LOAN DOCUMENT

PHOTOGRAPH THIS SHEET

UNCLASSIFIED

DTIC ACCESSION NUMBER

LEVEL

INVENTORY

NRL Memo Report 1741

DOCUMENT IDENTIFICATION

DISTRIBUTION STATEMENT

Approved for public release
Distribution Unlimited

ACCESSION FOR
NTIS GRA&I
DTIC TRAC
UNANNOUNCED
JUSTIFICATION

BY
DISTRIBUTION/
AVAILABILITY CODES

DISTRIBUTION	AVAILABILITY AND/OR SPECIAL
A-1	

DISTRIBUTION STAMP

DATE ACCESSIONED

DATE RETURNED

19980410 135

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NUMBER

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC

DTIC FORM 70A JUN 90

DOCUMENT PROCESSING SHEET

PREVIOUS EDITIONS MAY BE USED UNTIL STOCK IS EXHAUSTED.

LOAN DOCUMENT

UNCLASSIFIED

HANDLE WITH CARE

[redacted]

[redacted]

1065

5539

NRL Memorandum Report 1741

Copy No. 30 of 60 Copies

[redacted]

A Preliminary Report on the Infrared Signatures of Ships

[Unclassified Title]

G. L. Harvey and T. H. Cosden

General Sciences Branch
Optical Physics Division

January 31, 1967

NAVAL RESEARCH LABORATORY
Washington, D.C.

[redacted]

[redacted]

[redacted]

[redacted]

CONTENTS

TABLES

FIGURES

[redacted]

[redacted]

ABSTRACT

Measurements of the infrared radiation in the 7.8 to 20 micron region from a number of military and commercial ships was made on three hazy days. Ranges varied from 2500 to 15,000 yards. No radiation could be detected at wavelengths of 1.73 - 3.33 microns, 3.3 to 4.2 microns or 2.3 to 5 microns.

PROBLEM STATUS

This is an interim progress report; work on this problem is continuing.

AUTHORIZATION

NRL Problem 73R02-47
Project Number SF-010-02-01-9292

[redacted]

[redacted]

A PRELIMINARY REPORT ON THE INFRARED SIGNATURES OF SHIPS

INTRODUCTION

This report describes infrared radiation measurements of ships of opportunity made from the Naval Ordnance Test Facility, Battery Worcester, Fort Story, Virginia.

The data were taken with a Barnes Radiometer Model 12-122 on 5, 6, 7 December 1966 during the hours 0715 and 1700. No data were taken after sunset since identification of targets could not be made.

Additional tests of a more detailed nature are planned in the near future.

The radiometer was located about 50 feet above sea level so that the distance to the horizon was 15,000 yards. Ships approaching from the south and southeast shipping lanes were viewed from a bow or slightly port aspect as they appeared on the horizon. Those approaching from the north were obscured by land until within a few thousand yards and were nearing a starboard broadside aspect as they approached the line of sight.

There was no direct sunshine during the three days; visibility was limited to 10 miles or less and at times the atmosphere was very hazy.

TARGETS

Military targets observed were the Destroyer 943, Coast Guard Cutter W165, Heavy Cruiser 1, LST 1160, Command Ship 2, Submarine 523, and Fleet Oiler 99. Commercial carriers were mainly freighters and cargo ships.

The Destroyer 943 Blandy is a "Forest Sherman Class" ship 418 feet long with two stacks and 2 steam turbines. The Coast Guard Cutter W165 was a small craft about 125 feet long. The Heavy Cruiser 1, Boston, is listed as a Guided Missile Cruiser, converted Baltimore Class with a single stack. The LST 1160, Traverse County, is 384 feet long with a single stack and four diesel engines. The Command Ship 2, Wright, is a former Aircraft Carrier (CVL). The fore funnel has been removed leaving three funnels. The Submarine 523, Grampus, is a "Tench" Class 311 feet

[redacted]

[redacted]

long built in 1944 and fitted with a snorkel. The Fleet Oiler 99 appeared to be a "T3-S2-A1" Type which is 525 feet long and has a single stack near the stern.

