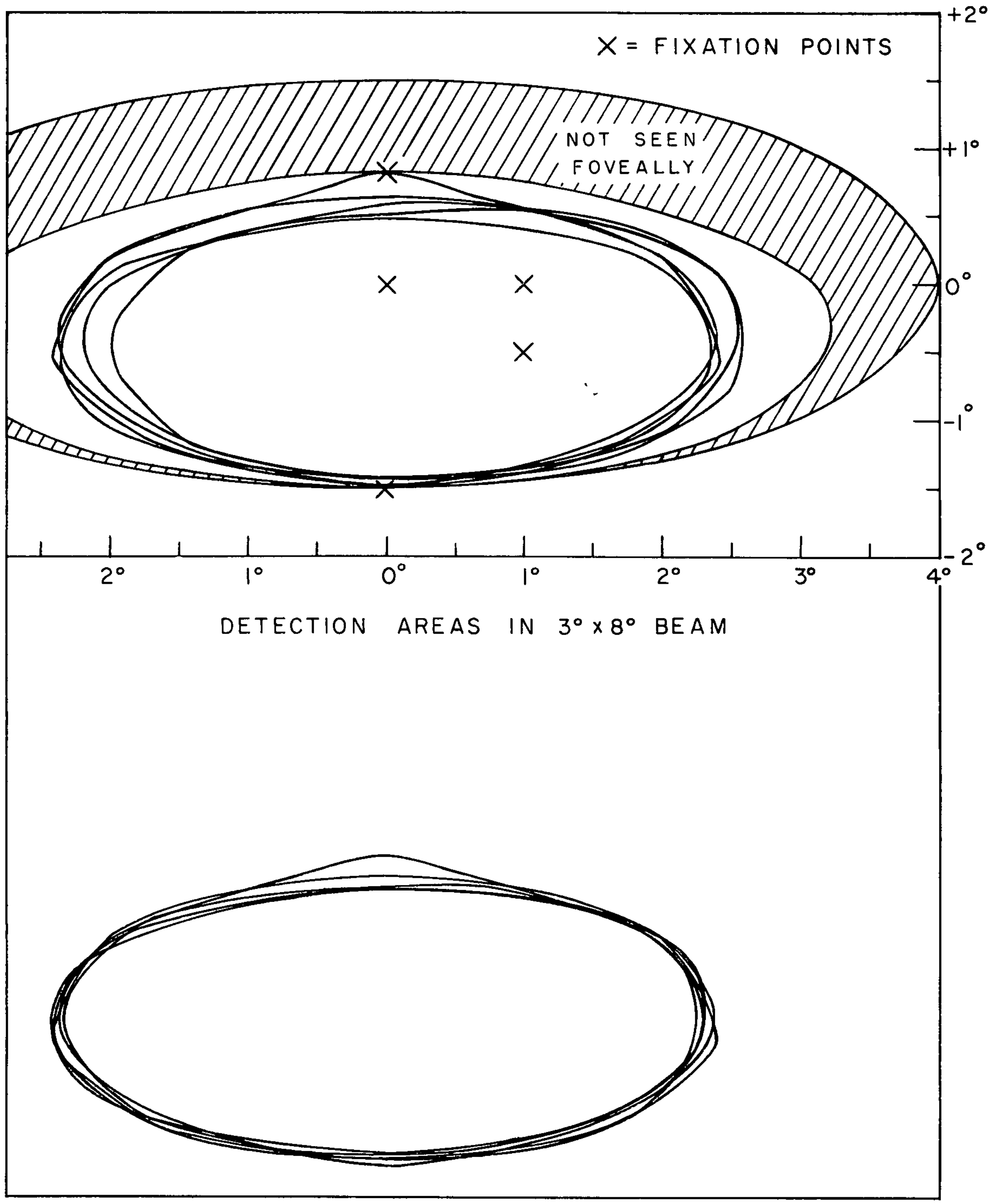

FIGURE DI - ANGULAR AREAS OF DETECTION WITH VARIOUS FIXATIONS equivalency in angular area for any of the five fixation points is clearly demonstrable. This minimal change in area, for any single look, as a function of fixation position permits the use of one fixation point for all search situations.

