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EVALUATION OF NIGHT VISION GOGGLES FOR MARITIME SEARCH AND RESCUE (Volume I - Technical Report)

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INTERIM REPORT

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This report is the first in a series that will document the Improvement of Search and Rescue Capabilities (ISARC) Project at the U.S.C.G. R&D Center and twenty-seventh in a series of R&D Center reports dealing with Search and Rescue.

16. Abstract

Three experiments were conducted during 1989 by the U.S. Coast Guard Research and Development (R&D) Center to evaluate night vision goggles (NVGs) for their effectiveness in detecting small targets at night. Three types of NVGs were evaluated: the AN/AVS-6 Aviators Night Vision Imaging System (ANVIS) NVG was tested onboard Coast Guard HH-3 and CH-3 helicopters, and the AN/PVS-5C and AN/PVS-7A NVGs were tested onboard 41-foot Coast Guard utility boats (UTBs). Simulated persons in the water (PIWs), 4- and 6-person life rafts, 18- and 21-foot white boats, and white, personal flotation device (PFD) strobe lights were employed as targets during realistically-simulated search missions.

A total of 1,490 target detection opportunities were generated during the experiments. These data were analyzed to determine which of 25 search parameters of interest exerted a statistically-significant influence on target detection probability. Lateral range curves and sweep width estimates are developed for each search unit/target type combination. Human factors data are presented and discussed. Recommendations for conducting NVG searches for small targets and for additional data collection and analysis are provided.

This report consists of two volumes. Volume I contains the text of the report and Volume II* contains the data listing.

* Requests for Volume II should be sent to the United States Coast Guard Research and Development Center.

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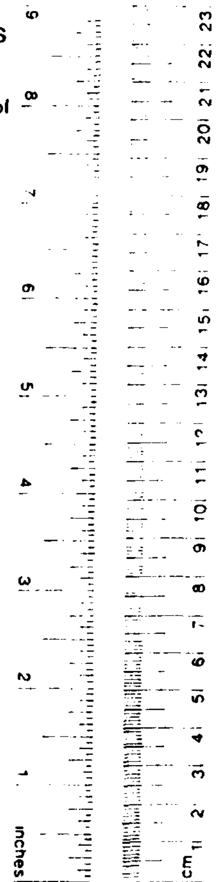
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
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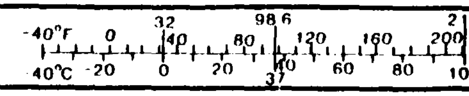

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EXECUTIVE SUMMARY

INTRODUCTION

1. Background

This report provides an interim evaluation of three types of night vision goggles (NVGs) for their effectiveness in the Coast Guard's maritime search and rescue (SAR) mission. The NVGs were evaluated onboard HH-3 and CH-3 helicopters from Coast Guard Air Station Traverse City, MI, and on 41-foot utility boats (UTBs) from Coast Guard Stations Fort Pierce, FL, New London, CT, Point Judith, RI, and Montauk, NY. Search targets included simulated persons in the water (PIWs); 4- and 6-person life rafts with orange canopies; white, 18-foot open boats; white, 21-foot boats with blue canvas shelters and bimini tops; and lifejacket strobe lights. Data were collected during a 3-week experiment in Fort Pierce, FL, in April 1989 and during two, 3-week experiments conducted in Block Island Sound (off the CT/RI/NY coasts) during the fall of 1989.

These evaluations were conducted by the U.S. Coast Guard Research and Development (R&D) Center as part of the Improvement of Search and Rescue Capabilities (ISARC) Project. This research is ongoing, with additional experiments and data analyses planned for calender year 1990.

2. NVG Descriptions

Three NVG models were evaluated during the experiments. The AN/AVS-6 Aviators Night Vision Imaging System (ANVIS) NVGs, equipped with Generation III photodetectors, were evaluated onboard the helicopters. All five helicopter crew positions were provided with ANVIS NVGs on hinged helmet mounts. UTB crews were provided with either AN/PVS-5C or AN/PVS-7A NVGs for use by lookouts only. The AN/PVS-5C and AN/PVS-7A are both equipped with Generation II-plus photodetectors and fixed headstrap mounts. Helmsmen and coxswains positioned inside the UTB wheelhouse were unable to operate with these NVGs due to the lack of NVG-compatible instruments and radar displays.

All three NVG models restrict visual perception in several ways. All models restrict the users to a 40-degree field of view, severely inhibit depth perception, reduce visual acuity to 20/40 at best, and provide a monochromatic (green) display. The ANVIS and the AN/PVS-7A designs allow limited, non-NVG peripheral vision. The AN/PVS-5C design does not permit any peripheral vision.

3. Approach

Data were collected using operational Coast Guard search craft and crews that had received basic instruction in NVG use. Standard search patterns were used to search for randomly-placed targets within assigned search areas. Search crews were not alerted in advance to target locations.

A precision microwave tracking system was used to monitor and record target and search craft positions. Target detections and human-factors data were logged by data recorders onboard each search unit. Environmental data were logged onboard a chartered work boat. An environmental data buoy was deployed within each exercise area to record winds, sea conditions, and air/water temperatures.

Data reconstruction was performed to determine which target opportunities resulted in detection and at what lateral range each opportunity occurred. Raw data files were developed that included each target detection or miss along with the values of 25 search parameters of interest for each target opportunity. These data were analyzed on a desktop computer using a variety of statistical techniques including binary, multivariate regression analysis. Lateral range versus target detection probability plots and sweep width estimates were developed for search conditions that were well-represented in the data.

Human factors data were compiled and analyzed quantitatively where possible. Subjective comments by search unit crews and data recorders were synopsized and incorporated into the conclusions and recommendations provided in this report.

RESULTS AND CONCLUSIONS

1. Results

A total of 1,490 target detection opportunities were reconstructed from the 3 experiments. Of the eight search unit/target type combinations evaluated, sufficient data were collected to perform a detailed detection performance analysis for all but the UTB/strobe light combination. Data quantities categorized by search unit and target type are provided in table 1.

Table 1. Numbers of Target Detection Opportunities by SRU and Target Type

TARGET TYPE \ SRU TYPE	Helicopter	UTB
18- and 21-foot Boats	288	130
4- and 6-person Life Rafts	249	190
PIWs	242	227
Strobe	152	12

Table 2 summarizes the range of search conditions represented in the data set. Fitted lateral range plots and sweep width (W) estimates were developed for the following conditions.

a. Helicopter/PIW Targets. All data at visibility = 15 nmi.

b. Helicopter/Life Raft Targets. All data combined.

Table 2. Range of Environmental and Moon Parameters Encountered

SRU/ TARGET	ENVIRONMENTAL PARAMETER									MOON	
	Precipitation Level	Visibility (nmi)	Wind Speed (knots)	Cloud Cover (tenths)	Significent Wave Height (ft)	Whitecap Coverage	Relative Humidity (percent)	Air Temperature (deg. C)	Water Temperature (deg. C)	Elevation (degrees)	Phase
Helo/ Boats	0 to 1	1.5 to 15	2 to 20	0 to 1.0	1.3 to 4.3	0 to 2	64 to 96	10.4 to 24.3	13.4 to 24.2	-68 to +64	none to full
Helo/ Rafts	0 to 3	1.5 to 15	3 to 16	0 to 1.0	1.6 to 5.2	0 to 2	64 to 100	10.4 to 24.3	13.4 to 23	-69 to +41	none to full
Helo/ PIWs	0	4 to 15	5 to 22	0	1.3 to 3.6	0 to 2	74 to 86	11.6 to 24	13.3 to 23.9	-63 to +34	quarter to full
Helo/ Strobe	0	3	15 to 17	1.0	2.3 to 2.6	1	82	11.5	13.6	+30 to +46	half
UTB/ Boats	0 to 1	1.5 to 15	2 to 20	0 to 1.0	1.3 to 4.3	0 to 2	64 to 96	5.5 to 24.3	13.4 to 24.2	-60 to +51	none to full
UTB/ Rafts	0 to 2	1.5 to 15	2 to 24	0 to 1.0	1.3 to 4.6	0 to 2	64 to 100	6.1 to 24	13.5 to 23.6	-62 to +33	none to 3 quarters
UTB/ PIWs	0	2 to 15	3 to 22	0	1.3 to 3.6	0 to 2	74 to 90	11.6 to 24.5	13.2 to 24	65 to +33	none to full
UTB/ Strobe	0	3	17	1.0	2.3 to 2.6	1	82	11.5	13.6	+43 to +46	half

c. Helicopter/Small Boat Targets. Three sets of search conditions described below.

(1) Significant wave height (H_S) 1.3 to 2.0 feet, visibility 10 to 15 nmi, and moon not visible.

(2) H_S 2.0 to 3.3 feet, visibility 6 to 15 nmi, and a visible moon.

(3) H_S 2.3 to 3.3 feet, visibility 6 to 15 nmi, and moon not visible.

d. Helicopter/Strobe Light Targets. All data collected on a single night in 2- to 4-nmi visibility.

e. UTB/PIW Targets. All data combined.

f. UTB/Life Raft Targets. All data combined.

g. UTB/18-Foot Boat Targets. All data at H_S = 2.0 to 3.0 feet.

h. UTB/21-Foot Boat Targets. All data at H_S = 2.0 to 3.3 feet.

Other search conditions were not well-enough represented in the data base to analyze in-depth.

Quantitative human factors analyses revealed that time on the search task exerted no clear or consistent effect on the target detection performance of either helicopters or UTBs. An analysis of detections by crew position revealed that:

a. Helicopter crew members aft of the cockpit make about half of all NVG detections. Past research has shown that pilots make more than half of the detections during visual daylight searches.

b. UTB crewmembers inside the wheelhouse can detect some targets that pass close-aboard even though they do not use NVGs. Radar may help direct NVG lookouts' attention in calm seas.

2. Conclusions

1. The helicopter crews achieved detection probabilities against PIW targets that were comparable to those found for daylight visual searches during earlier R&D Center research. The detectability of these targets by NVG was clearly enhanced by retroreflective tape on the personal flotation devices (PFDs).

2. The helicopter crews achieved about the same detection performance against 4- and 6-person life rafts as they did against PIW targets. The life rafts were not equipped with retroreflective material.

3. The helicopter crews performed best against the 18- and 21-foot boat targets. Detection performance varied with visibility, H_S, and the visibility of the moon. Detection performance, as measured by sweep width, was about one-fourth of comparable daytime visual search levels.

4. Although search conditions were seldom ideal in terms of ambient light and sea conditions, the helicopters were able to mount viable search efforts against all three unlighted target types.

5. The NVG-equipped helicopter crew achieved excellent search performance against the strobe light targets under adverse search conditions.

6. Glare from interior and exterior lights on helicopter windows is a constant problem, especially on dark nights. When haze or fog is present, reflections from the helicopter's exterior anticollision lights become troublesome.

7. The NVG-equipped UTBs achieved only marginal detection performance against the PIW targets. Even when the targets passed close aboard (0 lateral range), only one-third (5 out of 15) were detected.

8. Detection performance of NVG-equipped UTBs against the life raft targets, as measured by sweep width, was no more than one-tenth of comparable daylight visual search levels.

9. The UTB crews performed best against the 18- and 21-foot boat targets. Detection performance varied with H_S and target boat size. Detection performance, as measured by sweep width, was less than one-tenth of comparable daytime visual search levels against open, 18-foot targets and about one-fourth of the daytime levels against 21-foot targets with canvas.

10. NVG-equipped UTBs are only marginally capable of mounting a viable search effort against PIWs, life rafts, and open, 18-foot boats. When 21-foot boat targets with erected canvas are the search object, a viable UTB search capability appears to exist when seas are less than 3 feet.

11. UTB crews are not capable of conducting effective NVG searches in seas greater than 2.5 to 3 feet. Platform motion, coupled with the narrow NVG field of view, consistently causes seasickness and disorientation. Furthermore, the effectiveness of the NVGs is inhibited by the constant presence of salt spray even when lookouts seek shelter behind the wheelhouse.

12. Wheelhouse lights and running lights cause a great deal of interference with the NVGs. Lookouts are often forced to search directly abeam in a narrow sector because of this problem.

13. No obvious or consistent relationship between time on the search task and target detection probability was demonstrated in the test data. This result is surprising in light of the many SRU crew comments concerning eye fatigue and other forms of physical discomfort experienced while wearing NVGs.

14. Enhancement of small targets' light-reflecting capabilities (such as use of retroreflective tape) and use of a light source on the SRU that does not interfere with NVG operation (such as the helicopters' anticollision lights on clear nights), appear to provide a significant level of target detectability by NVGs.

15. Illumination of targets by a strobe light or similar device appears to provide a full order-of-magnitude improvement in target detectability by NVGs even when poor visibility exists. A means of rendering this illumination distinct from other light sources such as those on navigation aids would greatly simplify the search task. This distinction is particularly difficult with NVGs because of their monochromatic display.

RECOMMENDATIONS

1. NVG Searches With Helicopters

a. Pending additional data collection, the following guidelines should be applied when estimating sweep widths for night SAR missions by NVG-equipped helicopters. Fatigue, weather, and speed corrections listed in reference 7 are not to be applied unless specifically listed.

(1) PIW Targets With Retroreflective Material on PFD. The daylight visual sweep width for PFD-equipped PIWs and search altitudes up to 500 feet (0.4 nmi) should be used.

(2) 4- to 6-Person, Canopied Life Raft Targets Without Retroreflective Material. Multiply the daylight visual sweep width, corrected for weather only, by 0.25.

(3) Boat Targets Less Than 25 Feet - Seas < 3 Feet and Moon Visible. Multiply the uncorrected daylight visual sweep width, corrected for weather only, by 0.25.

(4) Boat Targets Less Than 25 Feet - Seas < 3 Feet and Moon Not Visible. Multiply the uncorrected daylight visual sweep width by 0.20.

(5) Strobe Lifejacket Light. The existing sweep width for this target (3.5 nmi) may be used when visibility is 2 nmi or greater.

b. Ongoing efforts to reduce glare from crew clothing and light reflections on helicopter windows and instrument panels, especially reflections generated by internal lighting, should be pursued vigorously.

2. NVG Searches With UTBs

a. Pending additional data collection, the following guidelines should be applied when planning night SAR missions by NVG-equipped UTBs. Fatigue, weather, and speed corrections listed in reference 7 are not to be applied unless specifically listed.

(1) PIW Targets With Retroreflective Material on PFD. NVG searches for these targets are not recommended.

(2) 4- to 6-Person, Canopied Life Rafts Without Retroreflective Material. No quantitative recommendation is made pending additional data collection. Sweep width may attain practical values in calm, clear, moonlit conditions.

(3) 18-Foot Open Boat Targets - Seas $\leq$ 3 Feet. No quantitative recommendation is made pending additional data collection. Sweep width may attain practical values in calm, clear, moonlit conditions.

(4) 21-Foot Boat Targets With Cabin or Canvas Shelter - Seas $\leq$ 3 Feet. Multiply the corrected daylight visual sweep width by 0.25.

(5) All Targets Less Than 25 Feet - Seas > 3 Feet. NVG searches by UTBs are not recommended under these conditions.

b. UTB crewmembers who are not equipped with NVGs should be instructed to search close-aboard the SRU and to direct NVG lookouts' attention to radar contacts at ranges less than 0.5 nmi.

3. General Recommendations

a. NVG-equipped SRUs should be launched promptly on night SAR cases to conduct a search before leeway and/or current drift expand the Desired Search Radius (R) to unacceptably large values. Exceptions to this guidance are the situations listed above where NVG search is not recommended.

b. The Coast Guard should consider promoting regulatory action that would require application of retroreflective materials to non-commercial watercraft, life rafts, and PFDs. Guidance in the Safety of Life at Sea (SOLAS) specifications on this subject appears to provide a good basis for developing such regulations.

4. Recommendations For Future Research

a. More NVG search performance data should be collected in clear, calm, moonlit conditions using unlighted PIW targets, life raft targets without retroreflective material, and small boat targets without retroreflective material.

b. The following additional data types should be collected in the near future to further evaluate NVG applicability to the SAR mission.

(1) Life raft targets with retroreflective material applied as recommended in the SOLAS specification.

(2) PIW targets with non-flashing chemical rescue lights attached.

(3) PFD strobe lights for detectability by UTBs.

(4) Larger surface SRUs such as Coast Guard WPBs as NVG search platforms, especially in seas $\geq$ 3 feet.

c. UTBs should be evaluated using four NVG lookouts on a 2-on/2-off rotation to alleviate fatigue and seasickness.

d. A hinged, NVG helmet-mount design should be developed for evaluation onboard small surface SRUs.

e. Sources of NVG-compatible target illumination should be evaluated on surface and air SRUs, particularly in conjunction with targets equipped with retroreflective material.

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CHAPTER 1
INTRODUCTION

1.1 SCOPE AND OBJECTIVES

This report is the first of a series which will document the U.S. Coast Guard Research and Development (R&D) Center's evaluation of night vision goggles (NVGs) and other night vision devices for search and rescue (SAR) missions. To date, three experiments have been conducted in support of this evaluation; one in Fort Pierce, FL and two in Block Island Sound off the CT/RI/NY coasts. Additional experiments and data analyses are planned for calender year 1990. During these experiments, three types of NVGs have been evaluated onboard HH- and CH-3 helicopters and 41-foot utility boats (UTBs) for their effectiveness in detecting unlit person-in-water (PIW), life raft, and small boat targets. Limited data have also been collected using personal floatation device (PFD) strobe lights as targets.

This evaluation of night vision devices is part of the R&D Center's Improvement of Search and Rescue Capabilities (ISARC) Project. Project objectives are to improve search planning and execution and to evaluate visual and electronic search methods, leeway drift, ocean current drift, and visual distress signals. Specific objectives of the night vision device evaluation are to:

1. Establish the night SAR capabilities of operational Coast Guard search and rescue units (SRUs) equipped with these devices, and

2. Develop operationally-realistic sweep widths that search planners can use to represent Coast Guard night search effectiveness under a variety of environmental and lighting conditions.

1.2 NIGHT VISION GOGGLE SYSTEM DESCRIPTIONS

The AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS) was evaluated onboard Coast Guard HH-3F and CH-3E helicopters. The AN/PVS-5C and AN/PVS-7A NVGs were evaluated onboard Coast Guard 41-foot UTBs. All three NVG models amplify available light to produce a monochromatic (green) image of the nighttime scene. As ambient light level varies, NVG image quality varies: Too much or too little light can cause poor image quality. All of the NVG systems severely inhibit depth perception and reduce visual acuity to no better than 20/40. Sections 1.2.1 and 1.2.2 describe specific features of the three NVG systems.

1.2.1 AN/AVS-6 ANVIS

The ANVIS goggles shown in figure 1-1 are a helmet-mounted NVG system designed for use by helicopter crews operating in a broad range of night illumination conditions including starlight and overcast. Two Generation III image intensifier tubes are incorporated into a hinged, binocular assembly that can easily be flipped up or down by the aviator. Adjustments for diopter correction, range focus, interpupillary separation, vertical positioning, fore-aft positioning (eye relief), and tilt positioning are also incorporated into the ANVIS goggles.

When in use (down position), the binocular assembly is offset from the eyes so that limited non-NVG peripheral vision is available. The eyes may also be focused beneath the goggles to view instruments and controls. The ANVIS goggles provide a 40-degree field of view (FOV). Peak spectral response is achieved with the ANVIS between wavelengths of 0.65 and 0.90 microns, which includes visible light from green through red and a portion of the near-infrared spectrum. A "minus blue" instrument light filter that eliminates wavelengths smaller than 0.625 microns is incorporated into the ANVIS. An automatic brightness control adjusts rapidly to changing illumination conditions.

The ANVIS goggles tested during the three R&D Center experiments were manufactured by ITT Electro-Optics Division, Litton Electron Devices, and Varian Corporation. Detailed ANVIS specifications and principals of operation can be found in references 1 and 2.

1.2.2 AN/PVS-5C and AN/PVS-7A NVG

The AN/PVS-5C and AN/PVS-7A shown in figures 1-2 and 1-3, respectively, are infantry-type NVGs designed to be worn with fixed headstrap mounts. The AN/PVS-5C goggles tested were Litton Model M-915A, incorporating 2 Generation II-plus image intensifier tubes and an available short-range infrared illuminator (not evaluated). The AN/PVS-7A goggles tested were

Figure 1-1. AN/AVS-6 ANVIS Night Vision Goggles

Figure 1-2. AN/PVS-5C Night Vision Goggles

Figure 1-3. AN/PVS-7A Night Vision Goggles

Litton model M-972, incorporating a single Generation II-plus image intensifier, a short-range infrared illuminator (not evaluated), and a binocular lens assembly. Adjustments for diopter correction, range focus, interpupillary separation, tilt positioning and fore-aft (eye relief) positioning are incorporated into both of these NVG models. The headstrap assemblies for both models adjust to fit the individual wearer.

When used with the headstrap assemblies, peripheral vision is unavailable with the AN/PVS-5C and restricted with the AN/PVS-7A. Both NVG models provide a 40-degree FOV. Peak response is in the visible portion of the spectrum, with reduced amplification in the near-infrared to 0.86-micron wavelengths. Automatic brightness control is provided in both NVG models.

The AN/PVS-5C and AN/PVS-7A NVGs tested during the three R&D Center experiments were all manufactured by Litton Electron Devices. Detailed specifications can be found in references 3 and 4.

1.3 EXPERIMENT DESCRIPTIONS

A total of three experiments have been conducted to date in support of the NVG evaluation effort. From 17 April to 6 May 1989, a 3-week experiment was conducted off Fort Pierce, FL. Reference 5 documents the "quick-look" results summary from the Florida test. From 18 September to 7 October and again from 23 October to 11 November 1989, additional experiments were conducted in Block Island Sound off the CT/RI/NY coasts. Reference 6 documents the "quick-look" results from the two Block Island Sound tests. Sections 1.3.1 through 1.3.6 provide detailed information concerning the three experiments.

1.3.1 Participants

The NVG experiments were controlled by the Oceanography Branch of the Coast Guard R&D Center, Avery Point, Groton, CT. R&D Center personnel assisted by contractor computer programmers and technicians erected, operated and maintained a precision microwave tracking system (MTS) and a radio-equipped control center at each experiment site. The R&D Center Project and Test Managers arranged for primary logistics support to these facilities, handled liaison among all Coast Guard and contractor participants, and maintained top-level control of all experiment communications and data collection activities.