EQUIPMENT AND TEST PROCEDURES

The Barnes 12-122 Radiometer is a special model with optics similar to the present R8T1. The collecting system has an 8 inch diameter parabola with a thermistor bolometer at the focus. The bolometer window is KRS-5. The radiometer was modified because the ambient background signal drove the recorder below zero under most conditions. Also provision was made for changing optical filters.

The field of view is 6.9 milliradians square. Thus, at a range of 3000 yards the projected field of view is a square about 60 x 60 feet, or 300 x 300 feet at 15,000 yards.

Considerable noise was generated when the radiometer was trained over the sky or water. It would have been impossible to scan the radiometer over the target and distinguish between background signal and weak signals, hence the procedure used was to aim the radiometer in front of the target and allow the target to pass through the field of view, recording the differential signal during the passage. The training telescope was not sufficiently precise to determine the exact center of the field of view nor does it contain any marks to delineate the field of view. The radiometer was trained on the targets in such a manner that the stack was always included in the field of view. Under this condition the background was nearly always above the horizon. The background temperature did not differ greatly from that of the water since the atmosphere was so hazy that the sky was not actually seen.

The Radiometer was calibrated in the laboratory using an extended black body source at temperatures from 30 to 70 degrees Celsius. The reference temperature was 23 degrees. These temperatures are higher than the field operating temperatures but it would not be practical to attempt to calibrate the radiometer at a lower temperature. All of the temperatures are within a region where the response of the thermistor is nearly linear and no corrections are necessary.

[redacted]

[redacted]

DISCUSSION OF RESULTS

The following information is tabulated in Table 1: Column 1, Target; Column 2, Date and Time; Column 3, Range obtained with range finder or estimated from position of ship in shipping lane; Column 4, Recorded signal in volts; Column 5, the Electronic Temperature Offset, i.e., the voltage required to keep the recorder on scale (this was always positive during the tests); Column 6, the wavelength region; Column 7, the number of divisions on the sighting telescope from the horizon to the ship's water line; Column 8, the range obtained from Column 7; Column 9, the irradiance on the radiometer mirror from the target; Column 10, Comments on weather and targets.

The irradiance values are those measured by the radiometer and are not corrected for atmospheric transmission. The humidity during the tests varied from 60 to 81 percent and the air temperature from 6.6 to 12.5 degrees Celsius. The amount of precipitable water varied from 0.45 to 0.88 cm km^{-1}.

The range data in Table I are not complete since there were not enough hands available during the tests to keep complete records.

The data which were transcribed from the recorder traces are shown in Table I. No attempt was made to determine the ship speeds, but in general they appeared to be traveling at standard speed. The ranges quoted are not very accurate, having been arrived at by devious means. A telescope with a vertical reticle was used to determine ranges. The telescope was leveled and the horizon at 15,000 yards was used as a reference point. The reticle was then calibrated using known ranges to buoys which were taken from a chart. A leg of the telescope tripod was invariably kicked at a critical moment which accounts for missing ranges. A one-meter split-field range finder was also available but the accuracy was rather poor at the ranges required. The location of the shipping lanes on the chart also served as a reference.

Virtually all the data of Table I were taken using a filter with a band pass of from 7.8 to 20 microns. On three occasions other filters were tried with negative results. The other filters had band widths of 1-3 microns, 3-4 microns, and 2-5 microns. Without a filter the response of the instrument was about 0.7 - 20 microns. Essentially the same response was obtained

[redacted]

with the 7.8 - 20 micron filter as with no filter since the sky was overcast and there was no sunshine.

As seen from Table I a differential flux of 1.4×10^{-10} watts cm^{-2} was received from the Freighter Vilano in the 2-5 micron band at a range of 4500 yards. At a range of about 2500 yards the irradiance was 9.85×10^{-9} watts cm^{-2} in the 7.8 - 20 micron band. The minimum detectable irradiance with all four filters was the order of $1\text{-}2 \times 10^{-10}$ watts cm^{-2} with the climatic conditions existing at the time of the measurement and provided one knew that a target was present.