Fixation at the center of the beam was selected as it is the simplest task for the observer. However, should the observer fixate off center, the change in area is not critical.

D2 MAXIMIZING THE AREA

Assume that the observer is using a single look and fixating at the center of the light beam. For any one altitude and speed of the observer, the vertical position of the beam must be selected at which the area wherein the target is detectable is maximized.

The results of the following analysis show the best position to be the smallest depression angle at which one fixation covers the full area of the beam.

The sample chosen to illustrate the situation is for an exceptionally clear starlight night. The searchlight and the target with retrodirective inserts are used. The observer is hovering at 750 feet above the sea surface.

Figure D2 depicts the search situation angularly. Several vertical positions of the searchlight beam are shown. The solid lines indicate the area within the beam, as it strikes the water surface, within which the target can be detected with center fixation. The target can be detected anywhere within the $3^{\circ} \times 8^{\circ}$ ellipse from 6.5° to 45° below the horizontal. At depression angles less than 6.5°, the target is detected only in the lower part of the ellipse. This portion decreases as the angle diminishes.

Figure D3 translates this information into distances on the horizontal plane at the sea surface. The area on the sea surface included in the beam increases with decreasing depression angle. The most efficient search angle is 4.7°, where the target is visible in most but not all of the ellipse.

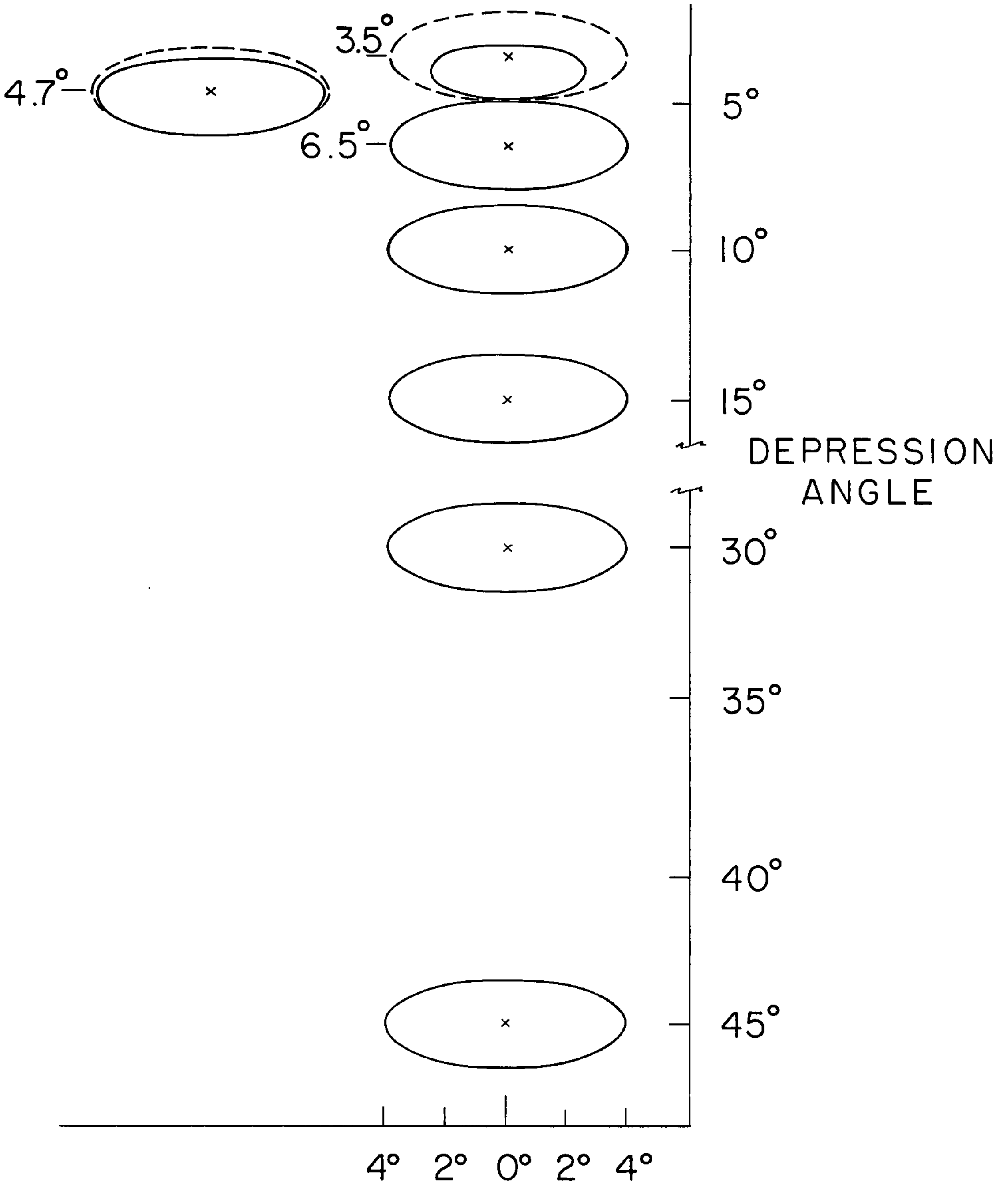

FIGURE D2 - CHANGE OF ANGULAR AREAS OF DETECTION WITH DEPRESSION ANGLE

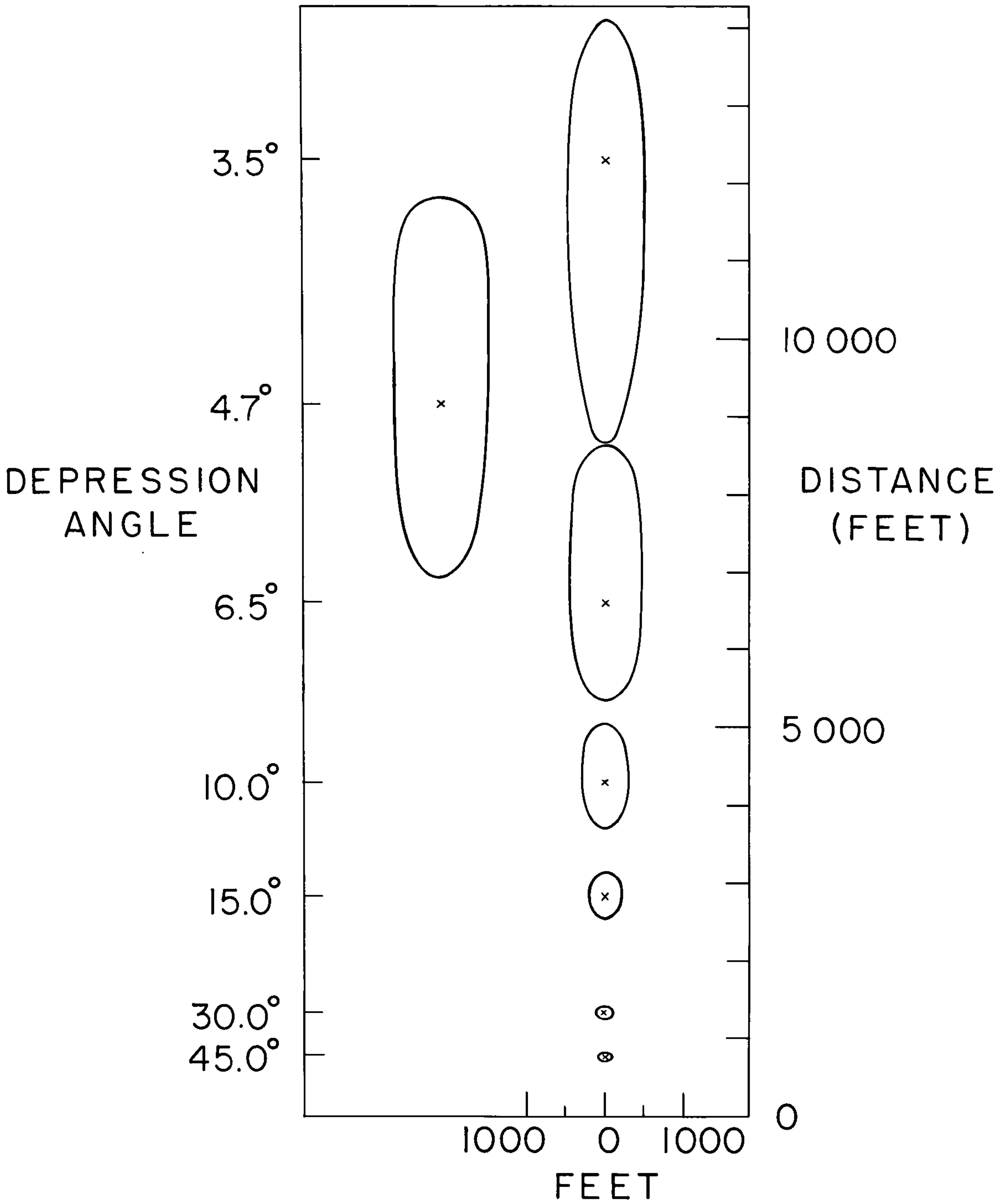

FIGURE D3 - CHANGE OF LINEAR AREAS OF DETECTION WITH DEPRESSION ANGLE