The prime contractor was Analysis & Technology, Inc. (A&T). A&T prepared test plans, installed MTS equipment and provided data recorders onboard participating search and rescue units (SRUs); procured and maintained target craft; and provided a chartered workboat at each site to deploy and recover an environmental data buoy and target craft.

1.3.1.1 Florida Experiment

During the Florida Experiment a Coast Guard HH-3F helicopter (CG 1469) from Air Station Traverse City, MI was provided on-site at St. Lucie County Airport with a 7-person crew on temporary active duty (TAD) status. Pilots were rotated midway through the 3-week test period while the 5-man aircrew remained for the entire period with three flying on any particular night. Coast Guard Air Station Clearwater, FL provided limited maintenance and logistics support to the Traverse City aircraft and crew during its deployment.

Coast Guard Station Fort Pierce, FL scheduled a 41-foot UTB (CG 41461) and crew for each night using its normal complement of personnel. Station Fort Pierce also provided dockage for the chartered workboat, provided staging area and dockspace for target craft, and assisted A&T personnel with the handling of target craft. Experiment-related message traffic was passed to and from the R&D Center Test Manager via the Station Fort Pierce communications center.

A 95-foot workboat, the R/V OSPREY, was chartered by A&T from the Florida Institute of Technology (FIT) to provide on-scene support to the Florida experiment. R/V OSPREY deployed and retrieved the instrumented environmental data buoy in the Fort Pierce exercise area. R/V OSPREY also deployed and retrieved all target craft used during data collection and provided backup weather observations each night.

1.3.1.2 Block Island Sound Experiments

During both Block Island Sound experiments Coast Guard Air Station Traverse City, MI provided a CH-3E helicopter on-site at Groton-New London Airport and a 7-person crew TAD to support data collection. During the first experiment, aircraft number CG 9691 was provided with a complete aircrew change midway through the 3-week period. During the second experiment, aircraft number CG 2793 was provided with a complete aircrew change midway through the experiment. Coast Guard Air Station Cape Cod, MA provided limited logistics support to the Traverse City crews during these deployments.

Coast Guard Stations Montauk, NY, New London, CT, and Point Judith, RI were each scheduled to provide a 41-foot UTB nightly to support Block Island Sound data collection. Vessels that participated on one or more nights are listed below.

Unit	Vessel(s)
CG Station Montauk, NY	CG 41342
CG Station New London, CT	CG 41337, CG 41350
CG Station Point Judith, RI	CG 41385

Experiment-related message traffic was handled directly through the R&D Center in Groton, CT and a tenant command, the International Ice Patrol.

A 65-foot workboat, the R/V UCONN, was chartered by A&T from the University of Connecticut's Marine Sciences Institute to provide on-scene support to the two Block Island Sound experiments. R/V UCONN deployed the environmental data buoy, handled all target deployments/retrievals and obtained backup weather observations. The environmental data buoy was recovered by the F/V QURANBAUG QUEEN under a direct charter from the R&D Center.

1.3.2 Exercise Areas

The primary exercise area for the Fort Pierce experiment was a 10- by 20- nmi area centered at 27°32.6'N, 80°09.0'W along a major axis of 160 degrees magnetic. Figure 1-4 depicts the Fort Pierce exercise area and indicates the locations of land-based components of the MTS. SRUs were assigned specific search patterns within this area which varied in size from 4 by 8 nmi to 10 by 12 nmi, depending on target and SRU type.

In Block Island Sound, search patterns ranging in size from 4 by 5 nmi to 8 by 12 nmi were assigned in various parts of the exercise area according to target type, SRU type and prevailing winds/seas. Figure 1-5 depicts the Block Island Sound exercise area and indicates the locations of land-based MTS components.

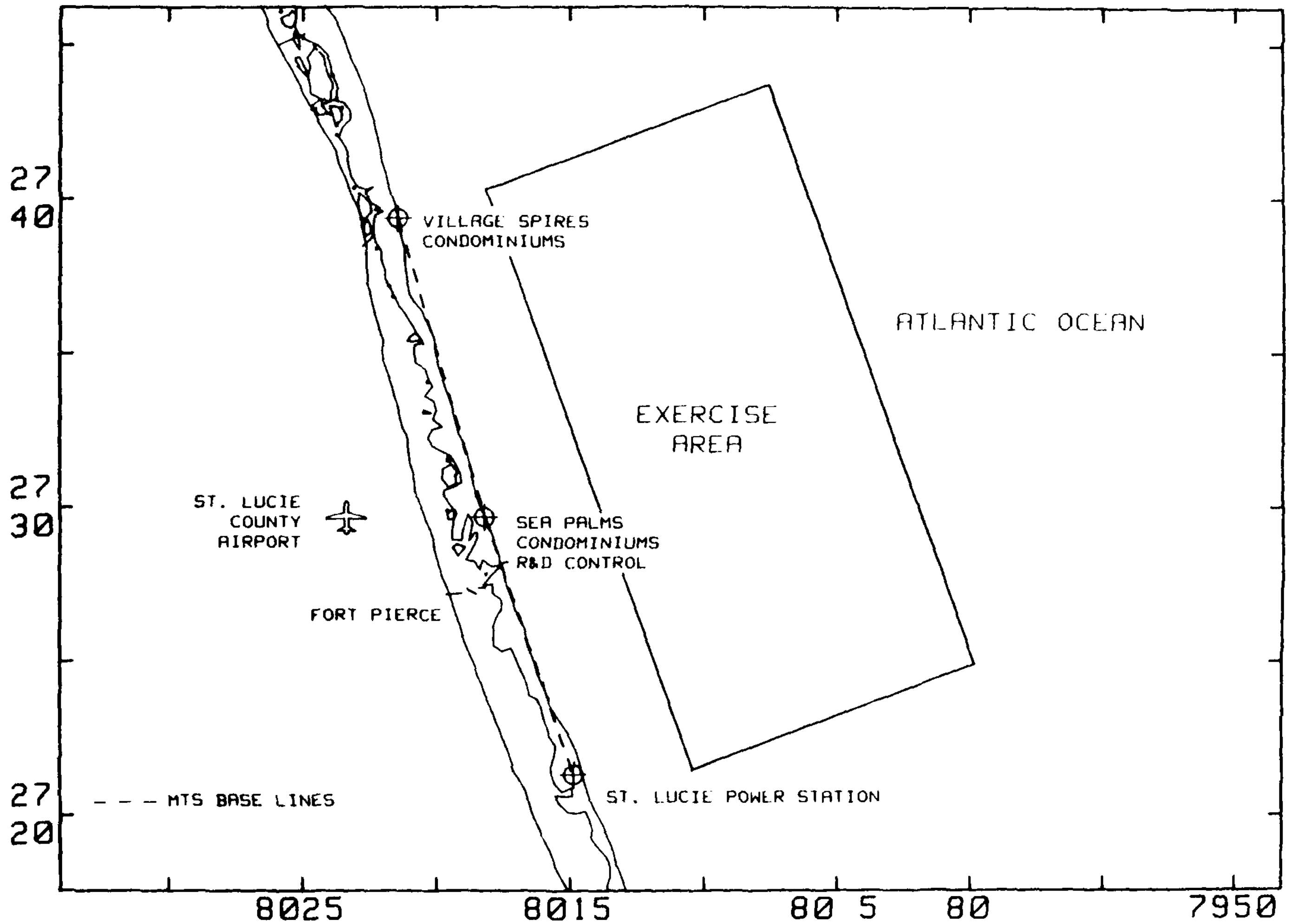


Figure 1-4. Fort Pierce Exercise Area

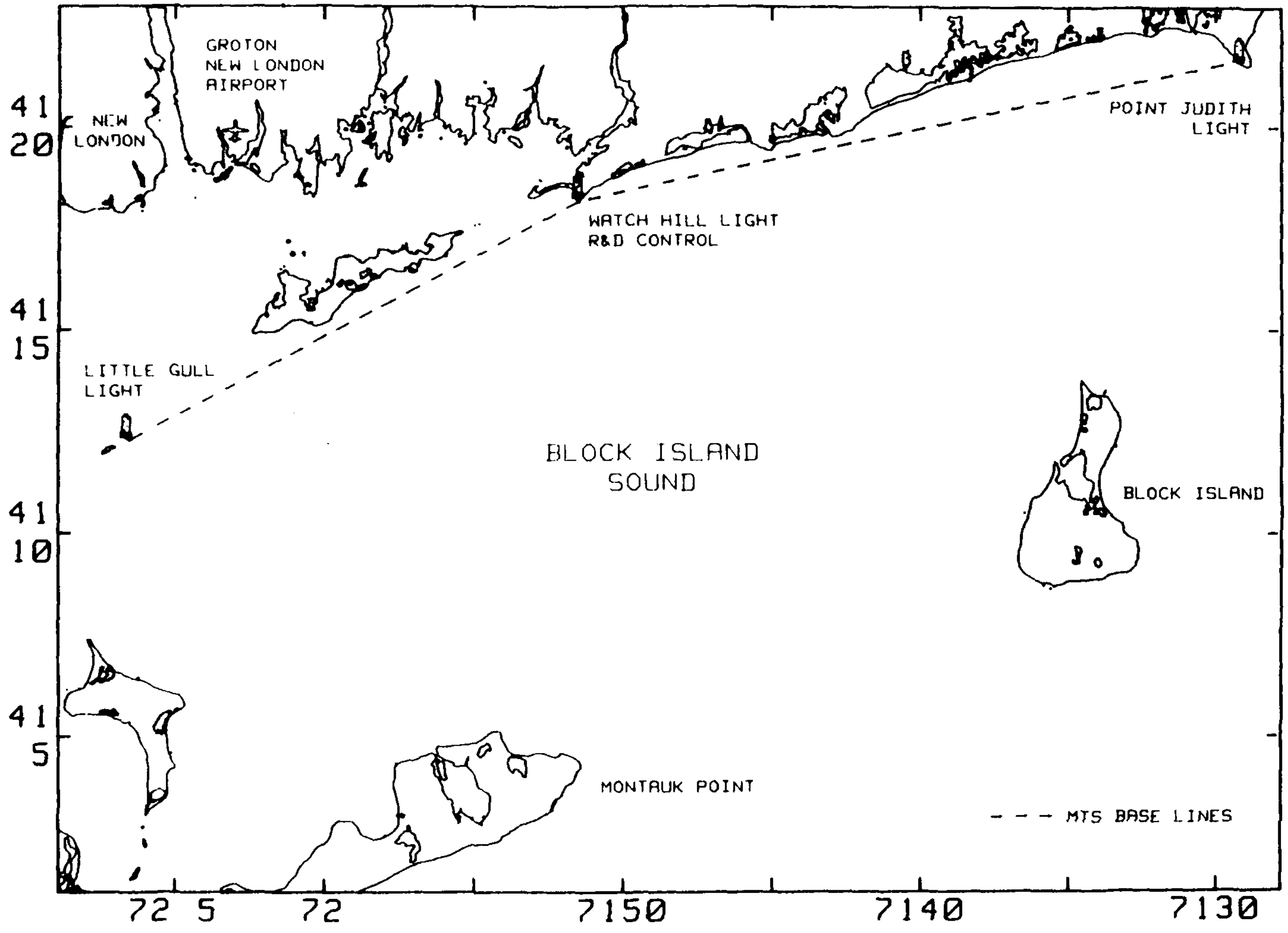


Figure 1-5. Block Island Sound Exercise Area

In both exercise areas, an operations center was established at the MTS master station location and equipped with all computer and communications equipment required to direct data collection activities and record target and SRU position information. This facility, known as R&D Control, was located at the Sea Palms Condominiums in Fort Pierce and at Watch Hill Light on Block Island Sound. These locations are depicted in figures 1-4 and 1-5, respectively.

1.3.3 Targets

Four types of search targets have been used to date in the NVG evaluations. Simulated persons in the water (PIWs), 4- to 6- person life rafts, and 18- and 21- foot boats have been deployed without lights. The PIW targets were also deployed one night with a military-issue 1-sec personal floatation device (PFD) strobe light. Table 1-1 provides the salient characteristics of each target type. Figures 1-6 through 1-9 provide representative photographs of the targets.

Table 1-1. NVG Target Descriptions

TARGET (qty)	TARGET DESCRIPTION	PRINCIPAL MATERIAL	DIMENSIONS length x beam x freeboard (feet)
PIW (10)	Department store style mannequin w/Type I PFD and retro-reflective tape	Plastic	1.5 x 1.0 x 1.0
PIW strobe (10)	PIW target w/ACR Firefly Rescue Light	Plastic	Same as above equipped with a 1 second flash, 250,000 candle power strobe light
Raft (4)	6-person Beaufort Orange canopy , no retro-reflective tape	Rubber/fabric	7.2 dia x 3.7 ht
Raft (1)	6-person Avon Orange canopy, no retro-reflective tape	Rubber/fabric	7.2 dia x 3.7 ht
Boat (3)	Rectangular white skiff w/ console	Fiberglass	18 x 7.5 x 1.6
Boat (2)	Rectangular white skiff w/ console, blue canvas bimini top, and blue bow shelter canvas	Fiberglass	21 x 7.7 x 1.6

Figure 1-6. PIW Target

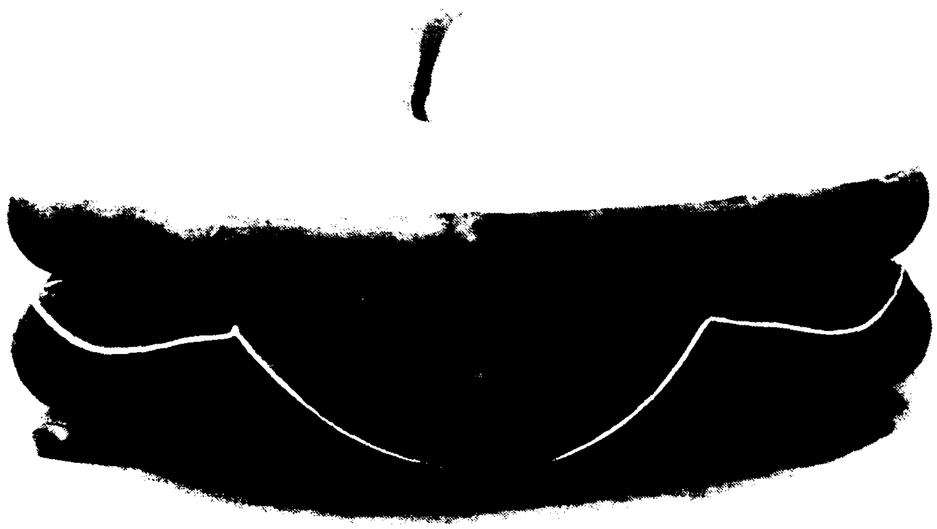


Figure 1-7. Six-Person Life Raft Target

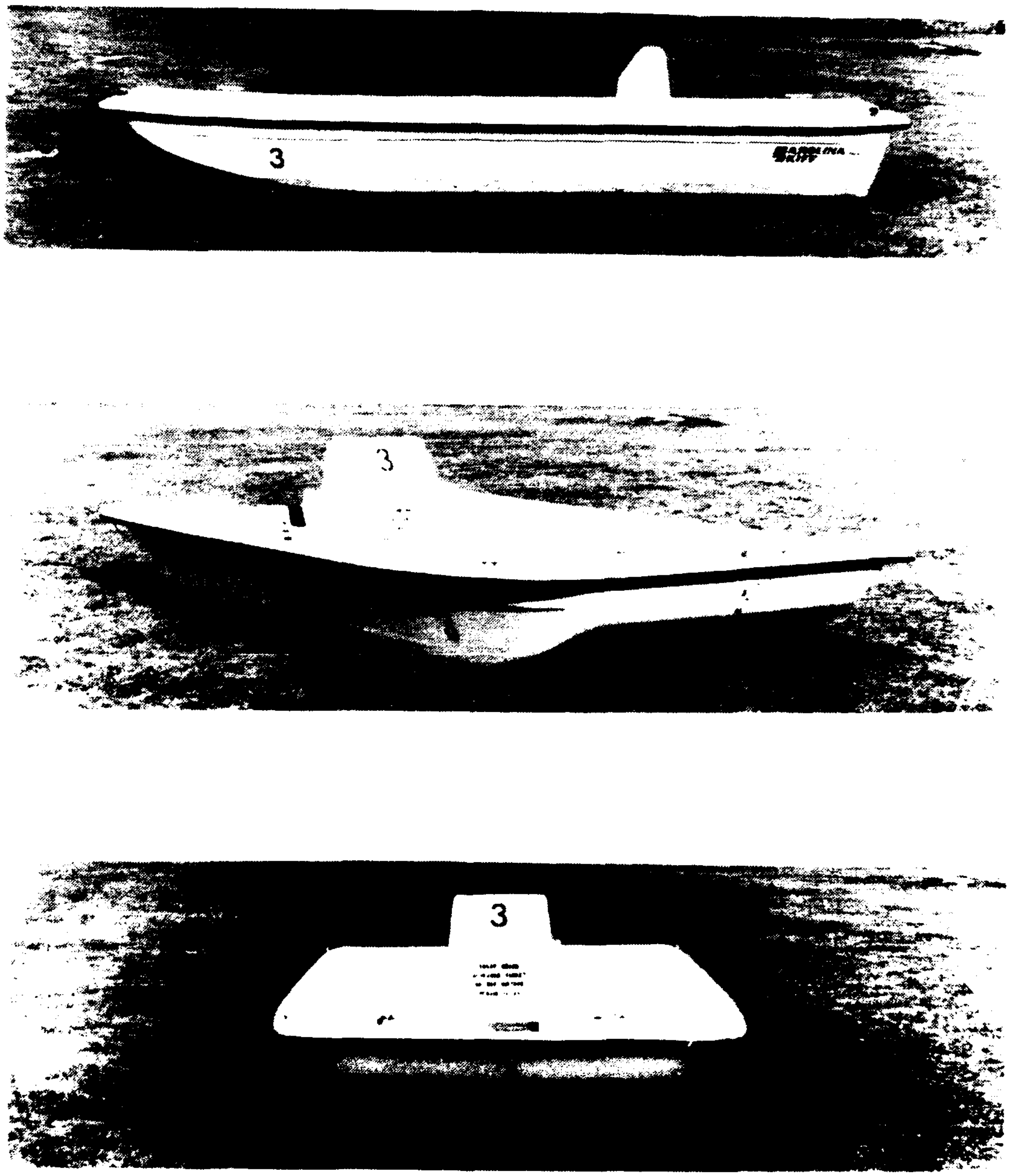


Figure 1-8. Eighteen-Foot Boat Target

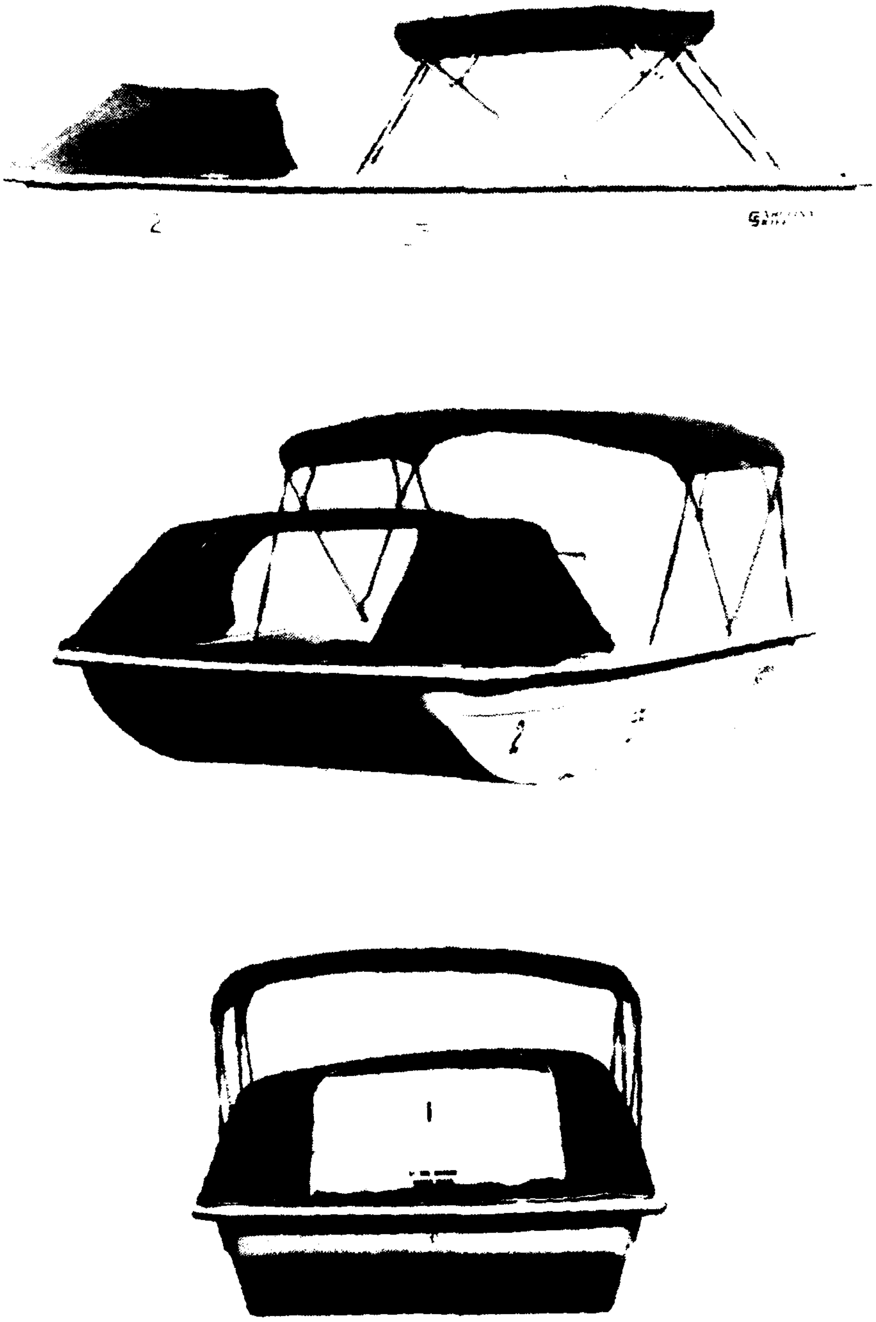


Figure 1-9. Twenty-One Foot Boat Target With Canvas

Target types were never mixed on a given night during the Florida experiment. In Block Island Sound, boats and life rafts were sometimes deployed on the same night, but PIWs were never mixed with other target types. On any particular night, PIWs were either all unlighted or all equipped with strobes.