A few of the radiometric traces are shown in Figs. 1 - 4. Figure 1a shows an outline of the Boston and at 1b the corresponding radiometric trace at a range of about 2500 yards nearly broadside. Figure 1c shows the projected size and approximate location of the field of view. An electronic band width of 6 hz was used during this run. Most of the other runs were made with a band width (as stated by the manufacturer) of 1/4 hz. and show no high frequency noise. There was no discernible difference in the traces with either a 6 hz. or 1/4 hz. band width other than the elimination of the "grass" at the narrow band widths.

In Figs. 1 - 4, the scale divisions shown correspond to 1.4×10^{-9} watts cm^{-2}.

Figure 2a is a very crude sketch of the freighter, Globe Progress. Figure 2b is a radiometric trace at 8000 yards from a bow-port aspect. Figure 2c is the trace obtained at about 4000 yards as it neared a broadside aspect.

Figure 3a is the outline of the Command Ship, Boston. Figures 3b and 3c are the radiometric traces at ranges of 6 - 8,000 yards and 3,000 yards respectively. The squares on Figs. 3b and 3c show the approximate size of the projected field of view at these ranges.

Figure 4a is a crude sketch of the very large freighter, Amelia Grimalder. Figure 4b is the radiometric trace at a range of 2.5 - 3000 yards.

One might expect that at 4,000 yards the signal would be very much greater than at 8,000 yards rather than the small increase shown in Fig. 3. However, there are many factors to be

considered, such as the fact that the target does not fill the field of view in either case, corrections have not been made for atmospheric attenuation and the ship is not uniformly heated.

The true temperature of the targets cannot be determined from data observed because of the many unknown factors such as the emissivity, the size of the target area being viewed, temperature gradients of the target, and atmospheric attenuation. However, it is of interest to compute an "effective" temperature differential which would correspond to the temperature of a black body which fills the field of view of the radiometer and produces a signal equivalent to that of the target.

Some idea of the range of "effective" temperature differentials involved can be obtained by calculating the ΔT corresponding to one division on the recorder (see Fig. 1) and assuming the ship is a black body. The irradiance H at the radiometer is given by

$$H = \frac{\sigma \omega}{\pi} (T_1^4 - T_2^4)$$

where $\sigma = 5.669 \times 10^{-12}$ watts cm^{-2} deg^{-4}

ω = field of view, 4.7×10^{-5} steradians

T_1 = Temperature of black body, degrees K

T_2 = Temperature of background, degrees K

For small increments of T

$$\Delta H = \frac{4 \sigma \omega}{\pi} T^3 \Delta T$$

In this particular case the background temperature was not accurately known but fortunately an error of several degrees does not greatly affect the value of ΔT. Assuming a value for T of $10^{\circ}C$ (283° K) and solving for ΔT gives a value of $0.18^{\circ}C$. This is called an "effective" temperature since the stacks of ships are obviously much more than 0.18° above the background temperature but their areas are small compared to the total area being observed. This effective temperature is further modified by the emissivity of the ship and the intervening atmosphere.

SUMMARY AND CONCLUSIONS

On several dull hazy days the infrared radiation from ships in the 8 - 13 micron window could be measured at ranges up to 15,000 yards (the horizon distance). With more sensitive detectors radiation might possibly have been measured in the shorter wavelength windows.

The values of differential irradiance at the measurement site ranged from 10^{-8} watts cm^{-2} for large fighting ships and cruisers at 2,500 yards to 0.98×10^{-9} watts cm^{-2} for small 30 foot fishing boats at 1500 yards.

The measurements were made with a radiometer using a thermistor chopped at 40 hz. The noise equivalent power density with 1/4 hz band width was approximately 5×10^{-11} watts cm^{-2} and the noise equivalent temperature 3.5×10^{-3} C.