The area function increases with decreasing depression angle until the last full ellipse. At that point the rate of increase begins to diminish although the area continues to increase to a maximum (in the sample the area nearly doubled) and then drops off. It was found difficult to determine this maximum point since it could not be done analytically. However, it was a much simpler task to determine the depression angle at which the last full ellipse occurred. Thus it was decided to determine the depression angles and areas for the last full ellipse for all cases of interest and to interpret the results in the following manner:

The specified depression angle would be interpreted as the maximum to be used in search. An attempt should be made to hold the search within 2° of that depression angle. In other words, if 6.5° were specified, search should be conducted at no larger a depression angle than 6.5° and no smaller than 4.5°. The area covered by a single look would thus be at least as large as that specified for 6.5°.

D3 SEARCH METHOD

Subsequent to determining the optimal depression angle and the most efficient method for the observer to look in the beam, it is requisite to specify how to search moving the light beam itself.

When the beam is kept at a constant vertical position and not moved azimuthally, the area search-rate equals the beam width in feet multiplied by the velocity of the helicopter in feet per second.

Usually there is ample time to move the beam to other positions while still obtaining 100 per cent coverage of an area. Since the area covered by the beam maximizes for a given vertical position, it is axiomatic that for maximum coverage the beam should be moved azimuthally. Locking the searchlight at the best depression angle and sweeping azimuthally yields the best area search-rate. This is feasible with the searchlight which can be locked in a vertical position; the spotlight is not controllable by this method, hence keeping a constant vertical position is problematic.