All targets were anchored at randomly-selected positions within the assigned search area each night before data collection started and recovered after all searching was completed. Target positions were selected by superimposing a 5 by 5 block grid (25 blocks total) on the assigned search area, generating a random grid number (1 to 25) for each target, and manually selecting a location for each target within its grid. Specific target position within a grid block was assigned with consideration given to bottom depth/type, currents, local shipping/fishing activity, and proximity of other targets.

1.3.4 Experiment Design and Conduct

Detection data were obtained by conducting operationally-realistic NVG searches using parallel single-unit (PS) and creeping line single-unit (CS) search patterns as defined in reference 7. Track spacing and search area dimensions were chosen to provide target detection opportunities at a variety of lateral ranges. Track spacing for boat and life raft targets was initially set at 2 nmi, which approximates the daylight sweep width for these targets when visibility is about 5 nmi. Early data collection in Florida, however, indicated that nearly all detections of these targets were made at distances less than 1 nmi. Subsequently, most boat and raft searches were conducted using 1-nmi track spacing, with 0.5-nmi spacing used when seas were particularly choppy. All searches for unlighted PIWs were conducted using 0.5-nmi track spacing. For the strobe light targets, the helicopter was assigned 2-nmi track spacing while UTBs used 1-nmi track spacing. Figures 1-10 and 1-11 illustrate the type of search instructions that were provided to participating SRUs during the experiments. Helicopters typically searched at 300-foot altitude and used a 60-knot ground speed for unlit PIW targets and a 90-knot ground speed for all other targets. UTBs used search speeds between 9 and 20 knots, depending on sea conditions. All search parameters were communicated to SRUs via a SAR Exercise (SAREX) message sent 12 to 24 hours before scheduled data collection.

Geographic Analysis, Archiving & Display Station
Night Vision Goggles - Block Island Sound

Search Plan No. Creeping Line Search

Center: 41°12.5 N 71°48 W AXES: Major: 120/300°T Minor: 030/210°T
START: 41°11.22N 71°54.35W Right Length: 8.00 nm Track Spacing: 1.00 nm
Speed: 90 kts Time: 00:42 Width: 8.00 nm Track Miles: 63.00 nm
41°11.04 71°55.26 41°17.96 71°49.94 41°13.96 71°40.72 41°07.04 71°46.04

Waypoint	Latitude	Longitude	Course	Range	Cumulative Distance
1	41°11.22N	71°54.35W			
2	41°17.28N	71°49.7 W	030 °T	7 nm	7 nm
3	41°16.78N	71°48.55W	120 °T	1 nm	8 nm
4	41°10.72N	71°53.2 W	210 °T	7 nm	15 nm
5	41°10.22N	71°52.05W	120 °T	1 nm	16 nm
6	41°16.28N	71°47.4 W	030 °T	7 nm	23 nm
7	41°15.78N	71°46.24W	120 °T	1 nm	24 nm
8	41°09.72N	71°50.9 W	210 °T	7 nm	31 nm
9	41°09.22N	71°49.75W	120 °T	1 nm	32 nm
10	41°15.28N	71°45.09W	030 °T	7 nm	39 nm
11	41°14.78N	71°43.94W	120 °T	1 nm	40 nm
12	41°08.72N	71°48.59W	210 °T	7 nm	47 nm
13	41°08.22N	71°47.44W	120 °T	1 nm	48 nm
14	41°14.28N	71°42.79W	030 °T	7 nm	55 nm
15	41°13.78N	71°41.64W	120 °T	1 nm	56 nm
16	41°07.72N	71°46.29W	210 °T	7 nm	63 nm

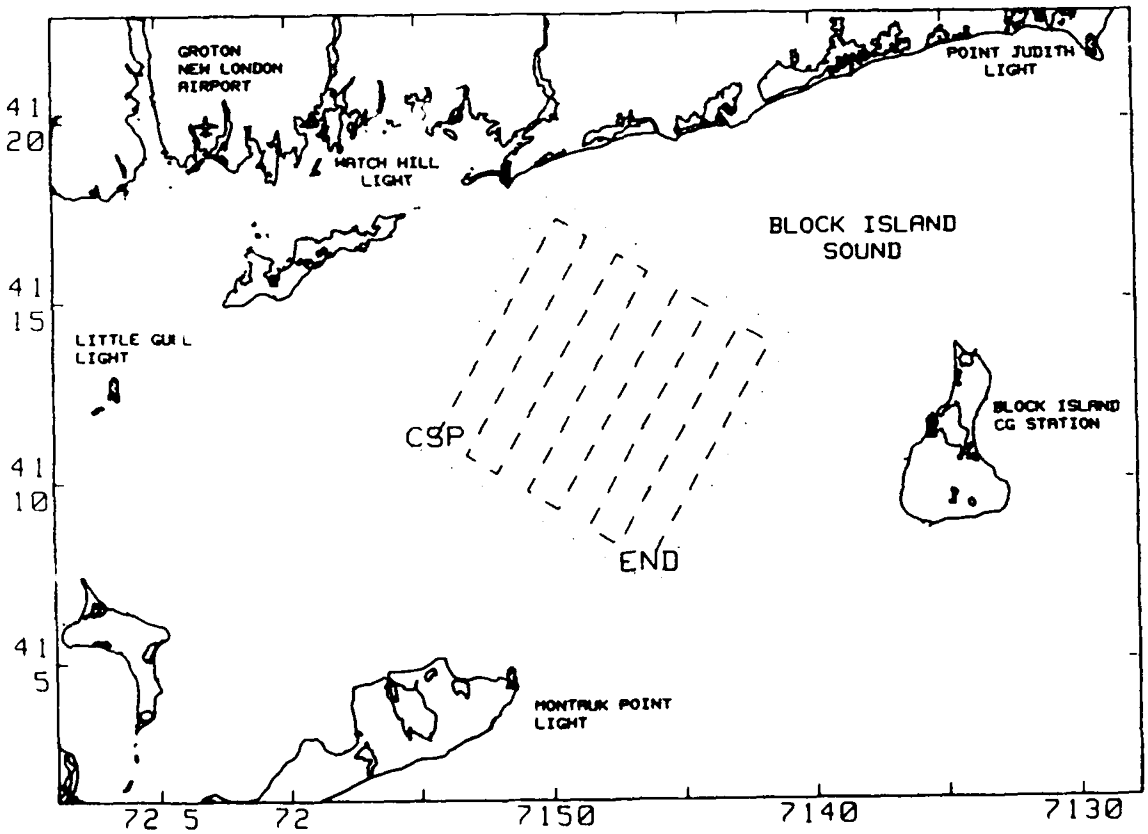


Figure 1-10. Example of Search Instructions Provided to Helicopter (Life Raft and Small Boat Targets)

Geographic Analysis, Archiving & Display Station
Night Vision Goggles - Block Island Sound

Search Plan No.   Parallel Search

Center: 41°17.1 N 71°45.4 W   AXES: Major: 075/255°T Minor: 165/345°T
START: 41°17.34N 71°50.65W Right Length: 8.00 nm Track Spacing: .50 nm
Speed: 15.0 kts Time: 03:10 Width: 3.00 nm Track Miles: 47.50 nm
Corners of search area: Area of this search: 24 sq nm
41°17.51 71°51.06   41°19.58 71°40.77   41°16.69 71°39.74   41°14.62 71°50.02

Waypoint	Latitude	Longitude	Course	Range	Cumulative Distance
1	41°17.34N	71°50.65W			
2	41°19.28N	71°41.01W	075 °T	7.5 nm	7.5 nm
3	41°18.8 N	71°40.84W	165 °T	.5 nm	8 nm
4	41°16.85N	71°50.48W	255 °T	7.5 nm	15.5 nm
5	41°16.37N	71°50.31W	165 °T	.5 nm	16 nm
6	41°18.31N	71°40.66W	075 °T	7.5 nm	23.5 nm
7	41°17.83N	71°40.49W	165 °T	.5 nm	24 nm
8	41°15.89N	71°50.13W	255 °T	7.5 nm	31.5 nm
9	41°15.4 N	71°49.96W	165 °T	.5 nm	32 nm
10	41°17.35N	71°40.32W	075 °T	7.5 nm	39.5 nm
11	41°16.86N	71°40.15W	165 °T	.5 nm	40 nm
12	41°14.92N	71°49.79W	255 °T	7.5 nm	47.5 nm

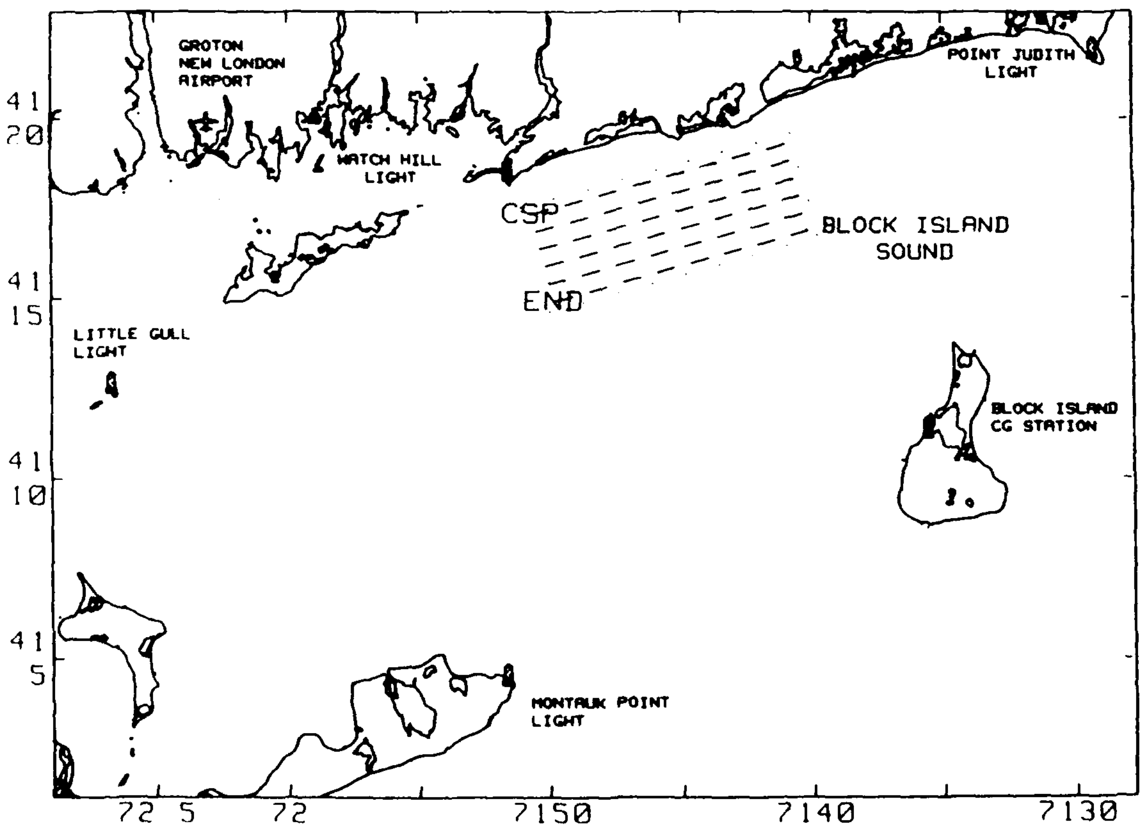


Figure 1-11. Example of Search Instructions Provided to UTBs (PIW Targets)

In the interest of realism, SRU crews were composed of personnel from the normal complement at their respective air or boat stations. With the exception of the helicopter pilots, special training for the crews in the adjustment, care, and use of NVG was usually limited to briefings and demonstrations by the R&D Center Test Manager. Except for some of the helicopter pilots who had prior NVG flight experience in the Army, most SRU crewmembers had very little or no operational experience with NVG. These experience and training levels are representative of what can currently be expected at typical Coast Guard SAR facilities where NVGs are available. The SRU crews were instructed to treat the data collection sorties as they would an actual SAR case. The crews were encouraged to maintain motivational levels that would prevail during an actual SAR mission and to conduct operations as they normally would, with one key exception. In the interest of data collection efficiency, no diversions from the assigned search pattern were made by the SRUs for the purpose of confirming target sightings. Target confirmation was done through post-experiment data analysis.

Targets were anchored within the search area each night and were seldom moved until recovered. SRU crews knew which target type(s) were deployed each night but were never told where the targets were located and did not know the exact number of targets deployed each night. Crews were told to report to an onboard data recorder any sighting of an object that could conceivably be one of the search targets.

While NVGs were the primary sensor employed in these searches, a few incidental detections that were made by coxswains and helmsmen with the naked eye or with a radar assist are also included in the UTB data set. Helicopter crewmembers all wore the ANVIS goggles whenever searching and used radar only for avoiding severe weather.

Each night, a data recorder from A&T's field team accompanied each SRU to log human factors data, target detections, and crew comments. Crew information was recorded on the SRU Information Form (figure 1-12). Target detections, crew comments, and general observations were recorded on the NVG Detection Log (figure 1-13).

When a target was sighted, lookouts immediately relayed its relative bearing ("clock" method), its estimated range (expressed as a fraction of the distance to the horizon) and a brief description of its appearance to the data recorder. The data recorder then logged the detection time, relative bearing, range, visibility of the moon, SRU heading, lookout position, and remarks on the

SRU INFORMATION FORM

DATE ______________ MTS TRANSPONDER CODE ______________

SRU TYPE ______________ SERIAL NUMBER ______________

COAST GUARD COMMAND ______________________

NAVIGATION INPUTS USED
(check all that apply)

TACAN _____ VOR/DME _____ INS ____ LORAN-C _____ RDF ____ RADAR _____ DEAD REC. _____

CREW NAMES

POSITION	NAME	RANK	FUNCTION	EXPERIENCE W/NVG (hr)
A				
B				
C				
D				
E				
F				

SKETCH (show positions)

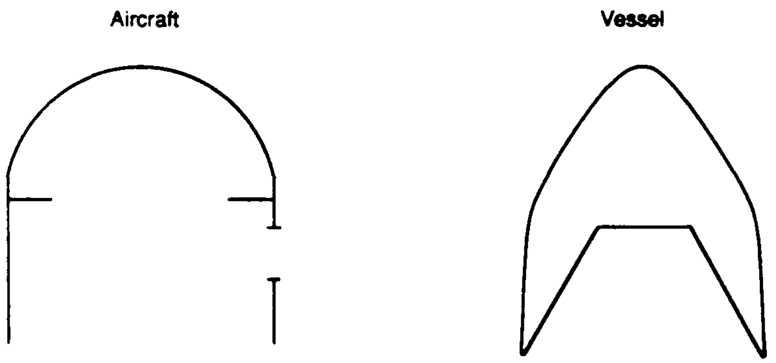


Figure 1-12. SRU Information Form

NVG DETECTION LOG

AIRCRAFT/BOAT NO. ____________ SEARCH START TIME ____________ DATE ____________

TRANSPONDER CODE ____________ SEARCH END TIME ____________ SEARCH ____________

NVG MODEL ____________ SEARCH DURATION ____________ SPEED ____________

ALTITUDE ____________

EVENT/ DETECTION NO.	TIME (HH:MM:SS)	SIGHTING RANGE (rel. to horiz.)	RELATIVE BEARING (deg/clock)	MOON VISIBLE? (Y/N)	SRU HEADING (deg T or M)	LOOKOUT/ POSITION	REMARKS (visibility, precip., fog, target appearance, etc.)

RECORDER: ____________

Figure 1-13. NVG Detection Log

NVG Detection Log. Times were synchronized to the nearest second with the MTS clock so that detections could be validated during post-experiment analysis of the logs and SRU track histories. The A&T data recorders were instructed not to assist with the search effort in any way and did not wear NVGs while recording data.

On-scene environmental conditions were recorded via two means. An A&T technician onboard the chartered workboat recorded environmental data on the Environmental Conditions Summary (figure 1-14). The MiniMet environmental data buoy relayed information to the R&D Control facility over a UHF data link three times per hour. This information was also stored in an internal memory onboard the buoy as a backup.

Figure 1-15 depicts the data messages received from the buoy. Two of the three hourly messages relayed wind data, water temperature, and air temperature at 10 minutes and 40 minutes past the hour. At 30 minutes past the hour, wave spectrum data including significant wave height (H_S) were relayed. The buoy was the preferred environmental data source when both sets of information (work boat and buoy) were available.

1.3.5 Tracking and Reconstruction

Target locations and aircraft positions were monitored using the automated MTS consisting of a Motorola Falcon 492 system controlled by a Hewlett-Packard desktop computer. The controlling software system was developed by the R&D Center to provide real time positioning and tracking with search reconstruction accurate to better than 0.1 nmi. A mobile MTS transponder was installed on the workboat for use in target positioning and on each SRU so that a track history of each search pattern could be generated. SRU positions were recorded continuously by the MTS, displayed in real time on a CRT at R&D Control, and recorded on a microcomputer hard disk every 10 to 30 seconds. Target positions were recorded by obtaining an MTS fix on the workboat when deploying each target, then verifying that each position was unchanged upon target retrieval. A more detailed description of this system can be found in reference 8.

In the Fort Pierce, FL exercise area the system recorded the range from a transponder to the MTS Master Unit located at the Sea Palms Condominiums in Fort Pierce and from a transponder to the two relay stations (located on a meteorological tower at the Florida Power and Light Company

ENVIRONMENTAL CONDITIONS SUMMARY

REPORTING UNIT ________

DATE ________

TIME	SURFACE WIND TRUE SPEED (knots)	SURFACE WIND TRUE DIRECTION (deg M)	CLOUD COVER (tenths)	MOON VISIBLE (Y/N)	VISIBILITY (nmi)	WEATHER DESCRIPTION (clear, rain, fog, etc.)	SEA STATE H_S* (ft)	SEA STATE WHITE CAPS (N/S/M)	SEA STATE SWELL DIR (deg M)	RELATIVE HUMIDITY (%)	AIR TEMP. (°C)	WATER TEMP. (°C)
**METHOD OF MEASUREMENT												

*Significant wave height.

**Note: Method may be scientific (anemometer, radar, psychrometer, etc.) or an estimate. Indicate method used to measure each parameter.

OBSERVER: ________

Figure 1-14. Environmental Conditions Summary Form

Z901MET 890927 21 10 045 129 045 045 086 059 178 121 153 259800 439209 00
Buoy #901 - Met. Data - 27 Sep 1989 / 21:10:00
    Vector Wind Speed: 4.5 mps (8.75 knots)
    Vector Wind Direction: 129°M
    Average Wind Speed: 4.5 mps (8.75 knots)
    Average Azimuth Reading: 45°M
    Average Vane Reading: 86°M
    Wind Gust: 5.9 mps (11.47 knots)
    Water Temperature: 17.8°C (64°F)
    Air Temperature: 12.1°C (53.8°F)
    Battery Voltage: 15.3 volts
    Loran Time Delays: 25980 / 43920.9 S/N: 0 C/S: 0
    Latitude/Longitude: 41°12.171'N / 71°47.905'W

1 Z901WAV 890927 21 087 110 104 095 112 113 126 175 174 206 204 239 246
2 Z901WAV 890927 21 239 223 204 206 198 189 193 196 168 189 171 187 205
3 Z901WAV 890927 21 224 241 255 251 245 250 001 004 009
Buoy #901 - Wave Data
    Record #1 - Wave Spectral Values 1 to 13 - 27 Sep 1989 / 21:30:00
        087 110 104 095 112 113 126 175 174 206 204 239 246
    Record #2 - Wave Spectral Values 14 to 26 - 27 Sep 1989 / 21:30:00
        239 223 204 206 198 189 193 196 168 189 171 187 205
    Record #3 - Wave Spectral Values 27 to 32 - 27 Sep 1989 / 21:30:00
        224 241 255 251 245 250
    Scaling Factor: 1
    Significant Wave Height: .4 m (1.3 ft)
    Maximum Wave Period: .9 sec

Z901MET 890927 21 40 051 115 051 045 072 062 178 118 158 259800 439209 00
Buoy #901 - Met. Data - 27 Sep 1989 / 21:40:00
    Vector Wind Speed: 5.1 mps (9.91 knots)
    Vector Wind Direction: 115°M
    Average Wind Speed: 5.1 mps (9.91 knots)
    Average Azimuth Reading: 45°M
    Average Vane Reading: 72°M
    Wind Gust: 6.2 mps (12.05 knots)
    Water Temperature: 17.8°C (64°F)
    Air Temperature: 11.8°C (53.2°F)
    Battery Voltage: 15.8 volts
    Loran Time Delays: 25980 / 43920.9 S/N: 0 C/S: 0
    Latitude/Longitude: 41°12.171'N / 71°47.905'W

Figure 1-15. Environmental Data Buoy Message Formats

St. Lucie Plant and at the Village Spires Condominiums in Riomar). These locations were depicted in figure 1-4. In the Block Island Sound exercise area the system recorded the range from a transponder to the Master Unit located at Watch Hill Light and from a transponder to the two primary relay stations (located at Little Gull Light and Point Judith Light). These locations were depicted in figure 1-5.

Search tracks and target locations were reconstructed by using the recorded target and SRU position data to generate an accurate geographic representation on hard copy plots. On each plot, target positions were plotted using identifying letters and the SRU track was identified by dots and plusses. Plotting the SRU position marks created a trackline history for each search craft. Each position mark was associated with a known time on a hardcopy printout that accompanied each plot. Figures 1-16 and 1-17 are MTS-generated reconstruction plots of actual searches that were conducted during the second Block Island Sound experiment. Figure 1-16 depicts the execution by a CH-3E helicopter of the search instructions shown in figure 1-10. Figure 1-17 depicts the execution by a 41-foot UTB of the search instructions shown in figure 1-11.

Analysts used the MTS plots and NVG Detection Logs to determine which R&D Center targets were detected and which were missed on each leg of an SRU's search pattern. Normally, a target was considered an opportunity for detection on any given search leg if the SRU passed it within the assigned track spacing distance. Occasionally, analysts considered targets to be detection opportunities at distances greater than the track spacing. This was done when, on a given night, an SRU made one or more detections at lateral ranges that, when multiplied by 1.5, exceeded the assigned track spacing. In such instances, this computed distance (1.5 times maximum lateral range of detection) was used instead of the track spacing to determine which targets were considered to be valid opportunities for detection on each search leg. This rule, although somewhat arbitrary, provided sufficient data to identify an asymptotic limit to the NVG lateral range curve (to be discussed in section 1.4) without adding a large number of meaningless (very long-range) target misses to the data set.