The S/N ratios are certainly large enough to permit infrared homing devices to track on all of the targets at useful ranges. However, it should be pointed out that the background was static during the measurements and had the background been scanned the S/N ratio would have been degraded.

Further measurements are recommended and planned under different climatic conditions, with different detectors and with efforts to evaluate the effect of scanning the background.

ACKNOWLEDGMENTS

These measurements would not have been possible without the help of the following whose assistance is gratefully acknowledged: Lt. W. C. Arnett, Officer in Charge, NOLTF, Fort Monroe, Virginia, and Mr. W. M. Pettit, Jr., who located the test site and arranged for its use; Mr. J. A. Curcio, who assisted with the collection of the data.

Table I
The Irradiance From Ships at 1500 to 15,000 Yards, December 5, 6, 7, 1966

Target	Date/Time	Range Yards	Signal	ETO	λ	Scope Div.	Range	H Irradiance Watts cm^{-2} x 10^{-9}	Comments
Esso Tanker	12-5-66/1520		.021x5		0.7-20			14.8	Hazy 0.7 cm km^{-1} H_2O
Esso Tanker		>10K	.025x2.5		7.8-20			8.8	Temperature: Wet bulb 45°F Dry bulb 48°F
Horizon & Sea			.015x2.5					5.27	Relative Humidity 80%
Va. Pilot	12-5-66	2500	.018			12	3500	2.53	
Va. Pilot			.02					2.8	
Cargo Ship	12-6-66/0730	10 - 15K	.01	.0007	7.8-20			1.4	Temp. $\frac{W38.5^{\circ}F}{D44}$
Cargo Ship			.015			14	3000	2.1	
Fishing Boat 3/4 bow 30-35' long	/0800	1K	.0175	.00125				2.46	R.H. = 60%
Va Pilot 3/4 stern		3200	.019	.00106		17	2500	2.68	0.45 cm km^{-1} H_2O
Va Pilot			.02			16	2700	2.8	
Destroyer #943		>10K	.003	.00106		4	5800	0.42	Approaching from S
Blandy			.0076			5	5500	1.07	
			.0146			6	5300	2.06	
			.02			10	4000	2.8	
			.037			20	2100	5.2	

(Table continues)

Table I (Continued)
The Irradiance From Ships at 1500 to 15,000 Yards, December 5, 6, 7, 1966

Target	Date/Time	Range Yards	Signal	ETO		Scope Div.	Range	H Irradiance Watts cm^{-2} x 10^{-9}	Comments
British (S) Freighter CAPTO		>15K	.001	.00098	7.8-10			0.14	
		15K	.0036	.00095		1	7 - 15K	.506	
			.02			14	3000	2.8	
Freighter			.017	.001		8	4500	2.4	
			.025	.00105		10	4000	3.5	
Amoco Tanker			.025					3.5	
			.025	.0011		9	4200	3.5	
Oil Tanker,		5000	.022					3.1	Stack
Freestate		5000	.007					.985	Midship
Coast Guard Cutter W165			.0125	.00118		13	3300	1.75	
Heavy Cruiser		12000	.01			1	7 - 15K	1.4	
Boston	/0925		.0125			2	6600	1.75	
			.016			3	6300	2.25	
		6000	.03			9 - 10	4000	4.22	
		3000	.07					9.85	Broadside
		2500	.082					11.5	
US Freighter,	/1510		.07	.0004	7.8-20	30		9.85	Stack
Vilano			.0012					1.7	Bow
			.001					1.4	Stern
Tanker			.028	.0012				3.94	Fwd wheelhouse
			.038					5.36	Stack
			.042					5.9	Broadside, two equal peaks
	12-7-66/0715			.0012					40% cloud coverage, clear
LST 1160	/0745	12K	.02	.00102				2.8	
Traverse County			.042			3	6300	5.9	
			.019			11	3700	2.68	

(Table continues)

Table I (Continued)
The Irradiance From Ships at 1500 to 15,000 Yards, December 5, 6, 7, 1966