Search Patterns

Two patterns for azimuthal beam sweep are feasible.

One pattern is composed of discrete beam positions of 1/3 second duration. The beam is placed so as to obtain 100 per cent coverage by overlapping a portion of the ellipse; the maximum inscribed rectangle is essentially all that is used. The upper half of Fig. D4 depicts this concept for the static case. The pattern for the maximum obtainable angular sweep for each light is shown. For this case, there are 16 discrete positions for the searchlight and 20 positions for the spotlight.

Total time on sweep is 5-1/3 seconds for the searchlight and 6-1/2 seconds for the spotlight. The depression angle depicted for the searchlight is not the same as that for the spotlight in this drawing.

The second pattern consists of a continuous azimuthal sweep of the beam at a constant depression angle. The angular rate for the searchlight is 17 degrees per second; the angular rate for the spotlight is 28 degrees per second. During the continuous movement of the beam, the eye executes a regular alternation of rapid jumps and fixational pauses. The fixation ideally begins on the horizontal axis but on the right-hand edge of the rectangle shown in Fig. D4. During the fixation, which is of 1/3-second duration, the beam moves so that at the end of the 1/3 second the fixation is on the left-hand edge of the rectangle. Although the computations were based on the first pattern of search, the results are equally applicable to the second pattern.

For both patterns, the sweep width is determined such that coverage occurs in the time it takes for the helicopter to travel the horizontal distance equivalent to the vertical dimension of the maximum rectangle. At the end of each sweep, the beam is returned to the starting position and the pattern repeated. This is the dynamic case which is illustrated in the lower half of Fig. D4. The overlap, ensuring 100 per cent coverage, can be seen readily.