If a logged target report could be correlated with the position of a given R&D Center target, it was considered a detection. Analysts performed this correlation by using the time of a given detection reported in the NVG Detection Log to locate the search craft on the hard copy MTS plot. The range and bearing information for that detection was then compared to target positions on the MTS plot, and a detection validity determination was made. A miss was recorded for any target detection opportunity that could not be correlated with a logged detection report on a particular

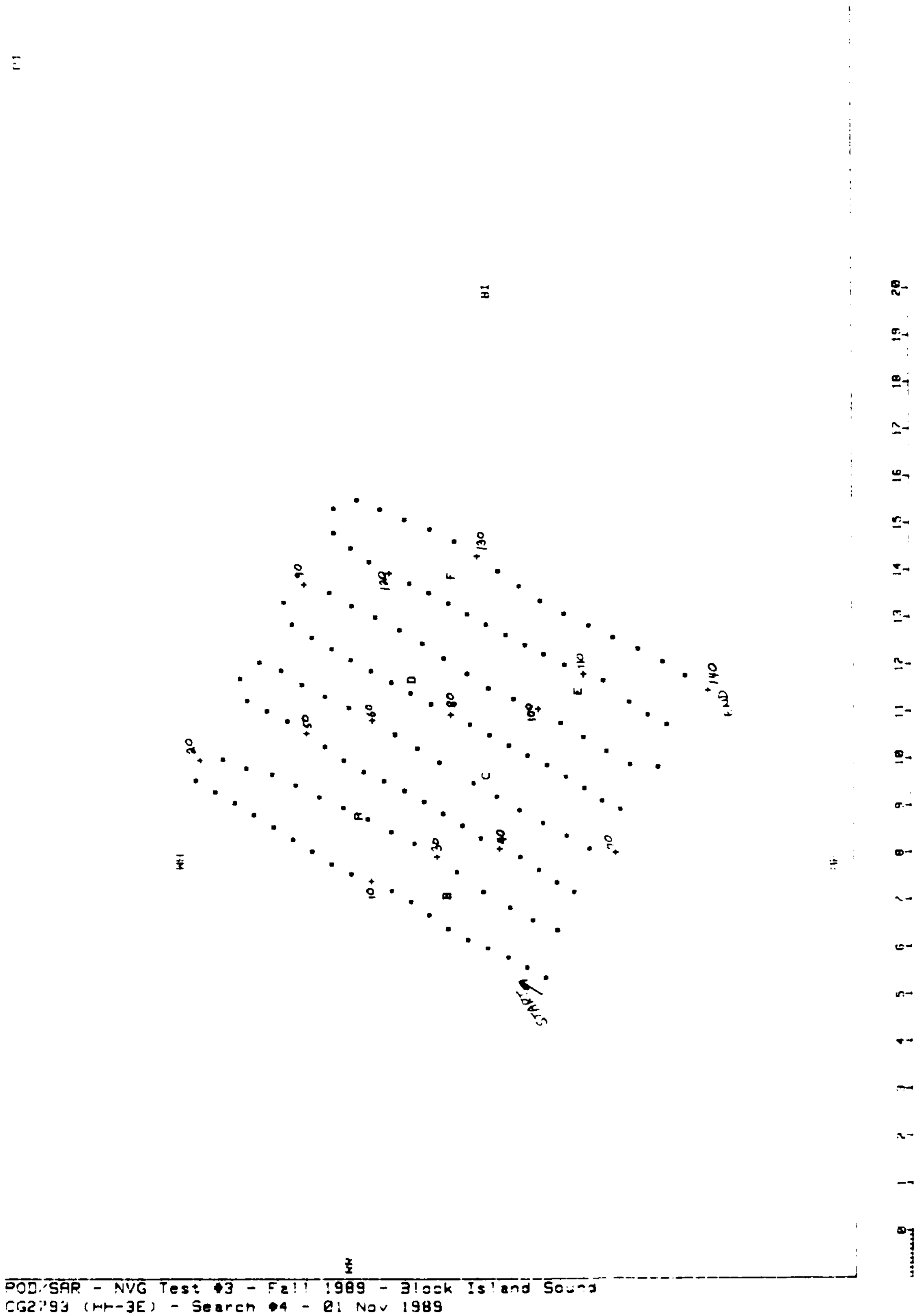


Figure 1-16. MTS Plot of a Typical Helicopter Search

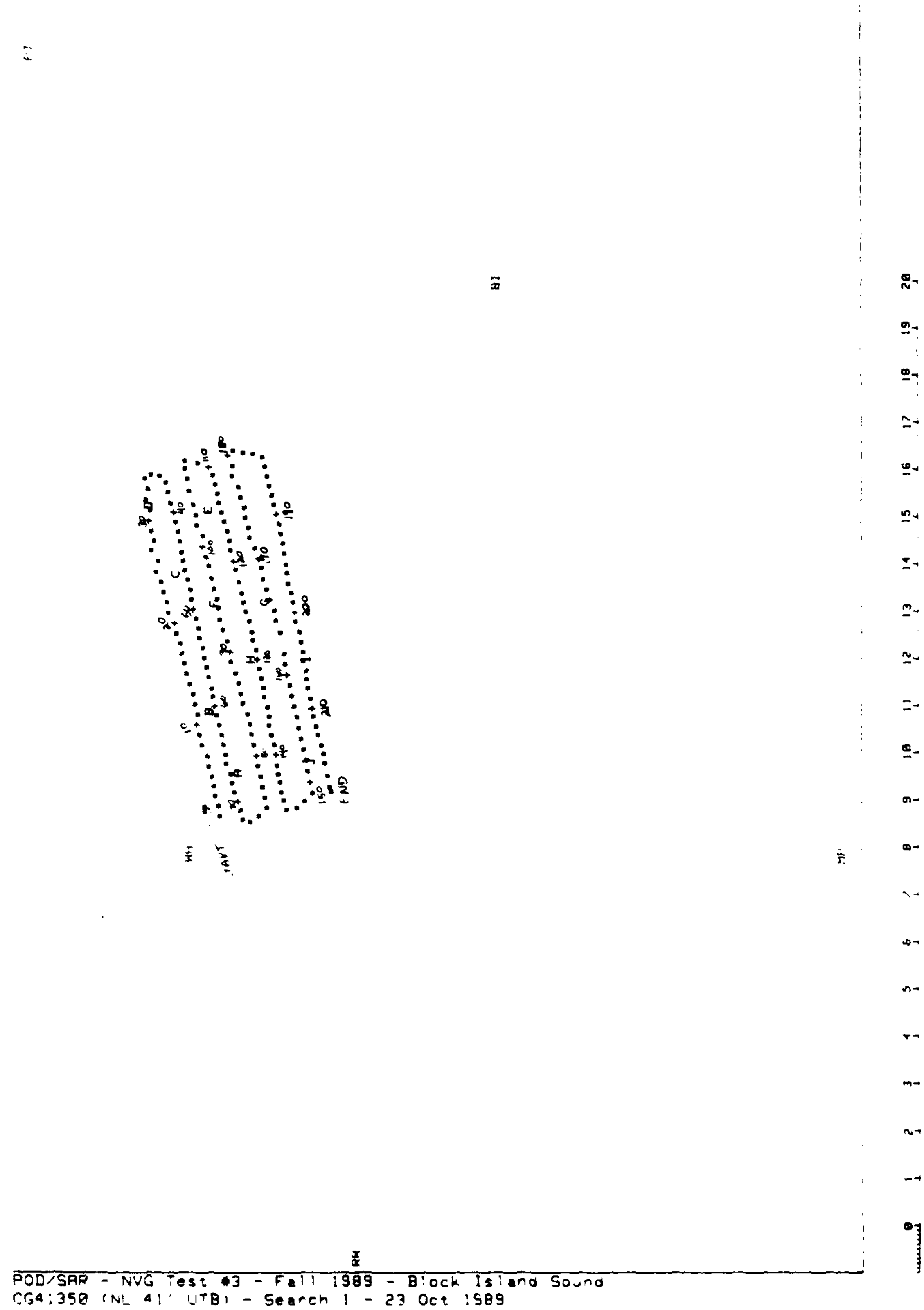


Figure 1-17. MTS Plot of a Typical UTB Search

search leg. An accurate lateral range measurement was then made on the MTS plot for each detection or miss. These detections and misses, along with associated search parameters and environmental conditions, were compiled into computer data files for analysis. These data files are listed in the Data Appendix, provided in Volume II of this report.

1.3.6 Range of Parameters Tested

A total of 25 potentially-significant search parameters were recorded for each valid target detection opportunity. These parameters can be broadly classified as relating to the target, the SRU, the environment, ambient light, and human factors. These search parameters and their units of measure are as follows.

	PARAMETER	UNIT OF MEASURE
	Target-Related	
1.	Target Type	PIWs: reflective tape or strobe Rafts: without reflective tape only Boats: 18-foot without canvas or 21-foot with canvas
2.	Lateral Range*	nautical miles (nmi)
	SRU-Related	
3.	NVG Type	41-foot UTB: AN/PVS-5 or AN/PVS-7 Helicopters: AN/AVS-6 only
4.	Search Speed	knots
5.	Search Altitude	feet (helicopter only)
	Environment - Related	
6.	Precipitation Level	none/light/moderate/heavy
7.	Visibility	nmi
8.	Wind Speed	knots

*See section 1.4.1 for definition.

PARAMETER	UNIT OF MEASURE
9. Cloud Cover	tenths of sky obscured
10. Significant Wave Height	feet
11. Whitecap Coverage	none/light/heavy
12. Relative Wave Direction	wave fronts traveling into/away from/across line-of-sight to target at SRU's closest point of approach (if target missed) or at time of detection.
13. Relative Humidity	percent
14. Air Temperature	degrees Celsius
15. Water Temperature	degrees Celsius
Ambient Light - Related	
16. Relative Azimuth of Artificial Light	Light source located along/away from/across line-of-sight to target at SRU's closest point of approach (if target missed) or at time of detection.
17. Artificial Light Level	rural/suburban/urban
18. Moon Elevation	degrees above or below the horizon
19. Moon Visible (from SRU)	yes/no
20. Relative Azimuth of the Moon	Moon (visible or not) located along/away from/across line-of-sight to target at SRU's closest point of approach (if target missed) or at time of detection
21. Moon Phase	none, 1/4, 1/2, 3/4, full
Human Factors - Related	
22. Lookout Position†	location onboard SRU
23. Lookout ID†	individual identifier
24. Lookout NVG Experience†	hours
25. Time on Task	hours (actually searching)

†Items 22 through 24 were recorded for detections only.

The range of target types evaluated was discussed in section 1.3.3. Lateral range for target opportunities varied from 0 to 2 nmi for boat and life raft targets, from 0 to 0.6 nmi for unlighted PIW targets, and from 0 to 4 nmi for strobe light targets.

The types of NVG used on each SRU were discussed in section 1.2. Helicopter search speed was approximately 60 knots for unlighted PIW targets and approximately 90 knots for boat, raft, and strobe targets. UTB search speeds varied between 9 and 20 knots depending on sea conditions. Search altitude for the helicopter was held constant at about 300 feet above the sea surface.

The range of environmental parameters encountered over the three experiments is summarized in table 1-2. Relative wave direction has been omitted from the table because all three possibilities are well-represented. Moon elevation and moon phase are also included in table 1-2. Artificial light levels were either rural or suburban in both locations.

A total of 34 individual helicopter lookouts and 89 UTB lookouts (not all of whom wore NVG to search) are represented in the data set. NVG experience ranged from 0 to 189 hours for helicopter crewmembers and from 0 to 43 hours for UTB crewmembers. Time on task ranged from 0 to 4.9 hours for the helicopter crews and from 0 to 6.2 hours for UTB crews.

All remaining parameters were well-represented over their range of possible values.

1.4 ANALYSIS APPROACH

1.4.1 Measure of Search Performance

The primary performance measure used by SAR mission coordinators to plan searches is sweep width (W). Because this NVG evaluation is intended to support improved Coast Guard SAR mission planning, sweep width was chosen as the measure of search performance to be developed during data analysis. Sweep width is a single-number summation of a more complex range/detection probability relationship. Mathematically,

$$W = \int_{-\infty}^{+\infty} P(x)dx ,$$

Table 1-2. Range of Environmental and Moon Parameters Encountered

SRU/ TARGET	ENVIRONMENTAL PARAMETER									MOON	
	Precipitation Level	Visibility (nmi)	Wind Speed (knots)	Cloud Cover (tenths)	Significant Wave Height (ft)	Whitecap Coverage	Relative Humidity (percent)	Air Temperature (deg. C)	Water Temperature (deg. C)	Elevation (degrees)	Phase
Helo./ Boats	0 to 1	1.5 to 15	2 to 20	0 to 1.0	1.3 to 4.3	0 to 2	64 to 96	10.4 to 24.3	13.4 to 24.2	-68 to +64	none to full
Helo./ Rafts	0 to 3	1.5 to 15	3 to 16	0 to 1.0	1.6 to 5.2	0 to 2	64 to 100	10.4 to 24.3	13.4 to 23	-69 to +41	none to full
Helo./ PIWs	0	4 to 15	5 to 22	0	1.3 to 3.6	0 to 2	74 to 86	11.6 to 24	13.3 to 23.9	-63 to +34	quarter to full
Helo./ Strobe	0	3	15 to 17	1.0	2.3 to 2.6	1	82	11.5	13.6	+30 to +46	half
UTB/ Boats	0 to 1	1.5 to 15	2 to 20	0 to 1.0	1.3 to 4.3	0 to 2	64 to 96	5.5 to 24.3	13.4 to 24.2	-60 to +51	none to full
UTB/ Rafts	0 to 2	1.5 to 15	2 to 24	0 to 1.0	1.3 to 4.6	0 to 2	64 to 100	6.1 to 24	13.5 to 23.6	-62 to +33	none to 3 quarters
UTB/ PIWs	0	2 to 15	3 to 22	0	1.3 to 3.6	0 to 2	74 to 90	11.6 to 24.5	13.2 to 24	-65 to +33	none to full
UTB/ Strobe	0	3	17	1.0	2.3 to 2.6	1	82	11.5	13.6	+43 to +46	half

where

x = Lateral range (i.e., closest point of approach) to targets of opportunity (see figure 1-18), and

P(x) = Target detection probability at lateral range x.

Figure 1-19 shows a typical P(x) curve as a function of lateral range. In this figure, x is the lateral range of detection opportunities.

Conceptually, sweep width is the numerical value obtained by choosing a value of lateral range less than the maximum detection distance for any given sweep so that scattered targets that may be detected beyond the limits of sweep width are equal in number to those that may be missed within those limits. Figure 1-20 (I and II) illustrates this concept of sweep width. The number of targets missed inside the distance W is indicated by the shaded portion near the top middle of the rectangle (area A); the number of targets sighted beyond the distance W out to maximum detection range (MAX R_D) is indicated by the shaded portion at each end of the rectangle (areas B). Referring only to the shaded areas, when the number of targets missed equals the number of targets sighted (area A = sum of areas B), sweep width is defined. A detailed mathematical development and explanation of sweep width can be found in reference 9.

1.4.2 Analysis of Search Data

Three primary questions were addressed in this interim analysis of NVG detection data.

1. Which of the 25 search parameters identified in section 1.3.6 exerted significant influence on the detection performance of the SRUs?

2. What are the NVG sweep width estimates for various combinations of significant parameters identified during step 1?

3. What guidance for NVG use onboard Coast Guard SRUs can be developed based on the quantitative analysis performed in step 1 and the subjective comments and observations obtained from experiment participants?

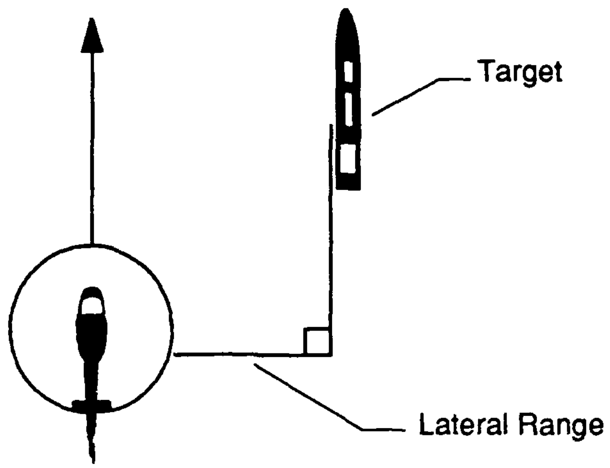


Figure 1-18. Definition of Lateral Range

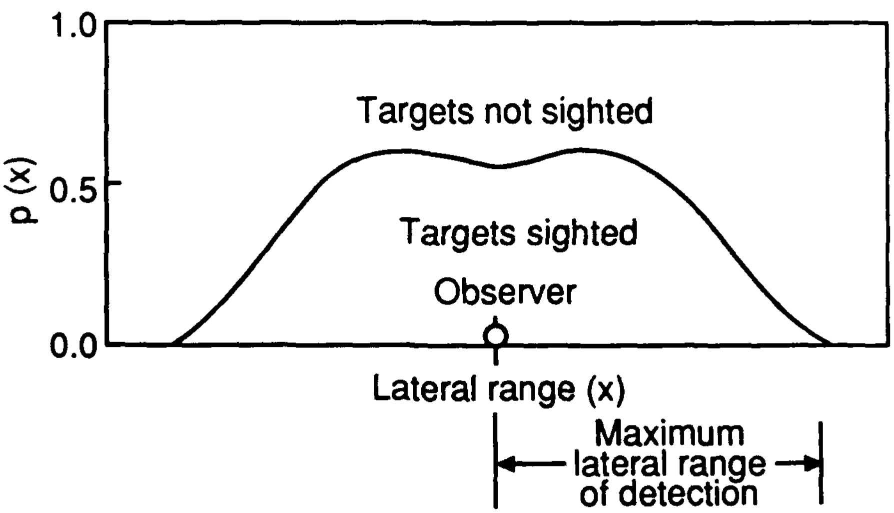


Figure 1-19. Relationship of Targets Detected to Targets Not Detected

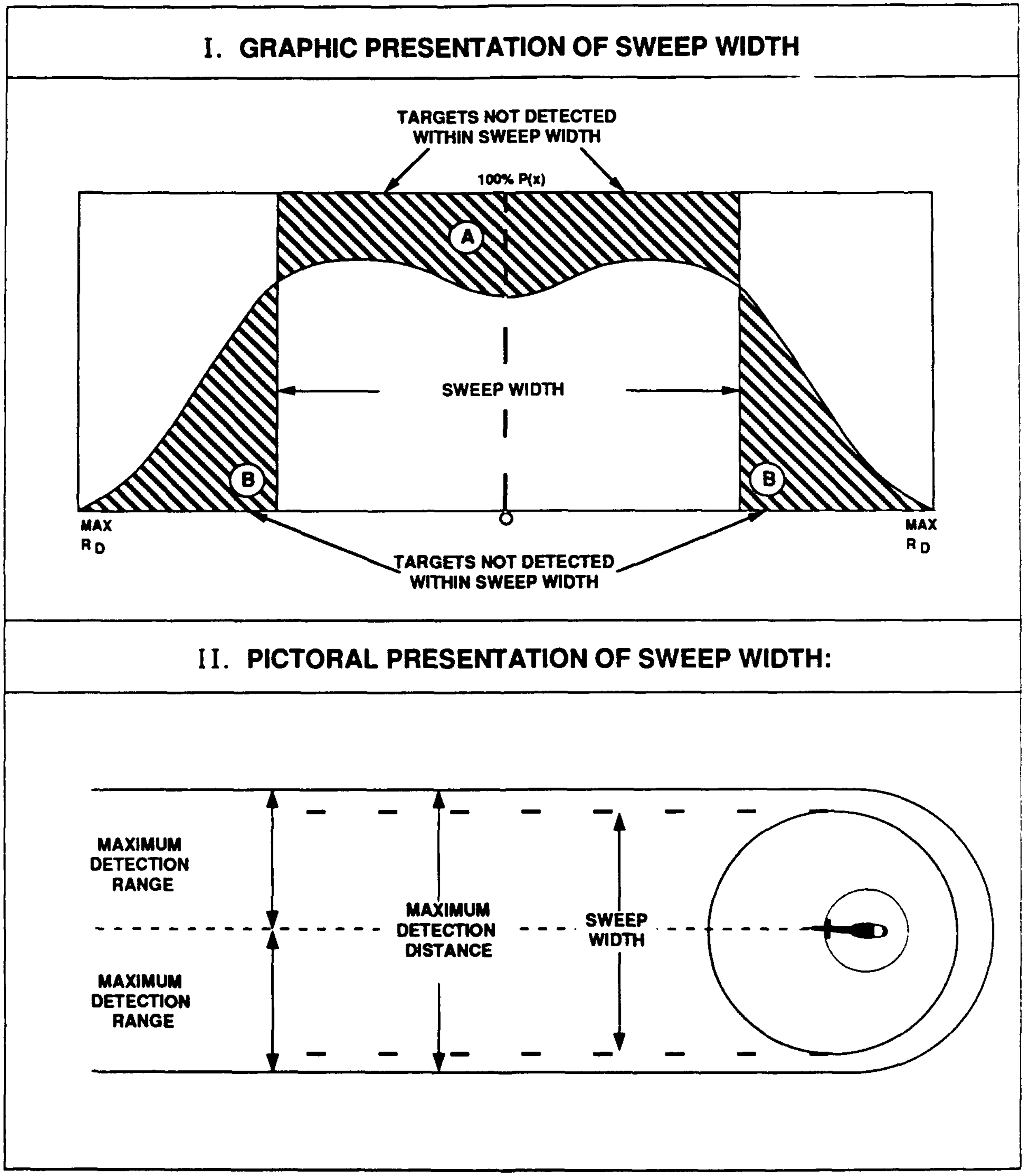


Figure 1-20. Graphic and Pictorial Presentation of Sweep Width

1.4.2.1 Development of Raw Data

After each experiment, the MTS plots and NVG detection logs were used as described in section 1.3.5 to determine which SRU-target encounters were valid detection opportunities, and which of those opportunities resulted in successful target detections by the SRUs. The analyst listed each target detection opportunity on a raw data sheet along with a detection/miss indicator. Values for the 25 search parameters listed in section 1.3.6 were then obtained for each listed detection opportunity by consulting appropriate logs and environmental data buoy messages. A separate raw data sheet was completed for each search that was conducted by each SRU. The contents of these raw data sheets were entered into computer data files on an Apple Macintosh II computer using spreadsheet software and stored on magnetic disk. A distinct data file was constructed for each SRU for each night it participated in data collection. Hard copies of these data files are provided in Volume II of this report.