	Date/Time	Range	Signal	ETO		Scope	Range	Irradiance	Comments
Freighter, NEGBA			.038					5.35	
Freighter (K)	/0820		.021	.001		10	4000	2.95	
Freighter, Norse		3000	.027					3.8	Temp 48.5°F = 9.2°C
Carrier, Oslo									
Freighter, Amelia Grimaldi		2500	.025					3.5	Bow 744'10" x 102'2"
			.025					3.5	Center
			.037					5.2	Stack
Surfaced Submarine		3000	.028	.00073				3.94	Hazy
Grampus 523									
Freighter, Japan Line	/1010	3000	.025					3.5	
Freighter, Vilano			0	.0004	3-4	12	3500		Very hazy
			0		1-3	10	4000		
			.001	.0006	2-5	8	4500	.14	Temp. W42°F / D47.5
			.007		.7-20			.95	
			.007	.0005	7.8 - 20			.95	W 5.5 °C / D8.6 °C
British Freighter			.065	.0011	7.8 - 20			9.15	R.H. = 64%
London			.055	.001		22	1850	7.75	0.5 cm km^{-1} H_2O
			.0465			18	2400	6.55	
			.037			14	3000	5.2	
American Export			.019	.0011		10	4000	2.68	Prop. out of water
			.022			14	3000	3.1	
Grain Ship (?)	/1642		.026					3.66	Temp. Air 44°F 6.6°C
Thorbjoro			.04					5.62	Angle 11 oclock
			.041	.00115				5.78	
			.04-.042					5.62-5.9	Stack only
			.008	.0015				1.13	Bow
			.035					4.92	Stack

(Table continues)

Table I (Continued)
The Irradiance From Ships at 1500 to 15,000 Yards, December 5, 6, 7, 1966

Target	Date/Time	Range	Signal	ETO		Scope	Range	Irradiance	Comments
Command Ship 2			.03	.00102				4.22	
Wright (Former Aircraft Carrier)		3000	.033					4.75	
		2500	.037					5.2	
French Freighter		6000	.037	.0014				5.2	
Halonia		5000	.047					6.6	
		4000	.05					7.4	
Cargo, Laponia	/1115		.037	.00165				5.2	
Stockholm		4-5K	.053	.00165				7.45	
Fleet Oiler, 99		10-12K	.02	.00171				2.8	Very hazy and increasing
	/1130		.028					5.25	Temp $\frac{49^\circ F}{52.5} = \frac{9.5^\circ C}{12.5}$ R.H. 81%
		4500	.05					7.04	$0.88\ cm\ km^{-1}\ H_2O$
Globe Progress	/1320	8000	.038	.0008				5.35	Wind 8-10 k
									Temp $\frac{W50^\circ F}{D54^\circ F} = \frac{10^\circ C}{12^\circ C}$
		5000	.058					8.15	
		4000	.065					9.15	Stack 571'9" x 75'3"
		4000	.059					8.2	Cabin
		2500	.082					11.05	R.H. = 76%
Fishing Boat, Black		1500	.007	.00092				.985	$0.8\ cm\ km^{-1}\ H_2O$
Fishing Boat, White		1500	.007					.985	