Front Versus Side Search

It was requested that this study include an evaluation of the efficacy of search out the front of the helicopter as compared to search out the side. Search out the front is better than search out

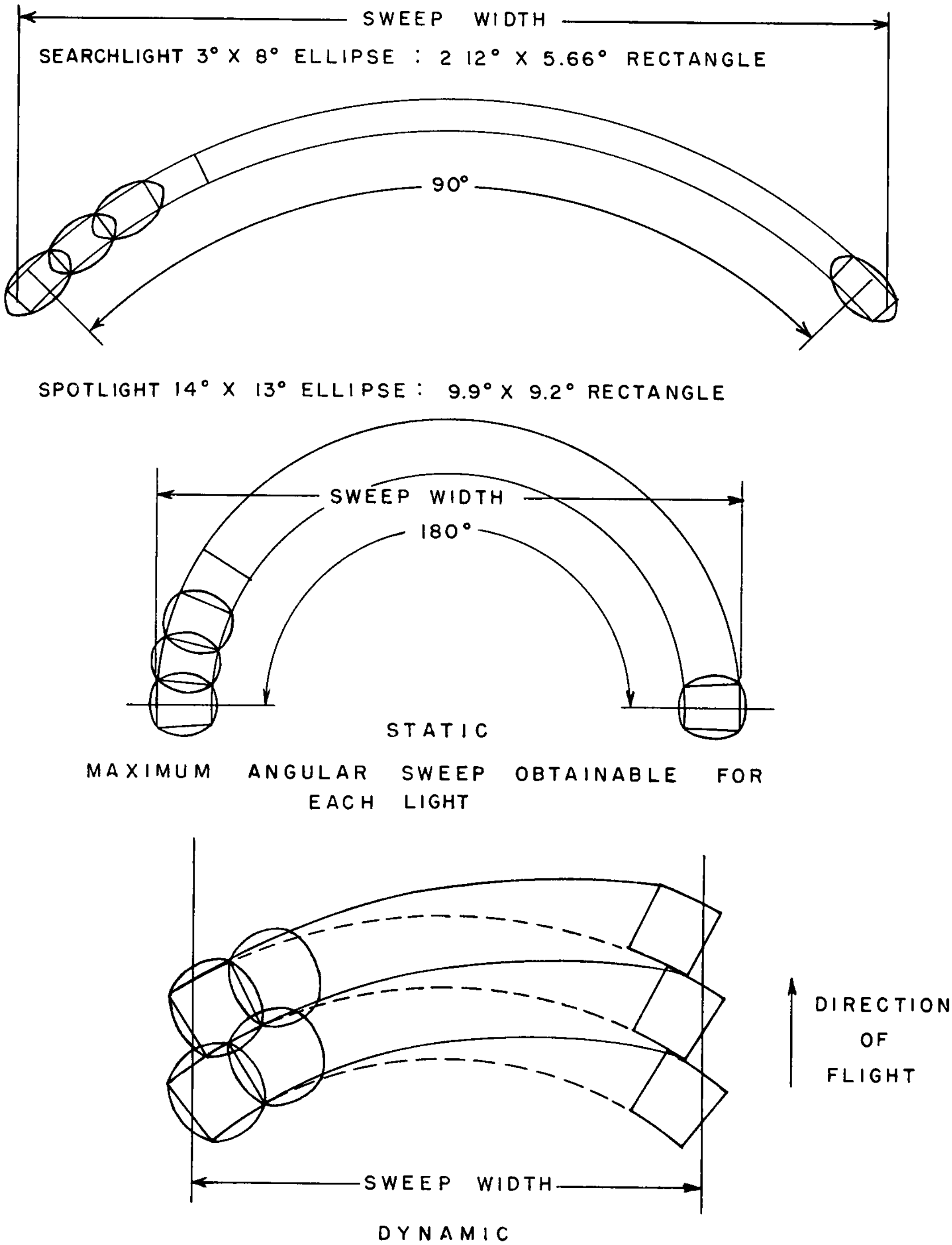

FIGURE D4 - SEARCH GEOMETRY SHOWING COVERAGE ON THE SEA SURFACE the side; the analysis on which this conclusion is predicated is described below:

As described in Sect. 3.2, the searchlight is capable of being positioned through a 90° arc azimuthally. To facilitate describing the light position in this section, this sweep is referred to as ±45° with 0° as the on-axis position. The spotlight is thus referred to as having a ±90° sweep, with 0° as the on-axis position.