From these single-SRU data files, eight aggregate raw data files were built; one file for each SRU/target type combination evaluated (two SRUs times four target types). These eight raw data files served as input to all subsequent data sorting and statistical analysis routines used for this evaluation.

1.4.2.2 Data Sorting and Statistics

Once the eight files of raw data were entered and verified to be correct on the computer, basic statistics were obtained to characterize the data sets. A commercial statistics and graphics software package purchased from SYSTAT, Inc. was used to perform this phase of the data analysis.

Various SYSTAT routines were used to produce simple statistics, histograms, and scatter plots showing the range of search parameter values and their combinations present in each data set. The minimum, maximum, mean, and standard deviation values for each search parameter in the eight data sets were obtained to determine the range of search conditions represented in each data set. Histograms showing the distribution of values for various parameters of interest were obtained to determine which search conditions were well-represented within each data set and which were not. Scatterplots depicting which combinations of search parameters were represented in each data set were also produced.

Once the data sets were characterized in this manner, logistic multivariate regression analysis was used to determine which search parameters exerted significant influence on NVG detection performance and to develop lateral range curves from which NVG sweep widths could be computed.

1.4.2.3 LOGIT Multivariate Regression Model

Multivariate logistic regression models have proven to be appropriate analysis tools for fitting Coast Guard visual search data where the dependent variable is a discrete response (i.e., detection/no detection). The detection data from this NVG evaluation have been analyzed using a commercially-available software package from SYSTAT, Inc. called LOGIT. LOGIT is an add-on module to SYSTAT's standard statistical analysis and graphics software package.

This type of regression model is useful in quantifying the relationship between independent variables (x_i) and a probability of interest, R (in this case the probability of detecting a target). The independent variables (x_i) can be continuous (e.g., range, wave height, wind speed) or binary (e.g., high/low altitude, SRU type 0 or 1). For example, A&T's logistic regression model, LOGODDS, has been used with great success during Improvement in Probability of Detection in Search and Rescue (POD/SAR) Project visual search performance analyses (reference 8). The LOGODDS model was shown to be an effective means of identifying statistically-significant search parameters and of quantifying their influence on the target detection probability versus lateral range relationship. This functional relationship, commonly referred to as the lateral range curve, provides a basis for computing sweep widths.

The equation for target detection probability that is used in the logistic regression model is

$$R = \frac{1}{1 + e^{-\lambda}},$$

where

R = target detection probability for a given searcher - target encounter,

$\lambda = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + \ldots + a_n x_n$

a_i = fitting coefficients (determined by computer program), and

x_i = independent variable values.

The method of maximum log likelihood is employed in the model to optimize values of the coefficients a_i. A detailed theoretical development of the logistic regression analysis methodology is given in reference 10.

A logistic regression model has the following advantages over other regression models and statistical methods.

1. The model implicitly contains the assumption that $0 \leq R \leq 1.0$, whereas, a linear model does not unless the assumption is added to the model (and then computation can become very difficult).

2. The model is analogous to normal-theory linear models; therefore, analysis of variance and regression implications can be drawn from the model.

3. The model can be used to observe the effects of several independent or interactive parameters that are continuous or discrete.

4. A regression technique is better than nonparametric hypothesis testing, which does not yield quantitative relationships between the probability in question and the values of independent variables.

The primary disadvantages of this type of regression model are:

1. For the basic models, the dependent variable (R) must be a monotonic function of the independent variables. This limitation can sometimes be overcome by employing appropriate variable transforms.

2. The computational effort is substantial, requiring use of relatively powerful computer resources. Until recently, a mini-mainframe computer (in the case of A&T's LOGODDS, a VAX 11/780) was required to perform the necessary calculations efficiently.

With the advent of more powerful desktop computers has come the capability to use them to perform multivariate logistic regression analysis on large data sets. The NVG detection data were analyzed on a Macintosh II desktop computer using LOGIT. The LOGIT software (reference 11) uses the maximum log-likelihood technique to fit a logistic curve to response data that can be broken down into discrete categories. As with LOGODDS, the influence of various independent explanatory variables on a discrete-choice response can be determined using the LOGIT module. The significance of these explanatory variables as predictors of the response can be evaluated using the output t-statistics. This process is equivalent to A&T's LOGODDS software, but allows for more than a binary (2-choice) response variable. When used to analyze a binary response data set, the LOGIT regression equation reduces to the same form as that given above for the LOGODDS model. Reference 12 documents a verification study performed by A&T that confirms the equivalence of the LOGODDS and LOGIT models for analysis of binary response data from Coast Guard detection performance evaluations.

The LOGIT regression model was used in an iterative fashion with each data set to arrive at a fitting function that contained only those search parameters found to exert statistically significant influence on the target detection response. These fitting functions were then solved for representative sets of search conditions to generate lateral range curves. From these lateral range curves, NVG sweep widths were computed.

1.4.2.4 Sweep Width Calculations

Sweep width, the measure of search performance used by Coast Guard search planners, was defined conceptually in section 1.4.1. Mathematically, the value of W is determined by computing the area under the lateral range curve. Before NVG sweep widths were computed for this report, the analysis procedure described in section 1.4.2.3 was used with the data set for each SRU/target type combination. This procedure identified search parameters that exerted statistically-significant influence on target detection probability. Histograms and scatterplots depicting the distribution of the significant parameters identified within each data set were then prepared. From these histograms and scatterplots a determination was made as to how the raw experiment data could be sorted into subsets of substantial size. These subsets would reflect distinct sets of search conditions. Lateral range curves and sweep widths were then computed for each data subset.

The preceding analysis procedure and the subsequent process of generating lateral range curves and computing sweep widths is best illustrated by the following example.

STEP 1: Identification of Data Subsets. LOGIT analysis of the data set representing helicopters searching for small boats indicated that, in addition to lateral range, visibility, significant wave height (H_S) and the presence or absence of a visible moon exerted statistically-significant influence on target detection probability. The distribution of the data relative to moon visibility was determined from a simple data sort, rather than a histogram, because this parameter could assume only two values. The distributions of visibility and significant wave height within the data set were then examined by generating histograms depicting values of these variables versus frequency of occurrence. Finally, the combinations of these variables within the data set were depicted by creating scatterplots of the distribution of each variable relative to the others. These scatterplots, combined with the histogram information, identified three combinations of visibility, significant wave height, and moon visibility that were well-represented in the data set. The first set of search conditions was represented by no visible moon, visibilities of 10 to 15 nmi, and significant wave heights of 1.3 to 2.0 feet. The second set of search conditions was represented by a visible moon, visibilities of 6 to 15 nmi, and significant wave heights of 2.0 to 3.3 feet. The third set of search conditions included data collected with no visible moon, visibilities of 6 to 15 nmi, and significant wave heights of 2.3 to 3.3 feet.

STEP 2: Generation of Lateral Range Curves. Three lateral range curve equations were generated by inputting the moon visibility parameters (0 for not visible, 1 for visible) and the mean values of visibility and H_S for each of the 3 data subsets to the LOGIT -generated expression for target detection probability. The 3 distinct equations that resulted were then plotted for lateral range values between 0 and 2 nmi. This process yielded three distinct plots of lateral range versus target detection probability; one for each combination of search parameters identified in step 1 above.

STEP 3: Calculation of Sweep Widths. Sweep width values were calculated for each of the three sets of search conditions by integrating the applicable LOGIT expressions for target detection probability over the limits 0 to 2 nmi. The integral of the 2-choice LOGIT function given in section 1.4.2.3 is:

$$A = \frac{1}{a_1} \ln \left(1 + e^{a_1 x_1 + c}\right) \Bigg|_{x_1 = 0 \text{ nmi}}^{x_1 = \text{selected lateral range limit}}$$

where

A = area under the LOGIT-fitted curve,

a_1 = value of the lateral range coefficient determined by the LOGIT regression analysis,

x_1 = lateral range, and

$c = a_0 + a_2 x_2 + a_3 x_3 + ... + a_n x_n$ for specified values of search parameters $x_2, x_3, ... x_n$. In this example $n = 4$ with x_2, x_3, and x_4 representing the specified values of visibility (in nautical miles), H_S (in feet), and moon visibility (0 or 1). The values of a_0, through a_4 would be determined by the LOGIT regression analysis.

Sweep width is defined as two times the value of the area A computed above because searching occurs to both sides of the SRU, thus:

$$W = 2A.$$

The methods illustrated in the example above were used with all the SRU/target type combinations for which values of W were computed in this report. Integration limits were selected to include a lateral range interval from 0 nmi to a value well beyond the limits at which any detections were made during the experiments. These limits varied with SRU/target type combination.

CHAPTER 2
TEST RESULTS

2.1 INTRODUCTION

This chapter summarizes the results of the NVG data analyses described in chapter 1. Two major discussions of results are presented in this chapter: Section 2.2 provides a quantitative analysis of SRU detection performance against each of the target types tested and section 2.3 provides an evaluation of human factors studied during the NVG experiments.

A total of 1,490 target detection opportunities were generated during the three NVG experiments conducted in 1989. Table 2-1 summarizes the distribution of these detection opportunities by SRU type and target type. Sufficient data were collected in seven of the eight SRU/target type categories to support a detailed analysis using the methods described in chapter 1. Only the UTB/strobe combination contained insufficient data for a detailed analysis to be performed.

Table 2-1. Numbers of Target Detection Opportunities by SRU Type and Target Type

TARGET TYPE \ SRU TYPE	Helicopter	UTB
18- and 21-foot Boats	288	130
4- and 6-person Life Rafts	249	190
PIWs	242	227
Strobe	152	12

2.2 DETECTION PERFORMANCE

Sections 2.2.1 and 2.2.2 present analysis results for each of the data subsets shown in table 2-1. Lateral range curve fits and sweep width estimates are provided for statistically-significant search parameter combinations that are well-represented in the raw data. Lateral range was identified as a significant search parameter for all of the SRU/target type combinations evaluated. Where other search parameters were also found to be significant, some of the available detection opportunities have not been included in any of the lateral range curve plots because of the data sorting schemes that were employed. These detection opportunities occurred under search conditions that were different from those for which plots were generated. These search conditions are not yet sufficiently represented within their respective data sets to support generation of additional lateral range curves.

The lateral range plots depicted in this chapter show lateral range from the SRU along the horizontal axis and target detection probability along the vertical axis. The figures expressed as ratios on the plots represent the number of detections divided by the total number of target detection opportunities occurring within a particular lateral range interval. These ratios correspond to the target detection probability achieved for each lateral range interval. Each plotted probability is denoted by a diamond that is located along the horizontal axis at the average lateral range for all detection opportunities occurring within the applicable lateral range interval. A vertical bar through each diamond denotes the 90-percent confidence limits on the plotted detection probability. The fitted lateral range curve included in each plot was generated using the LOGIT regression equation discussed in chapter 1 with all statistically-significant search variables included. When a data set was found to contain statistically-significant search variables in addition to lateral range, the mean values of these variables were first computed for input to the LOGIT equation. Each data subset plotted represents a unique combination of significant search variable values.

2.2.1 Helicopter Detection Performance

2.2.1.1 PIW Targets

LOGIT regression analysis at the 90-percent confidence level indicated that variation in target detection probability within the helicopter/PIW data set could best be explained by a combination of the lateral range and visibility parameters. Subsequently, the 242 detection opportunities in this data set were first sorted into 2 levels of visibility (5 nmi and 15 nmi).

The initial data sort resulted in a group of 20 detection opportunities at 5 nmi visibility and a second group of 222 detection opportunities at 15 nmi visibility. The smaller of the two data subsets was not large enough to produce a credible lateral range plot. The larger subset was sorted into seven, 0.1-nmi lateral range bins from 0.0 nmi through 0.6 nmi to produce the raw data points plotted in figure 2-1. A pronounced dip in target detection probability at 0.0-nmi lateral range is manifested in the raw data. This phenomenon is likely due to the lack of visibility of these targets to crewmembers in the aft section of the helicopter. The targets pass directly under the aircraft, out of the aft crewmembers' fields of view, leaving only the pilots with an opportunity to detect them.

The LOGIT-fitted lateral range curve shown in figure 2-1 was produced by solving the LOGIT regression model equation for 15 nmi visibility and lateral ranges from 0 to 1 nmi. A sweep width estimate of 0.39 nmi was obtained by integrating the fitted LOGIT probability equation over the limits 0 to 1 nmi.

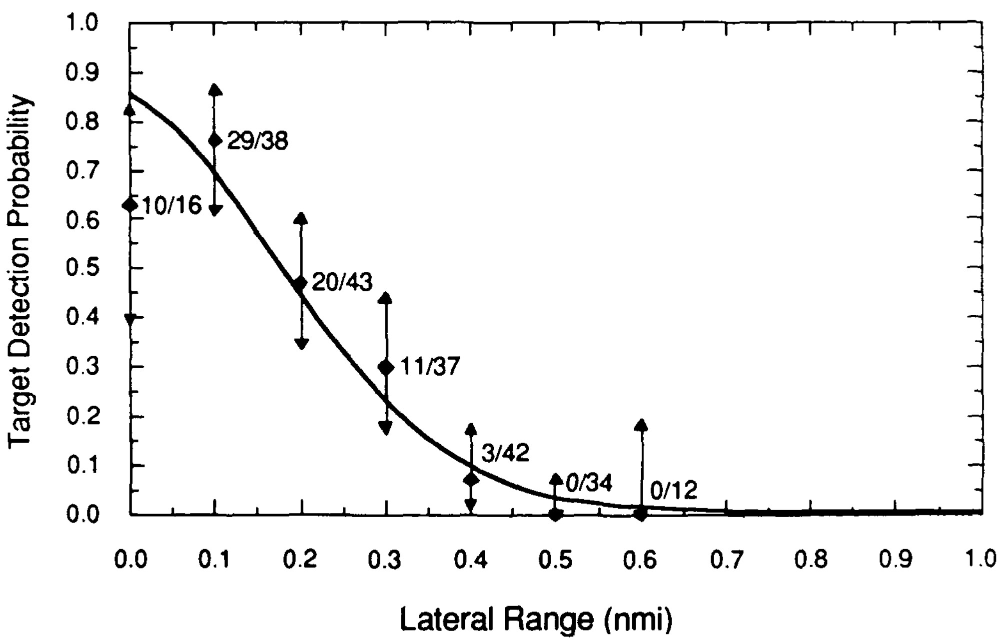


Figure 2-1. Helicopter Detection of PIWs (visibility = 15 nmi)

2.2.1.2 Life Raft Targets

No significant search parameters other than lateral range were identified through LOGIT analysis of the helicopter/life raft data set. Variation in target detection probability was adequately explained at the 90-percent confidence level by lateral range alone.

Figure 2-2 provides a raw data plot and LOGIT-fitted lateral range curve for the entire helicopter/life raft data set. The raw data were sorted into four, 0.25-nmi lateral range bins from 0 to 1 nmi. Twenty-four detection opportunities (all missed targets) that occurred at lateral ranges between 1 and 2 nmi have been omitted from the raw data plot in figure 2-2. The fitted lateral range curve was produced by solving the LOGIT regression model equation for lateral ranges from 0 to 1 nmi. A sweep width estimate of 0.36 nmi was obtained by integrating the fitted LOGIT probability equation over the limits 0 to 1 nmi.

2.2.1.3 Small Boat Targets

LOGIT regression analysis at the 90-percent confidence level indicated that variations in target detection probability within the helicopter/small boat data set could best be explained by a combination of the lateral range, significant wave height (H_S), visibility, and moon visibility parameters. The 288 detection opportunities in this data set were sorted into 6 subsets based on distinct combinations of the H_S, visibility, and moon visibility parameter values. These data subsets were defined as shown in table 2-2. Lateral range plots were developed for subsets 1, 2, and 3 by sorting the raw data into eight, 0.25 nmi lateral range bins from 0 to 2 nmi. These data are plotted in figures 2-3 through 2-5. Data subsets 4 through 6 were not large enough to support generation of lateral range plots.

The LOGIT-fitted lateral range curves shown in figures 2-3 through 2-5 were produced by solving the LOGIT regression model equation for the average parameter values listed in parentheses in table 2-2 and for lateral ranges from 0 to 2 nmi. Sweep width estimates were obtained by integrating the three fitted LOGIT probability equations over the limits 0 to 2 nmi. The resultant sweep width estimates were 0.84 nmi for data subset 1, 0.88 nmi for data subset 2, and 0.63 nmi for data subset 3.

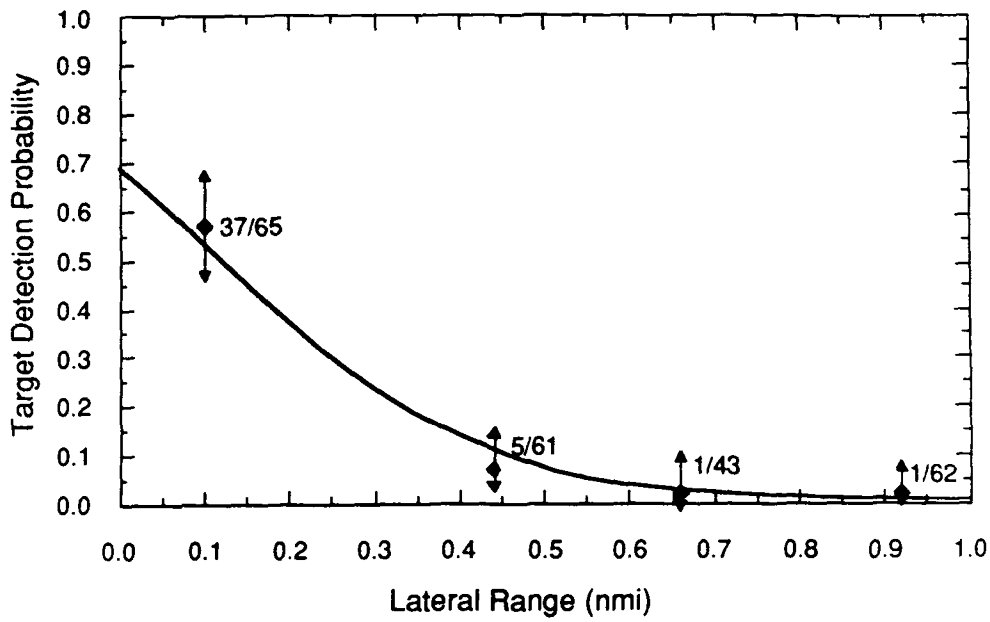


Figure 2-2. Helicopter Detection of Life Rafts (all data)

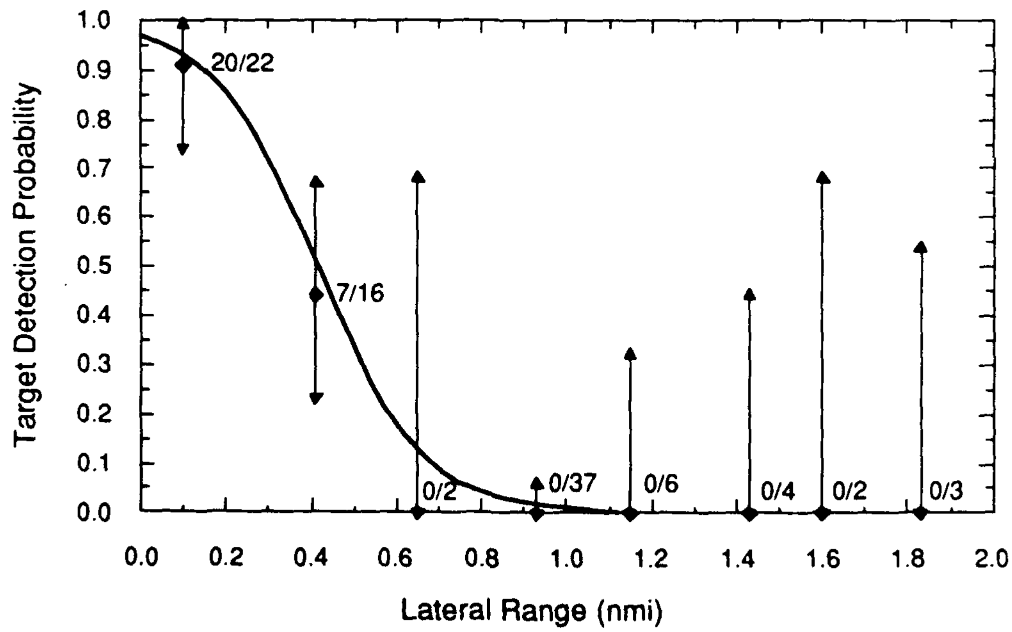


Figure 2-3. Helicopter Detection of 18- and 21-Foot Boats
(H_S = 1.3 to 2.0 feet, visibility = 10 to 15 nmi, moon not visible)

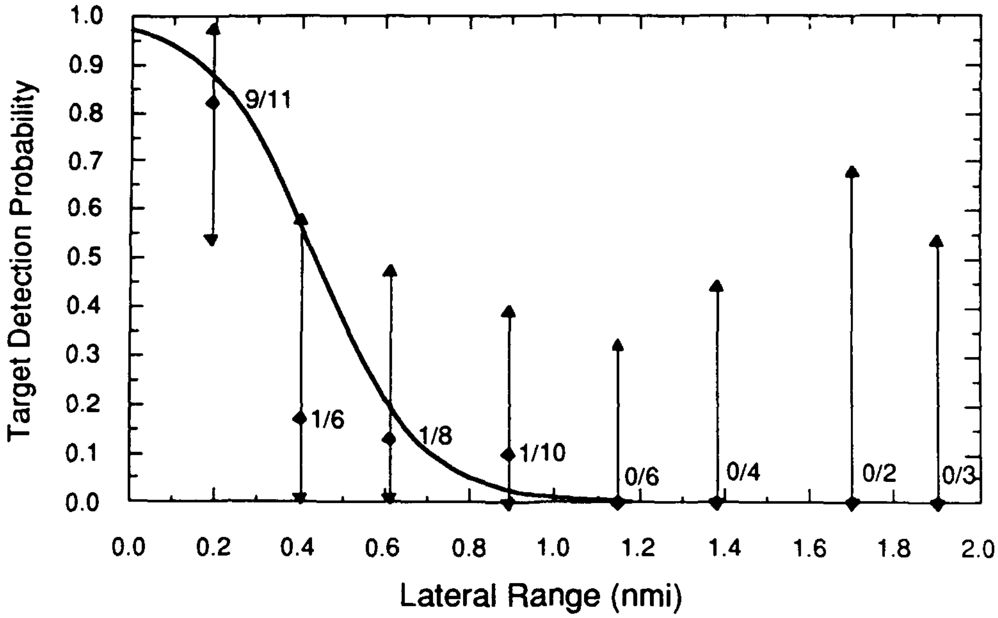


Figure 2-4. Helicopter Detection of 18- and 21- Foot Boats
(H_S = 2.0 to 3.3 feet, visibility = 6 to 15 nmi, moon visible)