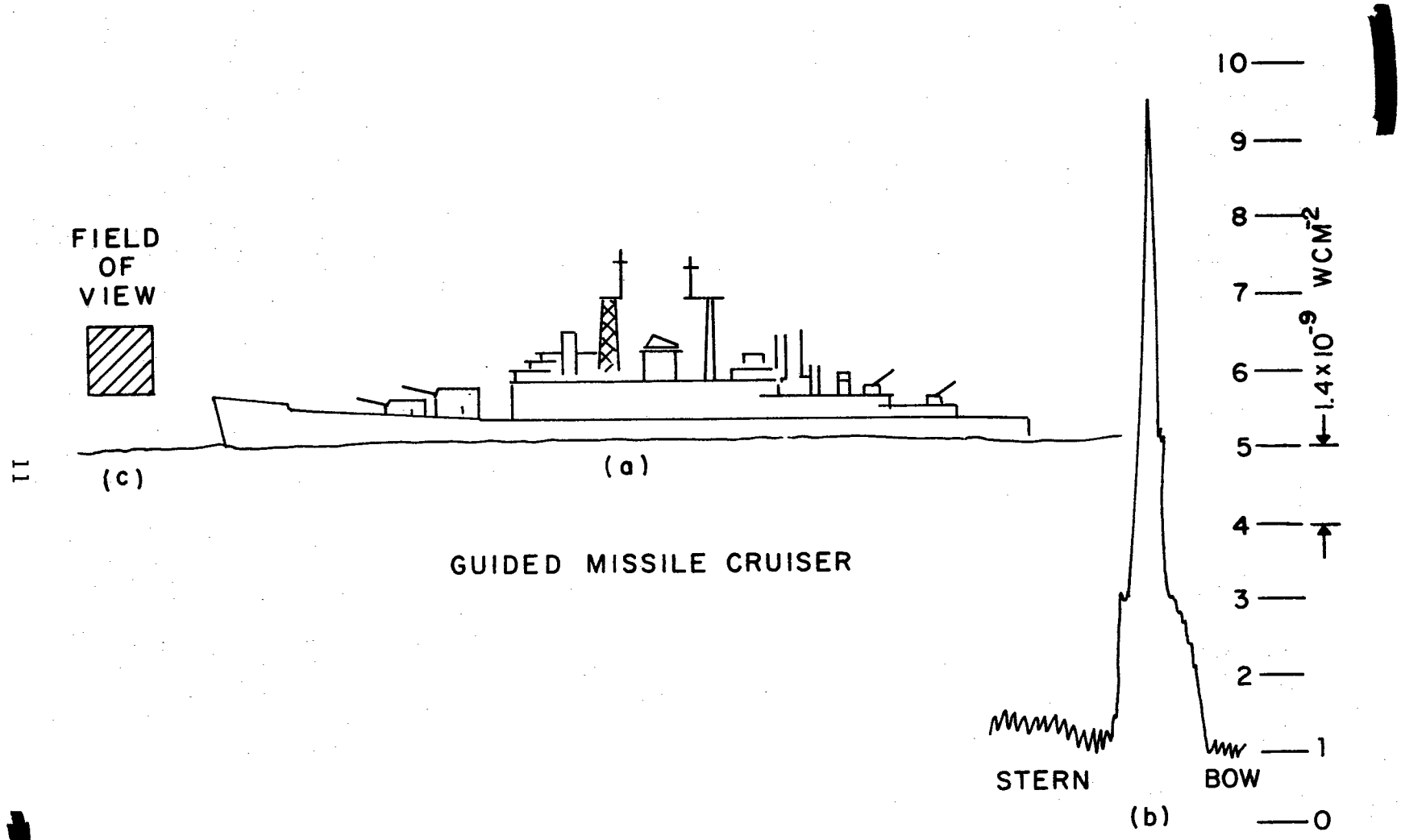

Figure 1

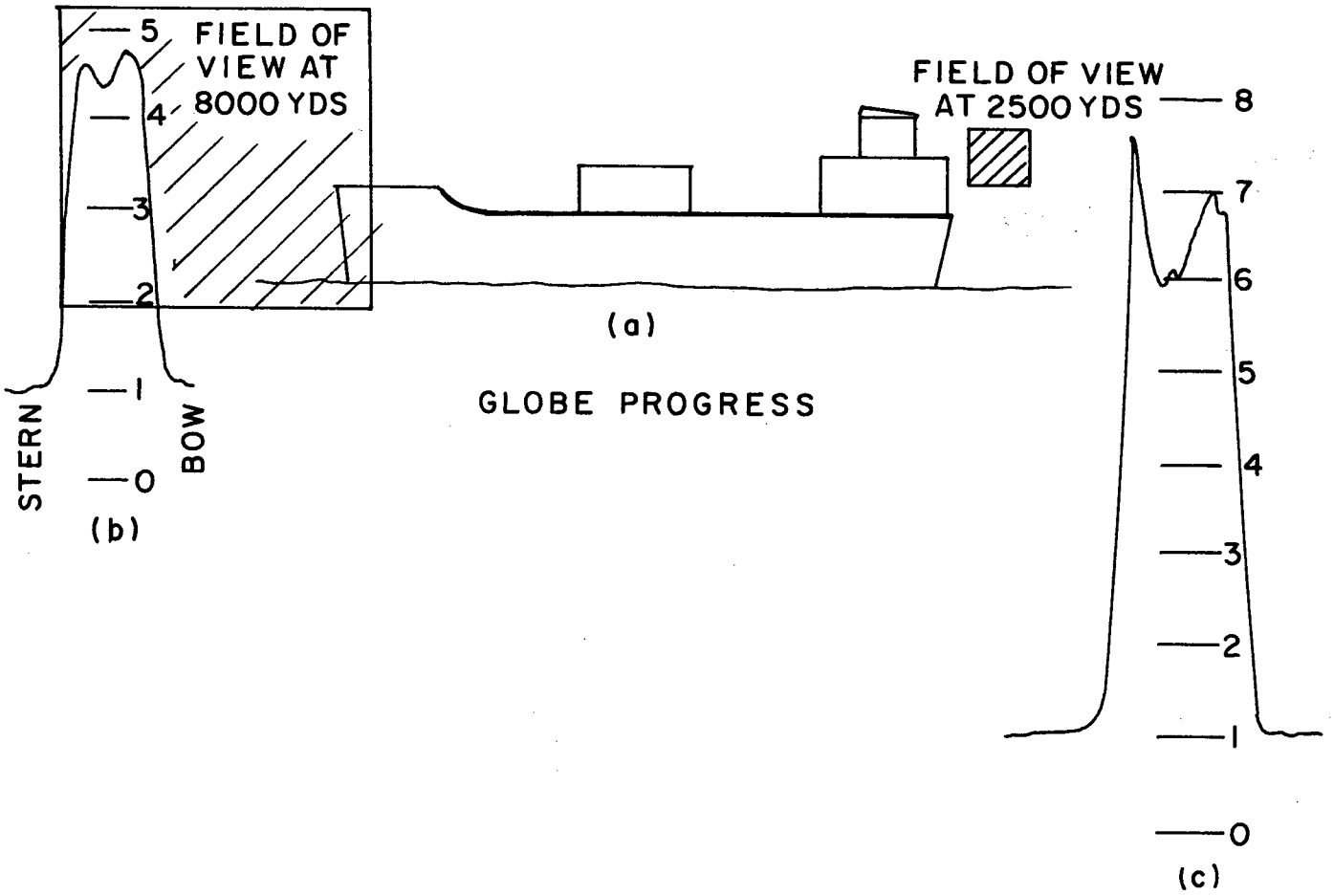
5
FIELD OF VIEW AT 8000 YDS
4
3
2
1
0
STERN
BOW
(b)
(a)
GLOBE PROGRESS
FIELD OF VIEW AT 2500 YDS
8
7
6
5
4
3
2
1
0
(c)