Search out the front is conducted with the on-axis position of the light in the same direction as the heading of the helicopter; that is 0°. For search conducted out the side of the helicopter, two on-axis positions were analyzed. For the searchlight, one on-axis position was +45° from the aircraft heading; that is, the ±45° sweep covers the arc from 0° to +90° in terms of the helicopter heading. The second analysis for the light was for the on-axis position +90° from the aircraft heading; that is, the ±45° sweep in reference to the helicopter heading is +45° or +135°. The conditions for the spotlight are analogous; for an on-axis position of +45°, the arc covers from -45° to +135°; for an on-axis position of +90°, the arc covers from 0° to +180°.

Front versus side search is evaluated in terms of sweep width. Sweep width is defined as the dimension of the area 100 per cent covered by a sweep, which is perpendicular to the line of flight.

For azimuthal sweeps, as the on-axis portion of the beam departs from head on, the maximum sweep width decreases, and consequently the area search-rate. For the searchlight the sweep width for the on-axis position at + 45° is 29 per cent less than for 0° (i.e., out front), and at + 90° it is 44 to 64 per cent less, depending on azimuthal coverage, beam depression angle, and altitude. For the spotlight the decrease at + 45° from head on is 29 per cent; the decrease for + 90° is 32 to 54 per cent.

For search out the side where the beam axis is + 90° from the plane heading, an alternate sweep pattern was investigated. This pattern is produced by locking the light in one azimuth and sweeping vertically. Compared to search out the front of the helicopter, the vertical sweep pattern results in a decrease in sweep width for the spotlight of 27 to 52 per cent, depending on beam depression angle, altitude, and velocity. For the searchlight the corresponding range of decrease in sweep width is 20 per cent to 55 per cent.

Thus in all types of side search, the sweep width is less than for frontal search.

D4 OPTIMIZATION OF ALTITUDE AND SPEED

Maximum area search-rate was determined, as described in the foregoing sections, for any given altitude and velocity. The next step was to investigate the area rates as a continuous function of altitude, as well as a continuous function of velocity.

The final results are given in terms of three parameters; the best depression angle, the best altitude, and the best velocity. The altitudes examined ranged from 100 to 1000 feet, and the depression angles investigated were 0.5 through 25 degrees.

Helicopter speeds investigated were 60 to 120 knots and a slow hover (1.5 knots). The area search-rate was always greater for speeds from 60 to 120 knots than for hover speed. The area covered by a single look during hover is larger than the area covered at higher speeds. However, this gain is obviated by a greatly reduced rate of coverage.

D5 COMPARISON BETWEEN LIGHT SOURCES

A comparison is made among the three lights available for search.

Searchlight

The maximum area search-rate using the searchlight always shows a slight gain over the spotlight for comparable targets. The best depression angle for the searchlight beam is always within 10° of the horizontal, well within the limits of the cockpit field of view of the H2 helicopter.

Spotlight

The helicopter field of view becomes critical for the larger beam spread and lower peak intensity of the spotlight. Analysis of the area search-rate function disclosed the following: the rate was increasing as the depression angle increased, and the maximum would have occurred at a beam position below that of the cockpit cutoff. Hence the area search-rate is computed for a position of the light where the near edge of the inscribed rectangle (see Fig. D4) is tangent to the front of the cockpit. If the field of view limit was not imposed, the difference between the searchlight and the spotlight would be further minimized.

Floodlight

A comparable analysis for the floodlight was not made because the broad beam spread did not lend itself to the same treatment. However, the following can be said: The floodlight is always less efficient than the other two lights for any place in the beam. Thus the light would have to be directed at a much lower depression angle than either of the searchlights, for the same altitude to obtain the same detection area coverage.

Since the field of view was already restrictive to the spotlight, it would seem axiomatic that the best use of the floodlight would be at angles lower than the 25° available in the forward direction. Thus, while search out the side of the helicopter is less efficient than frontal search (see Appendix D3), the floodlight could only be used in this manner.