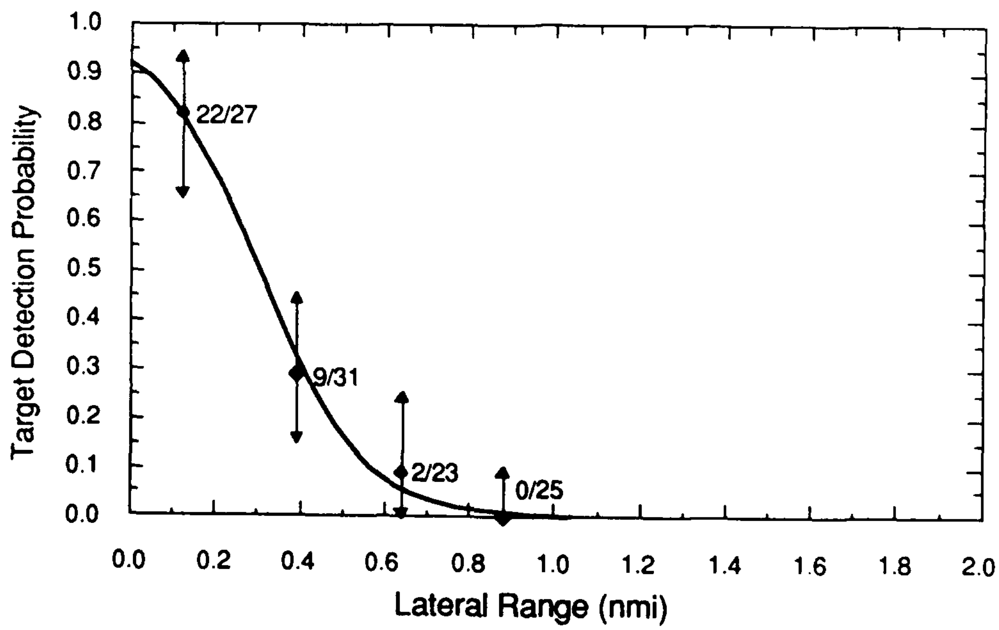


Figure 2-5. Helicopter Detection of 18- and 21-Foot Boats
(H_S = 2.3 to 3.3 feet, visibility = 6 to 15 nmi, moon not visible)

Table 2-2. Data Subsets Defined for Helicopter/Small Boat Detection Opportunities

Data Subset	Range of Parameter Values (Average Value)			Number of Detection Opportunities
	H_S	Visibility	Moon Visibility	
1	1.3 to 2.0 feet (1.6 feet)	10 to 15 nmi (12.0 nmi)	no (0)	92
2	2.0 to 3.3 feet (2.7 feet)	6 to 15 nmi (9.0 nmi)	yes (1)	50
3	2.3 to 3.3 feet (2.8 feet)	6 to 15 nmi (11.5 nmi)	no (0)	106
4	< 2 feet (1.6 feet)	1.5 to 2.0 nmi (1.6 nmi)	no (0)	12
5	3.6 to 4.3 feet (4.1 feet)	11 to 15 nmi (11.4 nmi)	no (0)	19
6	< 2 feet (1.6 feet)	> 5 nmi (15 nmi)	yes (1)	9

2.2.1.4 Strobe Light Targets

The LOGIT regression method was used to analyze only the influence of the lateral range and time on task parameters within the helicopter/strobe data set. The influence of other search parameters could not be evaluated because all data were collected on a single night with negligible variation in search conditions. The LOGIT analysis indicated that only lateral range was required to explain variation in target detection probability at the 90-percent confidence level.

Figure 2-6 provides a raw data plot and LOGIT-fitted lateral range curve for the helicopter/strobe data set. The raw data were sorted into eight, 0.5-nmi lateral range bins from 0 to 4 nmi. The fitted lateral range curve was produced by solving the LOGIT regression model equation for lateral ranges from 0 to 5 nmi. A sweep width estimate of 3.5 nmi was obtained by integrating the fitted LOGIT probability equation over the limits 0 to 5 nmi. Given the relatively poor search conditions that prevailed on the night these data were collected (see table 1-2), it is reasonable to expect that much larger helicopter/strobe sweep widths would be achieved in clear weather.

2.2.2 UTB Detection Performance

2.2.2.1 PIW Targets

No significant search parameters other than lateral range were identified through LOGIT analysis of the UTB/PIW data set. Variation in target detection probability was adequately explained at the 90-percent confidence level by lateral range alone.

Figure 2-7 provides a raw data plot and LOGIT-fitted lateral range curve for the entire UTB/PIW data set. The raw data were sorted into six, 0.1-nmi lateral range bins from 0.0 to 0.5 nmi. The fitted lateral range curve was produced by solving the LOGIT regression model equation for lateral ranges from 0 to 1 nmi. A sweep width estimate of 0.06 nmi was obtained by integrating the fitted LOGIT probability equation over the limits 0 to 1 nmi, indicating an extremely limited capability to detect unlighted PIW targets on the part of NVG-equipped UTBs.

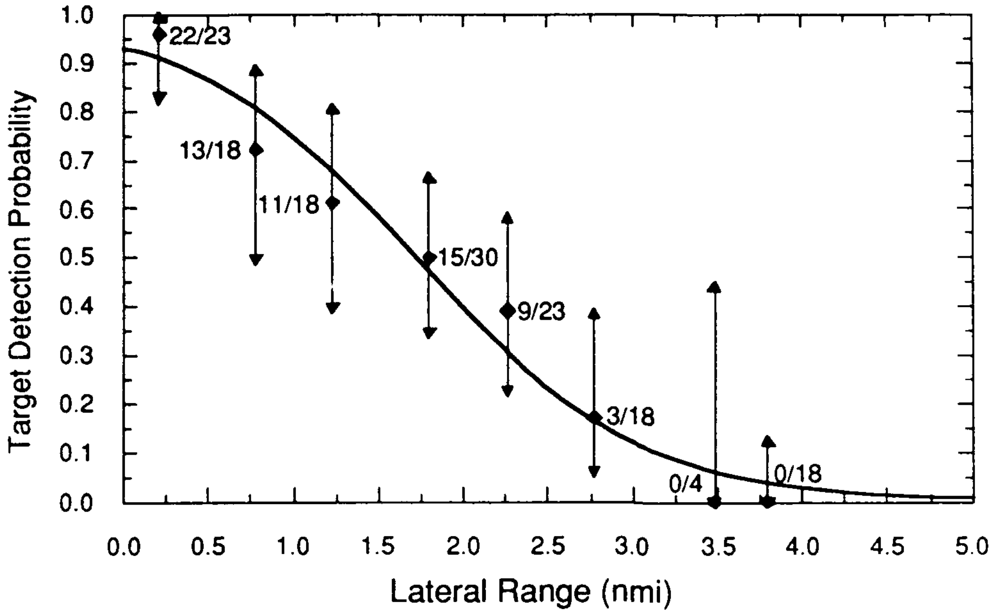


Figure 2-6. Helicopter Detection of Strobe Lights (poor search conditions)

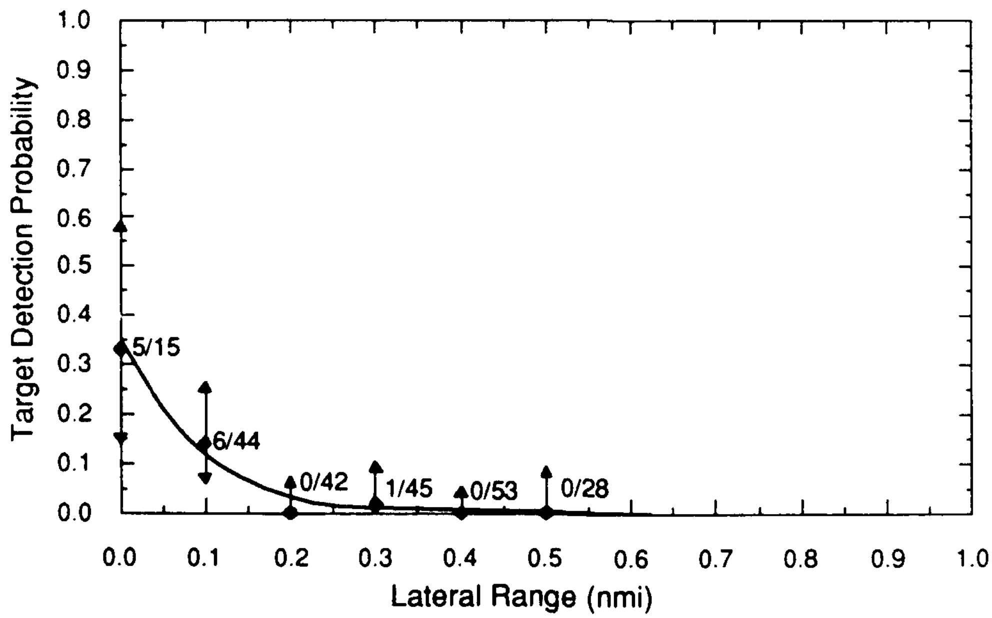


Figure 2-7. UTB Detection of PIWs (all data)

2.2.2.2 Life Raft Targets

No significant search parameters other than lateral range were identified through LOGIT analysis of the UTB/life raft data set. Variation in target detection probability was adequately explained at the 90-percent confidence level by lateral range alone.

Figure 2-8 provides a raw data plot and LOGIT-fitted lateral range curve for the entire UTB/life raft data set. The raw data were sorted into four, 0.25-nmi lateral range bins from 0 to 1 nmi. The fitted lateral range curve was produced by solving the LOGIT regression model equation for lateral ranges from 0 to 1 nmi. A sweep width estimate of 0.17 nmi was obtained by integrating the fitted LOGIT probability equation over the limits 0 to 1 nmi.

2.2.2.3 Small Boat Targets

LOGIT regression analysis at the 90-percent confidence level indicated that variations in target detection probability within the UTB/small boat data set could best be explained by a combination of the lateral range, H_S and boat size parameters. The 130 detection opportunities in this data set were first sorted into three subsets based on the H_S parameter alone. The initial data sort yielded 26 detection opportunities at H_S values from 1.3 to 1.6 feet, 78 opportunities at H_S values from 2.0 to 3.3 feet, and 26 opportunities at H_S values from 3.6 to 4.3 feet. No further analysis was performed on the first and third data subsets because of their small size.

The second data subset (H_S values of 2.0 to 3.3 feet) was further separated into two groups representing 18-foot and 21-foot boat targets. Each of these two data groups was then sorted into four, 0.25 nmi lateral range bins from 0 to 1.0 nmi. These data are plotted in figures 2-9 and 2-10. A total of six detection opportunities (all missed targets) that occurred at lateral ranges between 1 and 2 nmi have been omitted from the raw data plots in figures 2-9 and 2-10.

The LOGIT-fitted lateral range curves in figures 2-9 and 2-10 were produced by solving the LOGIT regression model equation for the appropriate boat type, the average value of H_S in each data subset, and for lateral ranges of 0 to 1 nmi. Sweep width estimates were obtained by integrating the two fitted LOGIT probability equations over the limits 0 to 1 nmi. The resultant sweep width estimates were 0.10 nmi for 18-foot boats and 0.40 nmi for 21-foot boats. The reader is cautioned that the data sets plotted in figures 2-9 and 2-10 are considerably smaller than

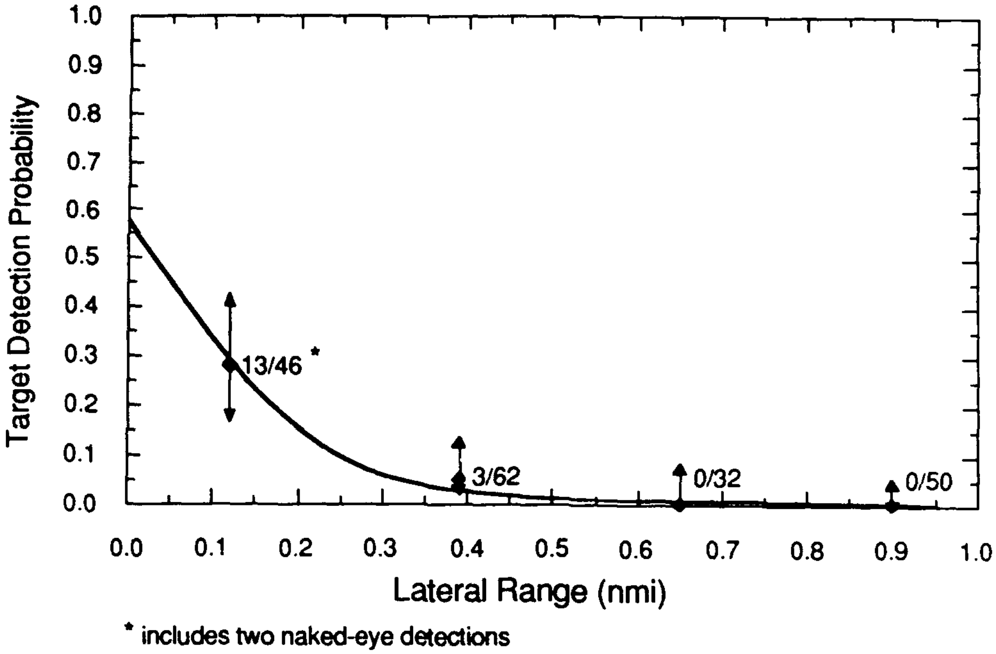


Figure 2-8. UTB Detection of Life Rafts (all data)

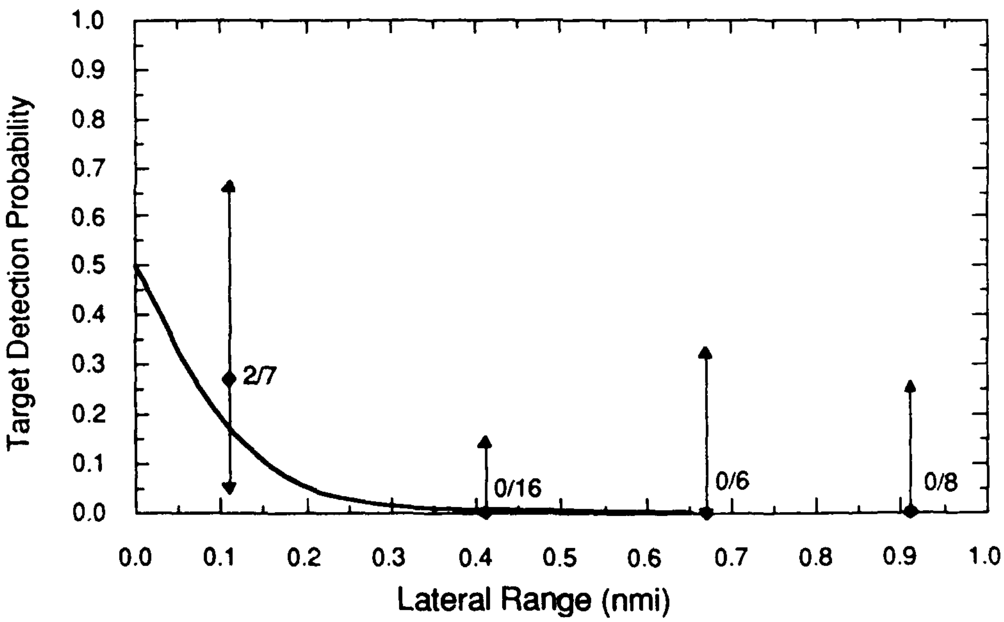
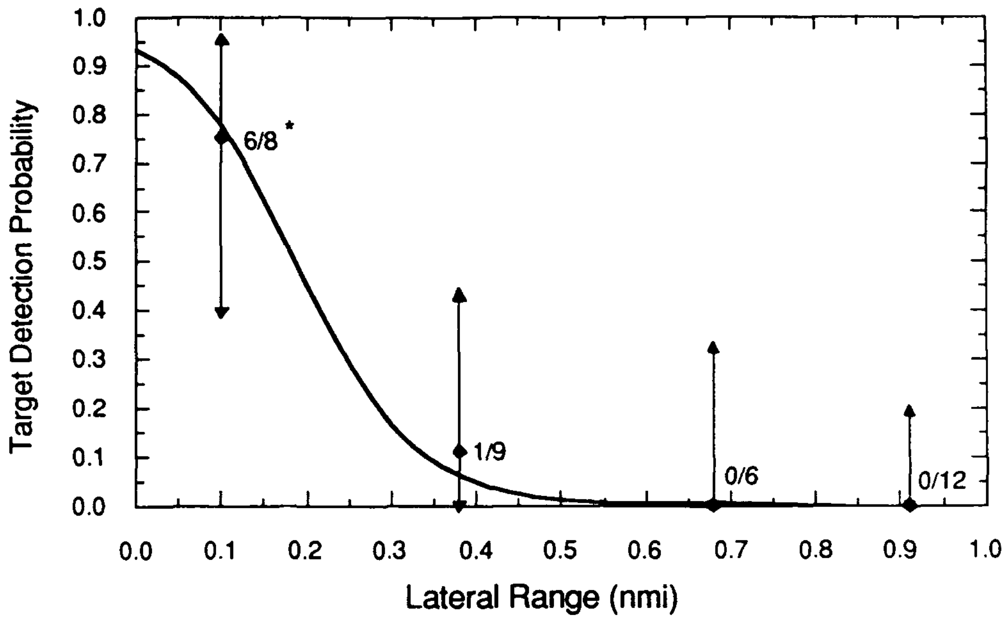


Figure 2-9. UTB Detection of 18-Foot Boats (H_S = 2.0 to 3.0 feet)



* includes one detection by collision

Figure 2-10. UTB Detection of 21-Foot Boats (H_S = 2.0 to 3.3 feet)

those depicted earlier in figures 2-1 through 2-8. Consequently, the UTB/small boat sweep width estimates provided here are less certain than those provided for the other SRU/target-type combinations tested.

2.2.2.4 Strobe Light Targets

Only 12 detection opportunities were generated by UTBs searching for strobe light targets. These opportunities occurred at lateral ranges from 0.2 to 0.6 nmi. Poor visibility and moderate seas caused early termination of UTB data collection on the sole night that strobe light targets were deployed. Only 2 of the 12 target detection opportunities resulted in a detection. The detections were made at lateral ranges of 0.2 and 0.5 nmi.

2.3 HUMAN FACTORS

The next four sections provide information that relates to the human factors aspects of conducting NVG-assisted searches in the marine environment. Section 2.3.1 provides quantitative data on where and from what crew positions NVG detections were made. Section 2.3.2 provides quantitative data on NVG detection performance as a function of time on the search task. Sections 2.3.3 and 2.3.4 summarize subjective comments and observations made by the SRU crews and members of the R&D Center test team.

2.3.1 Analysis of Detection by Position

Figure 2-11 depicts the distribution of target detections by helicopter SRUs. This information is provided by target type in the first four diagram pairs and for all helicopter detections combined in the fifth diagram pair. The circular diagrams on the left side of figure 2-11 show the distribution of initial target detections as a function of relative bearing (expressed in "clock" format). This information is independent of which crew position actually made the detection. The silhouette diagrams on the right side of figure 2-11 show the distribution of initial target detections as a function of the five crew positions onboard the HH-3 and CH-3 helicopters. The information in the silhouette diagrams is independent of the clock bearings at which the targets were initially sighted.

The information in figure 2-11 indicates that the copilot position (left seat) made nearly twice as many detections as the pilot position (right seat). This occurred even though the two pilots usually switched seats between sorties or on alternate nights. During many searches, the aircraft was even flown from the copilot seat for significant periods of time. This difference in the number of detections made by the two pilot positions is consistent across all four target types, and suggests a degradation in search capability that results from constant scan-shifting by the pilot between NVGs outside the cockpit and unaided vision inside the cockpit.