Figure 2

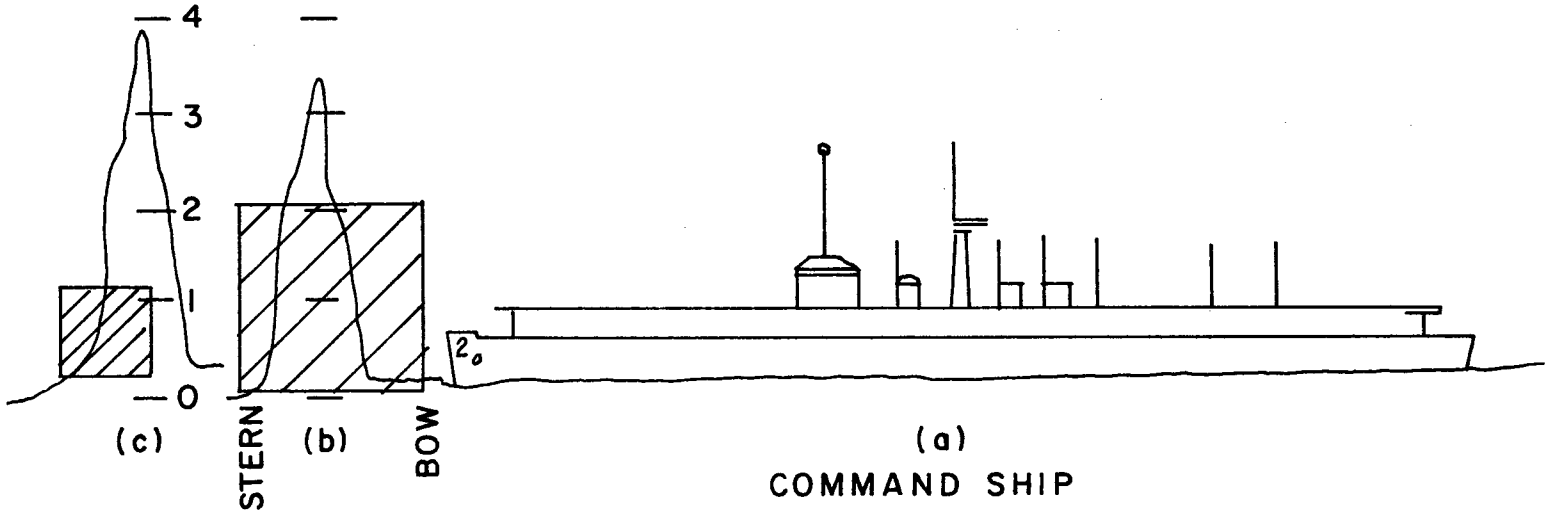

Figure 3

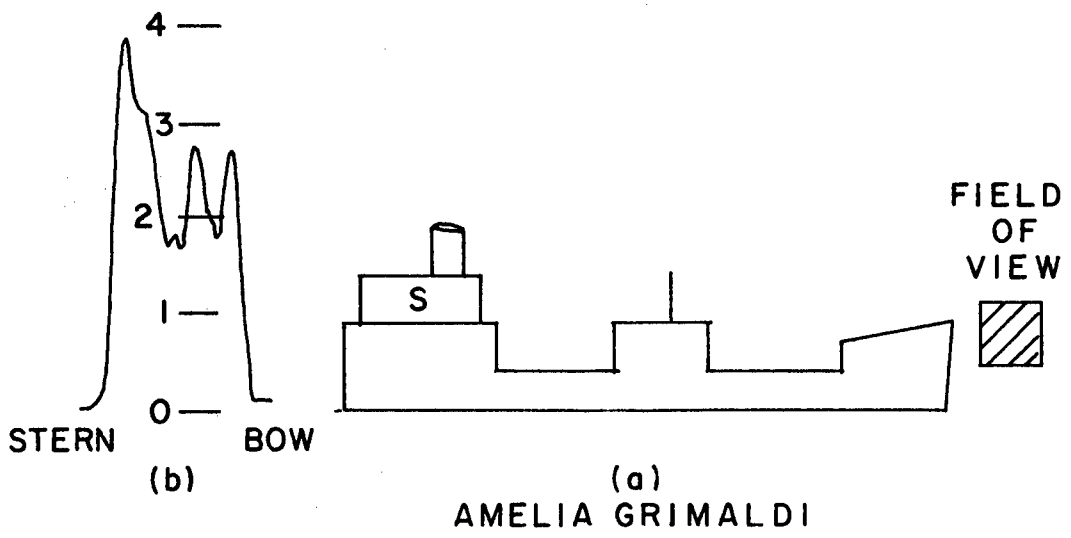

Figure 4