In the aft section of the helicopter, the flight engineer, who usually searches through an open door with a wide field of view and no glass to reflect light, made more detections overall than either the rescue swimmer position or the avionics position. The rescue swimmer position, which was not equipped with a seat on two of the three test helicopters, made substantially fewer

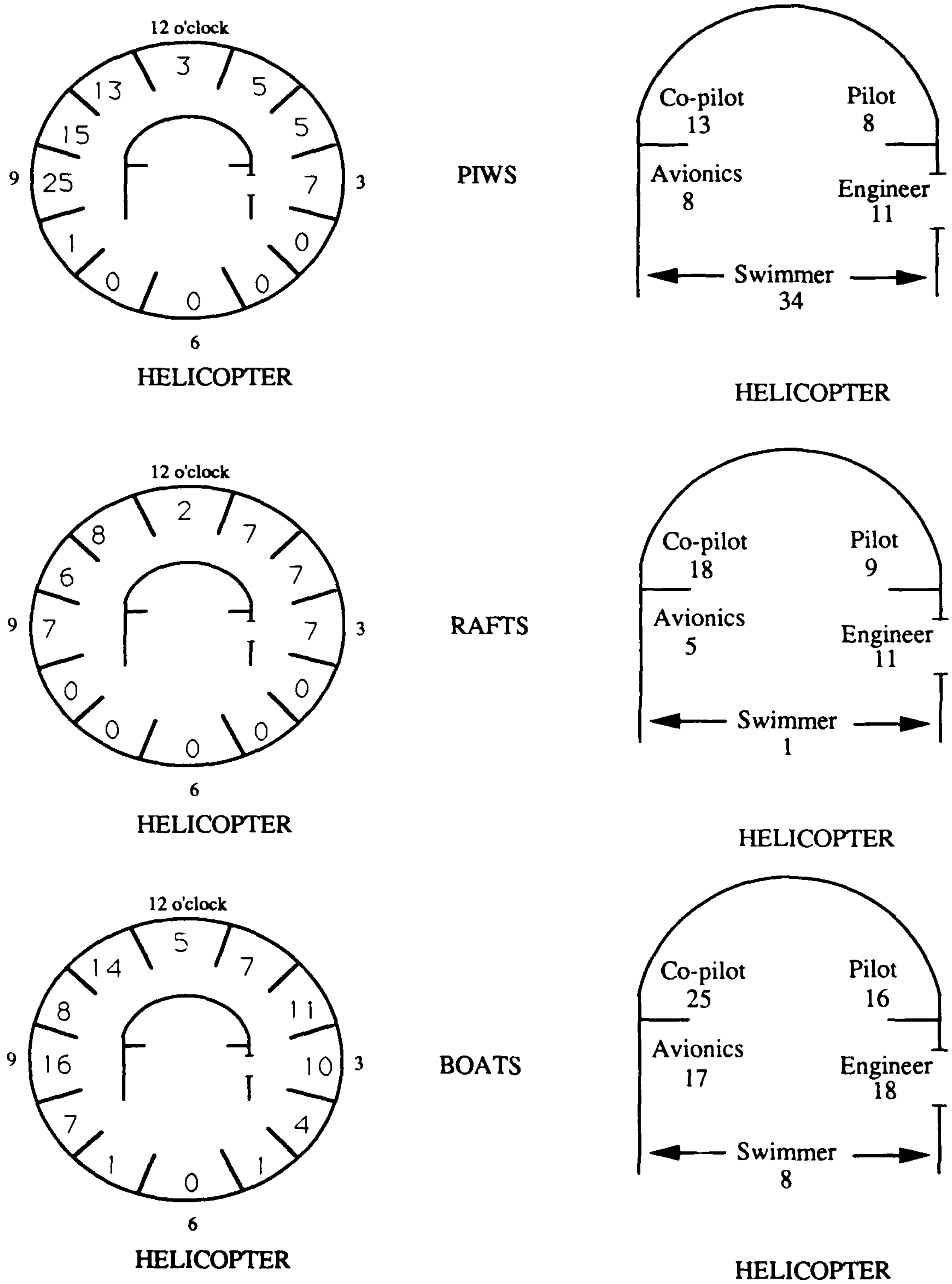


Figure 2-11. Distribution of Helicopter Detections by Clock Bearing and Crew Position
(Sheet 1 of 2)

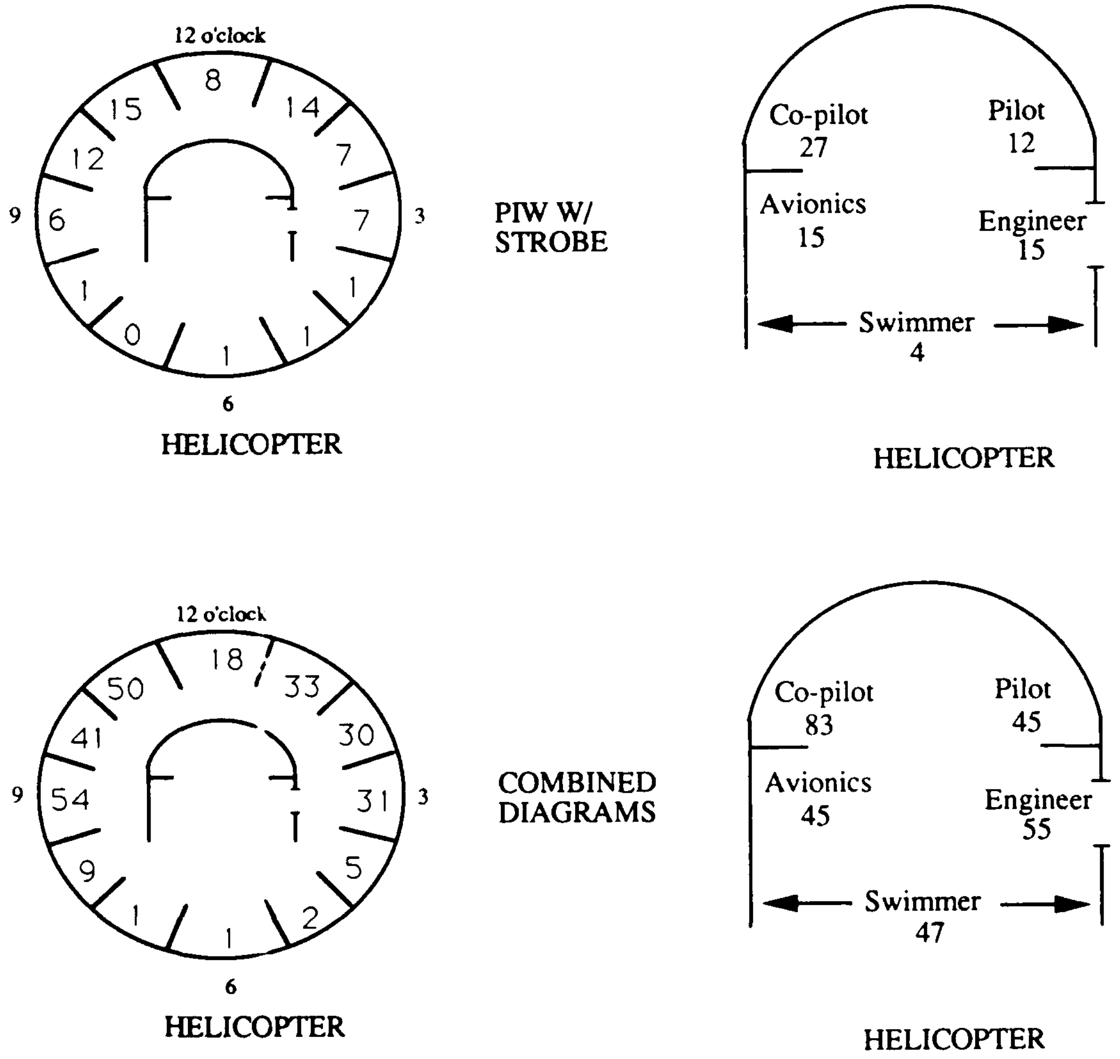


Figure 2-11. Distribution of Helicopter Detections by Clock Bearing and Crew Position
(Sheet 2 of 2)

detections than any other crew position except with the PIW targets. The PIW data may be skewed by a senior enlisted crewmember at the rescue swimmer position who displayed an exceptional ability to detect the retroreflective tape on these targets. This individual was credited with 17 of 29 total PIW detections made by the helicopter crew one night.

The clock-bearing data in figure 2-11 indicate that most helicopter detections were made between 9 and 11 o'clock on the port side and between 1 and 3 o'clock on the starboard side. A pronounced dip in detections consistently occurred dead-ahead of the aircraft.

Figure 2-12 depicts the distribution of detections for UTB SRUs. Unlike the helicopters, not all crew positions depicted on the UTB silhouette diagrams were always manned. The UTBs typically searched with two NVG-equipped lookouts who positioned themselves on the port and starboard bow when seas were calm and the weather was warm. When spray and/or cold wind was prevalent, the lookouts took shelter behind the wheelhouse at the port and starboard aft positions. The forward and aft center positions were seldom manned unless three or more NVG-equipped lookouts were available or only a single lookout was searching with NVG. All helm detections were made with the naked eye.

The clock-bearing data in figure 2-11 indicate that most UTB detections were made between 9 and 10 o'clock on the port side and between 2 and 3 o'clock on the starboard side. Comparison of the composite clock bearing and silhouette data indicates that the starboard aft lookouts made substantially more detections than the port aft lookouts. This may be because the cabin door is directly adjacent to the port aft lookout position. The open door may have allowed more light to interfere with NVG operation and more distraction of the port aft lookout due to conversations with personnel inside the wheelhouse.

2.3.2 Time on Task Effects

In light of the many comments by SRU crewmembers concerning eye fatigue, headaches, and other physical discomfort related to NVG use, it was surprising that time on the search task was not found during LOGIT analysis to exert a statistically significant effect on target detection probability. To confirm this result, the raw data for each SRU/target type combination were sorted into 1-hour time on task bins and plotted. These plots of target detection probability versus time on task are shown in figures 2-13 through 2-19.

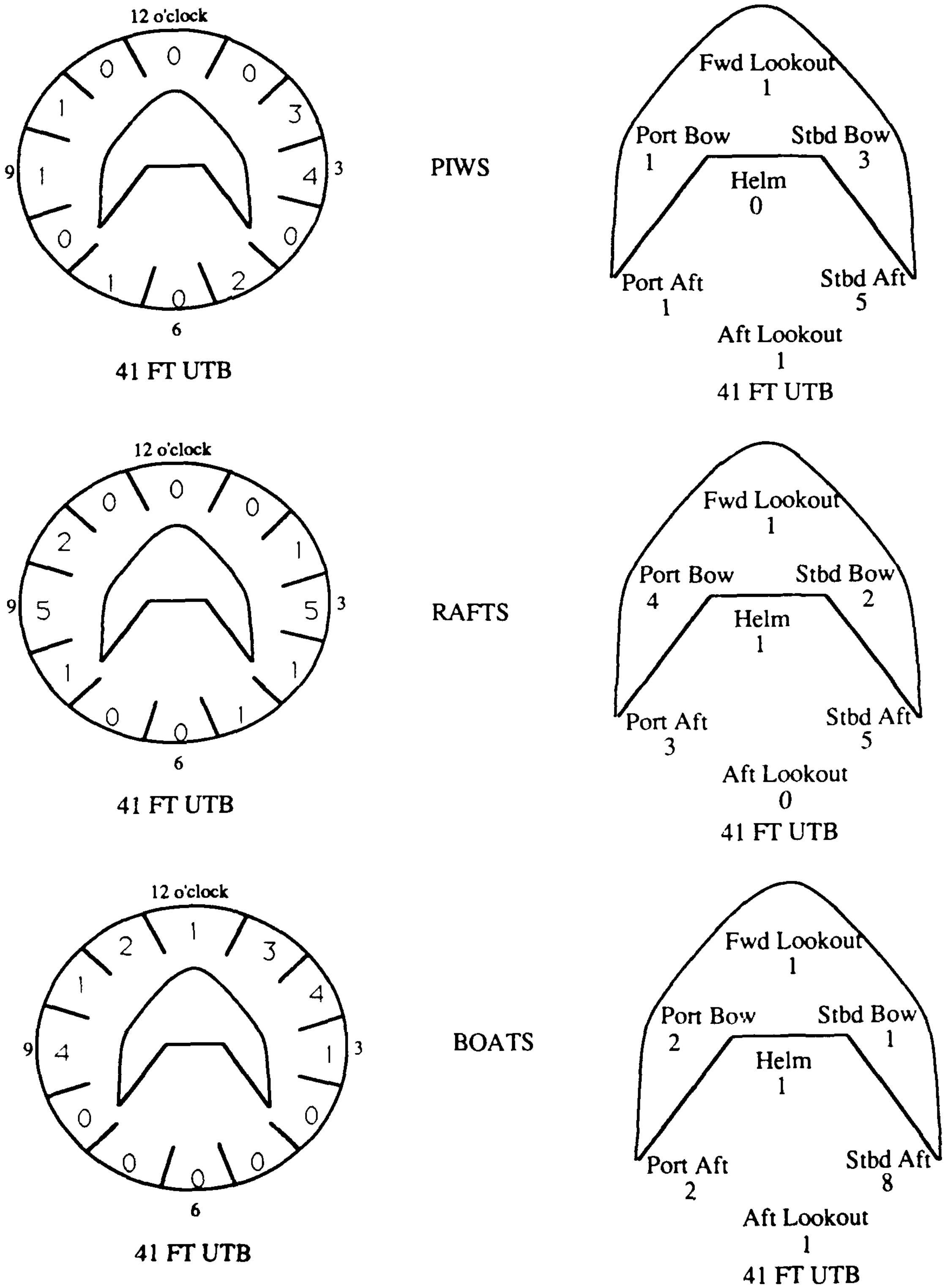


Figure 2-12. Distribution of UTB Detections by Clock Bearing and Crew Position
(Sheet 1 of 2)

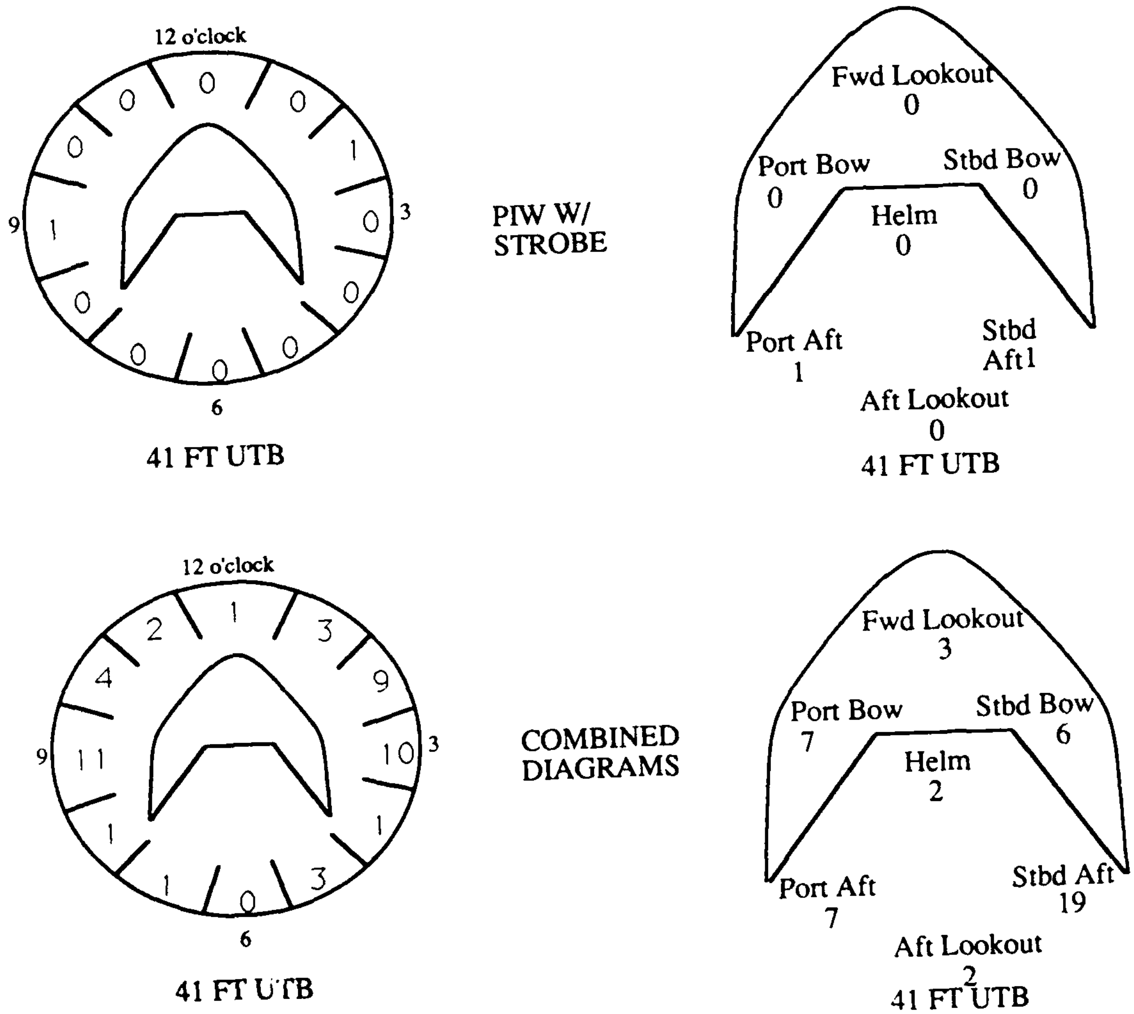


Figure 2-12. Distribution of UTB Detections by Clock Bearing and Crew Position
(Sheet 2 of 2)

Figures 2-13 through 2-19 show only slight variations in target detection probability with time on task. No consistent trend among the seven data sets is evident from inspection of the plots, although a few (such as figures 2-13 and 2-19) actually show a very slight upward trend in detection performance as time on task increases.

In the case of helicopter SRUs, the refueling breaks that were usually taken after 3 to 4 hours of searching may have mitigated crew fatigue enough to maintain search performance levels. These breaks typically lasted from 30 to 60 minutes. As for the UTBs, data collected at time on task levels greater than 4 to 5 hours were dominated by seas less than 2.5 feet and excellent visibility whereas a greater variety of environmental conditions are represented at time on task levels less than 4 hours. This occurred because UTB crews usually felt unable to continue NVG searches after 2 to 4 hours on scene in seas greater than 2.5 feet. This bias in the data had no clear effect on the time on task versus target detection probability relationship for UTBs, however. While figure 2-19 shows a brief improvement in small boat detection probability after 4 hours, figure 2-18 shows no life raft detections after 4 hours.

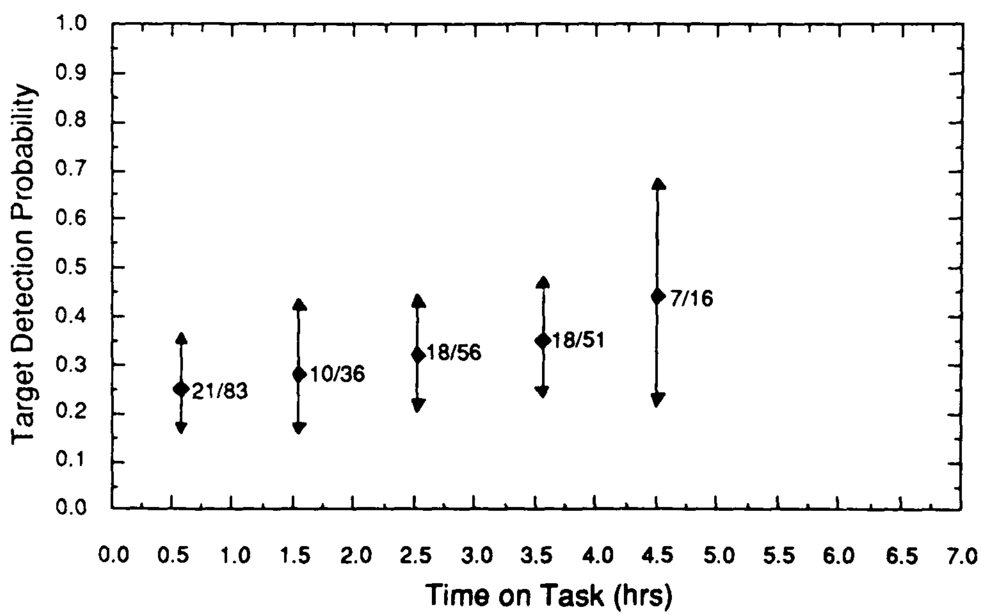


Figure 2-13. Effect of Time on Task on Helicopter Detection of PIWs

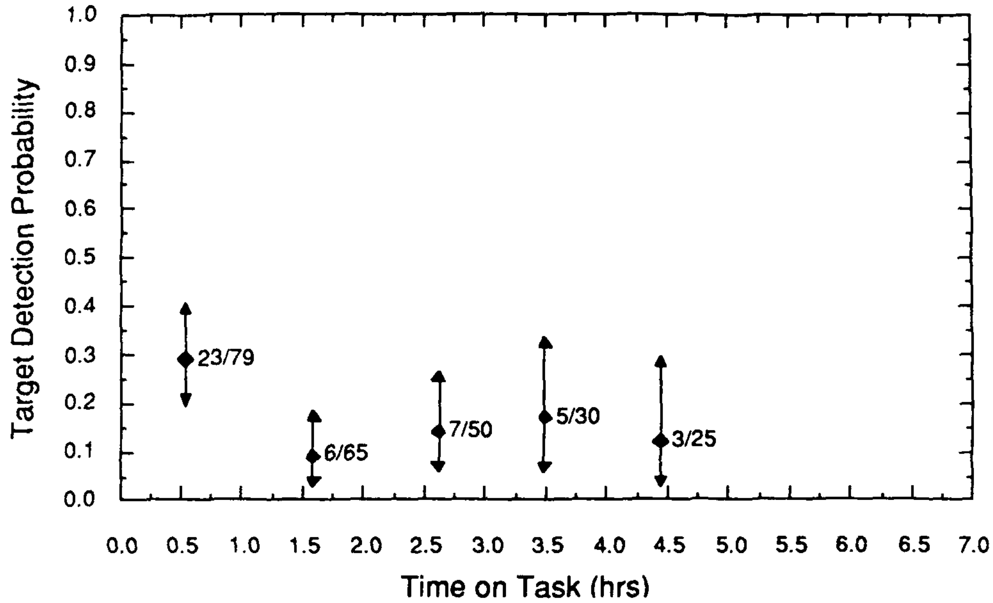


Figure 2-14. Effect of Time on Task on Helicopter Detection of Life Rafts

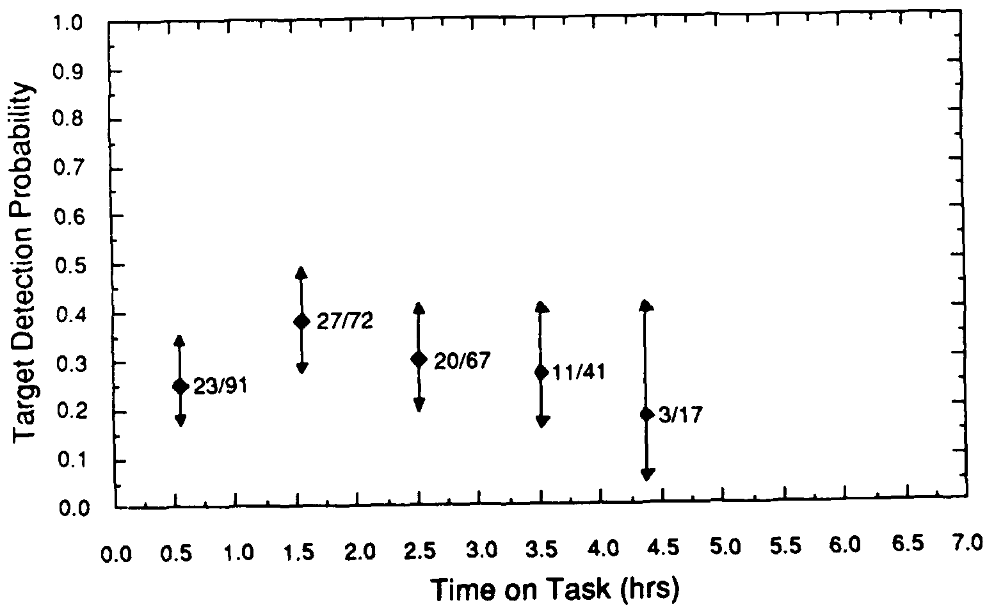


Figure 2-15. Effect of Time on Task on Helicopter Detection of 18- and 21-Foot Boats

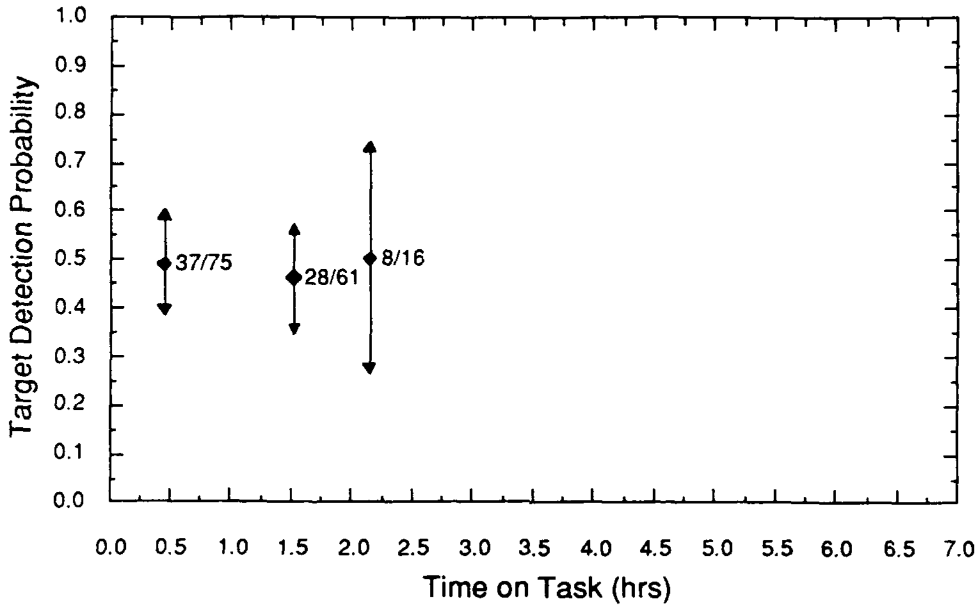


Figure 2-16. Effect of Time on Task on Helicopter Detection of Strobe Lights

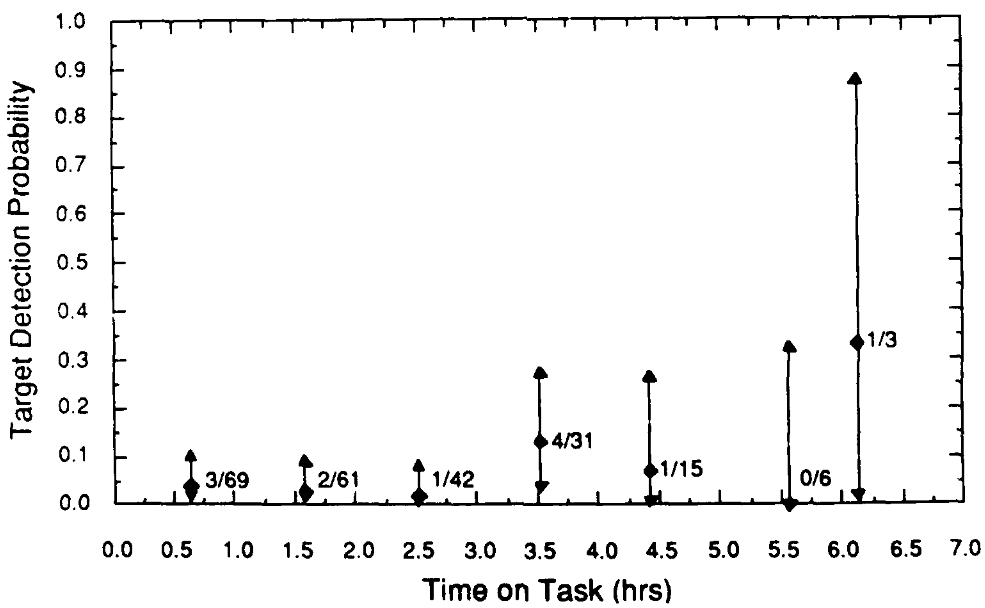


Figure 2-17. Effect of Time on Task on UTB Detection of PIWs

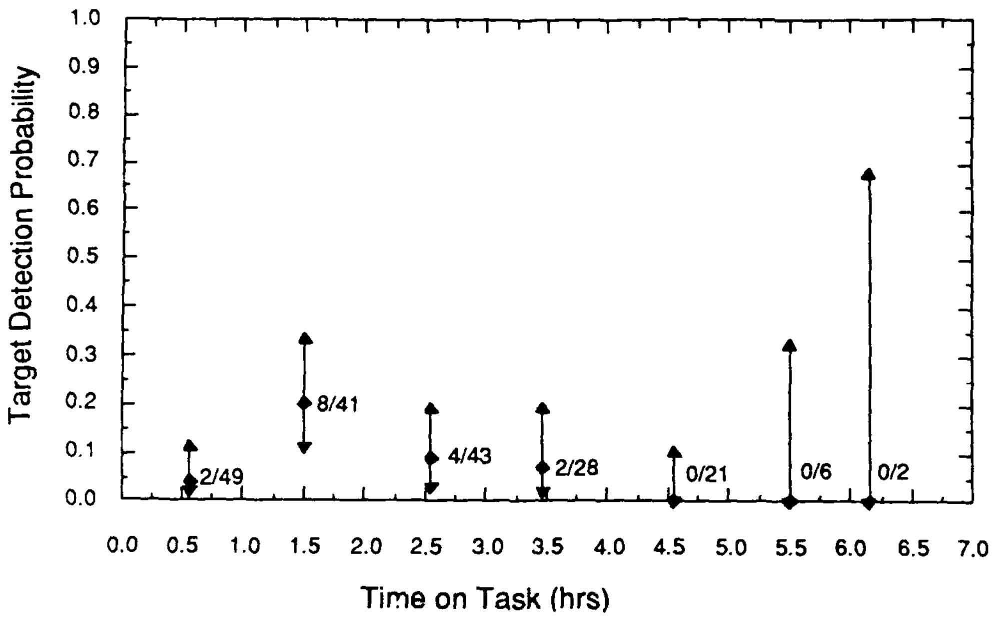


Figure 2-18. Effect of Time on Task on UTB Detection of Life Rafts

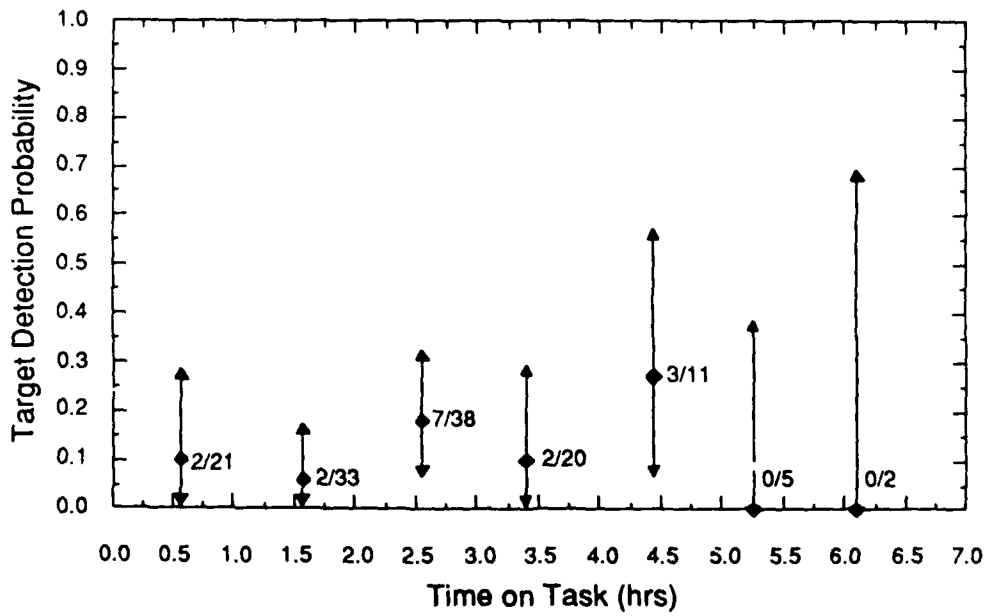


Figure 2-19. Effect of Time on Task on UTB Detection of 18- and 21-Foot Boats

2.3.3 SRU Crew Comments Concerning NVG Use and Target Appearance

Subjective comments from the SRU crews concerning the comfort, ease-of-use, and effectiveness of the NVGs and their suitability for Coast Guard SAR operations were solicited each night by the data recorders. References 5 and 6 contain verbatim lists of the comments received during the spring and fall experiments, respectively. A condensed summation of these comments is provided below.

Helicopter Crews

1. A low moon inhibited the lookouts' ability to detect small targets much like the sun does during daylight searches. Even a partial moon is a blinding light source when viewed through the NVGs.

2. NVGs appeared to perform better when looking toward shore.

3. Light sources, either from inside the helicopter or shore lights shining through a window or door on the other side of the aircraft, created glare on the inside surfaces of the window glass. Perhaps the inside surfaces of the windows should be coated with anti-glare materials much like the outside of the windows.

4. In periods of low ambient light, there was difficulty seeing outside the helicopter. The NVG display was black or grainy and the instruments created too much glare on the windows. Also, outside the aircraft, the rotating beacon became more visible. This was more of a problem in fog or haze than on clear nights.

5. Complaints of eye strain were common, especially after long sorties. Even 5-minute breaks seemed to help. Also, as the searches progressed, crews reported that goggle focus appeared to wander. After several hours, many crewmembers reported being unable to bring the NVGs back into focus.

6. Crews that were given the opportunity to view a target with the NVGs before commencing searches felt that it helped them by familiarizing them with what to look for.

7. Some crews felt that it was helpful to fly near the shoreline and refocus the NVGs between searches.

UTB Crews

1. Goggles were easier to focus in good light conditions, the visual presentation was better, and it was easier to maintain concentration. Lookouts found that, in lower light levels, concentrating on whitecaps helped keep them from simply staring at the display lens.

2. Coxswains and helmsmen preferred not using NVGs because they felt it interfered with their job of navigating the boat. Some coxswains felt that keeping a pair of NVGs at hand to check lookout reports was a good idea while others felt that the goggles didn't provide any more information than radar.

3. There were many variations of "my eyes are tired." Typically after an hour, lookouts reported tired/sore/watery eyes and after about two hours, they reported headaches and disorientation. Short breaks and lookout rotation appeared to help alleviate some of these problems.

4. Some lookouts, even those not normally prone to it, became seasick very easily while using NVGs. This occurred more often as seas became rougher and occasionally UTBs returned to port because of crew seasickness.

5. There were many complaints that the PVS-5 and PVS-7 head gear was very uncomfortable and that the goggles pressed on the face, but later in the searches, there were fewer complaints of this nature.

6. Looking at brighter shore lights reduced the effectiveness of the goggles. Often these lights would obscure up to half the distance from the horizon.

7. When sea conditions and sea spray forced lookouts behind the pilot house, the intensity of the running lights or stern light and their glare obscured or partially obscured the view through the NVGs. This left a fairly narrow sector abeam for effective searching.

8. Lighted objects could be easily seen on clear nights even when not visible to the naked eye.

9. Crews that were given the opportunity to view a target with the NVG before commencing searches felt that it helped them by familiarizing them with what to look for.

10. Plenty of lens cleaning paper was needed when spray or precipitation was present. Frequent breaks should be taken to rest eyes and clean lenses.

SRU crewmembers were also encouraged to provide descriptions of target appearance when detections were made. These target descriptions are listed in table 2-3 by SRU and target type. The descriptions appear in the table in descending order of frequency for each SRU/target type combination.

Table 2-3. Summary of Target Appearance Descriptions

SRU TYPE	TARGET TYPE		
	PIWs	RAFTS	BOATS
Helicopters	Flash/glow Bright/white/light Reflective tape Bucket Person/head Not bright	Raft Bright/white/light blob Light W/ dark bottom Black	Boat/Skiff Bright/white/light Black/dark Boat w/ canvas Raft-maybe boat White w/ dark bottom
UTB	Person/head Bucket	Raft Black Light w/ dark bottom Bright/white/light blob	Bright/white/light Boat/skiff Black/dark Boat w/ canvas Could not tell/something Greenish Dingy capsized

2.3.4 Test Team Observations Concerning NVG Use

Data recorders who accompanied the SRU crews on the NVG searches logged subjective comments as time and opportunity permitted. These comments were sometimes similar in nature to comments received directly from the SRU crews, but were made from a third-party viewpoint while not directly involved in the NVG search task. All data recorders were familiar with NVG characteristics and principles of operation. Some of the data recorders also had at least an hour or two of experience using the NVGs while underway onboard an SRU or workboat. Data recorder comments are synopsized below.

Helicopter Observations

1. Cockpit workload drew the pilot and/or copilot off NVGs frequently for communications, instrument scans and navigation computer adjustments. These distractions were usually brief, but occurred frequently. Coverage of the search area with NVGs was probably less thorough than with daytime visual search due to this frequent scan shifting without benefit of peripheral vision outside the cockpit.

2. Helicopter crews seemed well trained on NVG use and most maintained good scanning technique until late in the sortie.

3. Helicopter crewmembers, particularly those at the pilot, co-pilot and avionics positions, noticed glare from light shinning off the inside of the windows. Whether the light source was from inside the helicopter, or external light shining into the helicopter, it hampered NVG search efforts.

UTB Observations

1. Weather and sea conditions greatly affected searcher attitudes onboard the UTBs. Moderate sea swell or wind chop and/or poor ambient light brought on frequent instances of sea sickness and lack of enthusiasm for NVG use among the crews. Several crews were very positive about NVG testing when calm seas and good ambient light prevailed.

2. Crews consistently complained about soreness in their eyes and headaches when using the NVGs and some crews began experimenting with ways of relieving eye strain. These included using the goggles in a hand-held mode and occasionally searching without NVGs, sitting on the deck and supporting the goggles with their hands, laying on the deck, and taking frequent short breaks. These methods appeared to ease crew discomfort somewhat.

3. Some nights, radar detected targets that could be found with a search light, but not with goggles. Even when NVG-equipped lookouts were notified that radar had a target in a certain area, they often were unable to locate it whereas the coxswain using the search light could. (The majority of this type of incident occurred on darker nights when NVG performance was marginal.)

4. Boat crews achieved consistently poorer detection results than did helicopter crews, and this lack of success with the NVGs was reflected in crew attitudes and motivation during the later stages of the experiments.

5. The level of the UTB crews' knowledge and training relative to the use and care of the NVG systems was much more varied than with the helicopter crews.

6. UTB crews would likely benefit from a helmet-mounted NVG arrangement that allows for non-NVG peripheral vision and provides for flipping the goggles up and away from the face while performing engineering checks, navigation chores, radar scans, and other non-search duties.

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CHAPTER 3
CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

The following conclusions are based on the quantitative data analyses and subjective comments provided in chapter 2.

3.1.1 Search Performance of NVG-Equipped Helicopters

1. The HH-3 and CH-3 helicopter crews achieved detection probabilities against PIW targets that were comparable to those found for daylight visual searches during earlier R&D Center research (see references 7 and 8). The detectability of these targets was clearly enhanced by retroreflective tape on the PFDs. The tape reflected shore lights and/or the helicopters' anticollision lights to produce flashes that were very distinct when viewed with the ANVIS NVGs.

2. The helicopter crews achieved no better detection performance against 4- and 6-person life rafts than they did against PIW targets. Although much larger than the PIWs, the rafts were not equipped with reflective tape and were difficult to spot, especially when viewed against a lighted background or in low ambient light conditions.

3. The helicopter crews performed best against the 18- and 21-foot boat targets. Detection performance varied with visibility, H_S, and the visibility of the moon. Detection performance, as measured by sweep width, was about one-fourth of comparable daytime visual search levels.

4. Although search conditions were seldom ideal in terms of ambient light and sea conditions, the helicopters were able to mount viable search efforts against all three unlighted target types.

5. One NVG-equipped helicopter crew achieved excellent search performance against strobe light targets under adverse search conditions. The sweep width achieved with NVGs in 2- to 4-nmi visibility was comparable to values reported in reference 13 for non-NVG searches for more powerful strobes in 5- to 20-nmi visibility.

6. Glare from interior and exterior lights on helicopter windows is a constant problem, especially on dark nights. On hazy or foggy nights, reflections from the helicopters' exterior anticollision lights become troublesome.

3.1.2 Search Performance of NVG-Equipped UTBs

1. The NVG-equipped UTBs achieved only marginal detection performance against the PIW targets. Even when the targets passed close-aboard (0 lateral range), only one-third (5 out of 15) were detected.

2. Detection performance against the life raft targets, as measured by sweep width, was no more than one-tenth of comparable daylight visual search levels.

3. The UTB crews performed best against the 18- and 21-foot boat targets. Detection performance varied with H_S and target boat size. Detection performance, as measured by sweep width, was less than one-tenth of comparable daytime visual search levels against open, 18-foot targets and about one-fourth of the daytime levels against 21-foot targets with canvas.

4. NVG-equipped UTBs are only marginally capable of mounting a viable search effort against PIWs, life rafts, and open 18-foot boats. When 21-foot boat targets with erected canvas are the search object, a viable UTB search capability appears to exist when seas are less than 3 feet.

5. UTB crews are not capable of conducting effective NVG searches in seas greater than 2.5 to 3 feet. Platform motion, coupled with the narrow NVG field of view, consistently causes seasickness and disorientation. Furthermore, the effectiveness of the NVGs is inhibited by the constant presence of salt spray even when lookouts seek shelter behind the wheelhouse.

6. Wheelhouse lights and running lights cause a great deal of interference with the NVGs. Lookouts are often forced to search directly abeam in a narrow sector because of this problem.

3.1.3 General Conclusions

1. No obvious or consistent relationship between time on the search task and target detection probability was demonstrated in the test data. This result is surprising in light of the many SRU crew comments concerning eye fatigue and other forms of physical discomfort experienced while wearing NVGs.

2. Enhancement of small targets' light-reflecting capabilities (such as use of retroreflective tape) and use of a light source on the SRU that does not interfere with NVG operation (such as the helicopters' anticollision lights on clear nights), appears to provide a significant level of target detectability by NVGs.

3. Illumination of targets by a strobe light or similar device appears to provide a full order-of-magnitude improvement in target detectability by NVGs even when poor visibility exists.

3.2 RECOMMENDATIONS

The following interim recommendations are offered concerning the employment, use, and further evaluation of NVGs in the Coast Guard SAR mission. These recommendations are based primarily on the quantitative data analyses and qualitative observations provided in this report. Consideration was also given to additional inputs provided by SRU crews, other Coast Guard sources, and Department of Defense (DoD) night vision experts.

3.2.1 NVG Searches with Helicopters

1. Pending additional data collection, the following guidelines should be applied when estimating sweep widths for night SAR missions by NVG-equipped helicopters.

Daylight visual sweep widths are tabulated in reference 7. Fatigue, weather, and speed corrections listed in reference 7 are not to be applied unless specifically listed.

a. PIW Targets with Retroreflective Material on PFD. The daylight visual sweep width for PFD-equipped PIWs and search altitudes up to 500 feet (0.4 nmi) should be used.

b. 4- to 6-Person, Canopied Life Raft Targets Without Retroreflective Material. Multiply the daylight visual sweep width, corrected for weather only, by 0.25.

c. Boat Targets Less Than 25 Feet - Seas < 3 Feet and Moon Visible. Multiply the uncorrected daylight visual sweep width by 0.25.

d. Boat Targets Less Than 25 Feet - Seas < 3 Feet and Moon Not Visible. Multiply the uncorrected daylight visual sweep width by 0.20.

e. Strobe Lifejacket Light. The sweep width listed in reference 7 for this target may be used when visibility is 2 nmi or greater.

2. Ongoing efforts to reduce glare from crew clothing and light reflections on helicopter windows and instrument panels, especially reflections generated by internal lighting, should be pursued vigorously.

3.2.2 NVG Searches with UTBs

1. Pending additional data collection, the following guidelines should be applied when planning night SAR missions by NVG-equipped UTBs. Daylight visual sweep widths are tabulated in reference 7. Fatigue, weather, and speed corrections listed in reference 7 are not to be applied unless specifically listed.

a. PIW Targets With Retroreflective Material on PFD. NVG searches for these targets are not recommended.

b. 4- to 6-Person, Canopied Life Rafts Without Retroreflective Material. No quantitative recommendation is made pending additional data collection. Sweep width may attain practical values in calm, clear, moonlit conditions.

c. 18-Foot Open Boat Targets - Seas ≤ 3 Feet. No quantitative recommendation is made pending additional data collection. Sweep width may attain practical values in calm, clear, moonlit conditions.

d. 21-Foot Boat Targets with Cabin or Canvas Shelter - Seas ≤ 3 Feet. Multiply the corrected daylight visual sweep width by 0.25.

e. All Targets Less Than 25 Feet - Seas > 3 Feet. NVG searches by UTBs are not recommended under these conditions.

2. UTB crewmembers who are not equipped with NVGs should be instructed to search close-aboard the SRU and to direct NVG lookouts' attention to radar contacts at ranges less than 0.5 nmi.

3.2.3 General Recommendations

1. NVG-equipped SRUs should be launched promptly on night SAR cases to conduct a search before leeway and/or current drift expand the Desired Search Radius (R) to unacceptably large values. Searches at the relatively small W values characteristic of NVGs can still be valuable if they are conducted within a small, well-defined search area. Exceptions to this guidance are the situations listed in section 3.2.2 where NVG search is not recommended.

2. The Coast Guard should consider promoting regulatory action that would require application of retroreflective materials to non-commercial watercraft, life rafts, and PFDs. Guidance in the Safety of Life at Sea (SO'.AS) specifications on this subject appears to provide a good basis for developing such regulations.

3.2.4 Recommendations For Future Research

1. More NVG search performance data should be collected in clear, calm, moonlit conditions using unlighted PIW targets, life raft targets without retroreflective material, and small boat targets without retroreflective material.

2. The following additional data types should be collected in the near future to further evaluate NVG applicability to the SAR mission.

    a. Life raft targets with retroreflective material applied as recommended in the SOLAS specification.

    b. PIW targets with non-flashing chemical rescue lights attached.

    c. PFD strobe lights for detectability by UTBs.

    d. Larger surface SRUs such as Coast Guard WPBs as NVG search platforms, especially in seas $\geq$ 3 feet.

3. UTBs should be evaluated using four NVG lookouts on a 2-on/2-off rotation to alleviate fatigue and seasickness.

4. A hinged, NVG helmet-mount design should be developed for evaluation onboard small surface SRUs.

5. Sources of NVG-compatible target illumination should be evaluated on surface and air SRUs, particularly in conjunction with targets equipped with retroreflective material.

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