COPY 85

U.S. Naval Air Development Center

Johnsville, Pennsylvania

Anti-Submarine Warfare Laboratory

REPORT NO. NADC-AW-6421 27 AUG 1964

TECHNICAL NOTE

INFRARED RADIATION FROM SHIPS

WEPTASK NO. RUDC4B000/2021/WS-031

U. S. NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE, PENNSYLVANIA

Anti-Submarine Warfare Laboratory

REPORT NO. NADC-AW-6421 27 August 1964

TECHNICAL NOTE
INFRARED RADIATION FROM SHIPS

WEPTASK NO. RUDC4B000/2021/WS-031

This Technical Note is a transcript of a paper delivered by Mr. Joseph J. Pello at the Ninth National Infrared Information Symposium (IRIS), Dallas, Texas, 6-8 May 1963, and reprinted from the Proceedings of the Infrared Information Symposia, Volume 8, Number 3, August 1963.

Reported by: [redacted]
Special Methods Division

Approved by: [redacted]
for
Special Methods Division

[redacted]
Technical Director

INFRARED RADIATION FROM SHIPS

[redacted]
U. S. Naval Air Development Center
Johnsville, Pennsylvania

Infrared pictures of a variety of ships have been recorded by the Naval Air Development Center as by-products of an investigation of the capability of airborne, passive, infrared mapping devices for detecting effects produced on the surface of the water by submarines. These thermal pictures, which should be of value in the design of infrared-guided anti-ship missiles, provide semi-quantitative information on infrared radiation emitted as functions of position on the ships. Variations in the thermal appearance of ships as a function of season, time of day, and air-sea temperature differences are discussed. The application of airborne, passive, infrared mapping devices for nighttime tracking and partial classification of ships is demonstrated.

I. INTRODUCTION

The infrared radiation emitted from ships has been a natural object of military interests since World War II.[1] Recently, with the development of passive infrared-homing missiles and infrared devices capable of achieving high spatial and thermal resolution, this interest appears well justified.[2] During the past three years, studies of ship radiation characteristics have been sponsored by agencies of the United States[3] and Canada.[4] However, these studies were severely limited by the relatively low-information-rate infrared radiometers used.

The Naval Air Development Center (NAVAIRDEVCEN) has been conducting an investigation of the capability of airborne, passive, infrared mapping devices for detecting effects produced on the surface of the water by submarines. As by-products of this investigation, infrared pictures of submarines, ships, and many beautiful oceanographic and meteorological phenomena have been recorded.[5,6] This paper presents samples of thermal pictures which provide semi-quantitative information on infrared radiation emitted as functions of position on a variety of ships. These thermal pictures, which were recorded by an AN/AAD-2 infrared mapping set, demonstrate a number of military applications of airborne infrared devices.

II. AN/AAD-2 INFRARED MAPPING SET

The AN/AAD-2 is a small, lightweight, infrared mapping set developed by HRB-Singer, Inc.

[1] [redacted] "Final Report on Type L Nancy Equipment AN/ASQ-4(XN-2) and AN/ASA-5(XN-2)," Report No. R-0072, Naval Aircraft Modification Unit, Naval Air Development Center, Johnsville, Pennsylvania (7 March 1946) ~~(CONFIDENTIAL)~~.

[2] [redacted] "Feasibility of Infrared Terminal Guidance for Submarine Launched Anti-Ship Missiles," Report No. NADC-WR-6126, Naval Air Development Center, Johnsville, Pennsylvania, (July 1961) ~~(SECRET)~~.

[3] "Infrared Countermeasures Study," Final Engineering Report, Contract No. NObsr-72644, Melpar Inc., Falls Church, Virginia (July 1961) ~~(CONFIDENTIAL)~~.

[4] [redacted] "Infrared Characteristics of RCN Destroyer-Escorts," CARDE Report No. TR 413/62 Canadian Armament Research and Development Establishment, Valcartier, Quebec (July 1962) ~~(SECRET)~~.

[5] P. M. Moser, "Maritime Applications of Infrared Mapping Systems (U)," Proc. IRIS, Vol. 8, No. 1, pp. 147-162 (January 1963) ~~(SECRET)~~.

[6] P. M. Moser and [redacted] "Volume I, Atlas of Infrared Sea Background Patterns, 25 March 1959 to 28 March 1962," Report No. NADC-AW-6223, Naval Air Development Center, Johnsville, Pennsylvania (1 October 1962) ~~(CONFIDENTIAL)~~.

for the U. S. Army Electronic Proving Ground, Fort Huachuca, Arizona, for use in drone aircraft.[7] Figure 1 shows the AN/AAD-2 installed in the closed-off bomb bay of a P-2E (P2V-5F) aircraft.

The operation of the basic system is illustrated in Fig. 2. All objects radiate infrared energy at a rate dependent on their absolute temperatures. A small portion of the infrared radiation emitted by the objects under surveillance is intercepted by the scanner mirror, which is mounted on a rotating shaft whose axis is parallel to the flight path of the aircraft. As the scanner rotates, radiant energy from each object point along a line perpendicular to the flight path is sampled sequentially and focused by means of a parabolic mirror onto an infrared detector. In the detector an electrical signal proportional to the impinging infrared radiation is generated. This signal is amplified and passed on to a glow tube which emits light whose intensity is proportional to the electrical signal impressed upon it. Light from the glow tube is focused to a small spot by means of a microscopic objective, which is also mounted on the rotating shaft. The intensity-modulated spot of light scans, in synchronism with the scanner, across a piece of slowly advancing photographic film. As the aircraft advances, a wide-angle 120° field of view is swept out by the scanner and recorded on photographic film in the form of a continuous strip map.

III. INFRARED PICTURES OF SHIPS

In the following thermal pictures, warm objects appear light and cool objects appear dark. The angular width (vertical dimension) of each picture shown is approximately ~~28°~~ 56°. The spatial resolution of the system is a function of the detector size and is approximately six milliradians for a one-millimeter detector. In pictures showing a single ship with a hot stack, viewing angles are measured from the vertical up to the optical path to the hot stack of the ship. In pictures of more than one ship or of ships with no hot stacks, viewing angles are measured to the center of the picture shown. In many of these pictures, strong signals are followed by opposite-going signals, or overshoots. These overshoots arise because of the rolled-off low-frequency response of the video amplifiers; this roll-off is required when the equipment is being used for ASW studies.

IV. CLASSIFICATION OF VESSELS

If the upper surface of a vessel differs in temperature from the sea surface by an amount greater than the least detectable temperature difference of an infrared mapping system providing adequate spatial resolution, detection and a certain degree of classification are possible. Figure 3 is an infrared picture of a Russian cargo ship carrying ballistic missiles from Cuba. The tarpaulin-covered missile cases appear on the after deck. A single hot stack appears amidships. Figure 4 shows an oiler in Key West Harbor viewed at an angle of 16° from the vertical. A single hot stack appears on the cool after deck. This infrared picture was recorded from an attitude of 500 feet several hours before dawn on a November day.

The vessel may appear warm or cold with respect to the water depending on a number of variables, but in particular on air and sea temperatures, time of day, and meteorological conditions preceding the time of recording. Figure 5 shows three warm ships in the Delaware River in June about one hour after sunset. Each of the ships has one hot stack amidships. One of the ships is considerably cooler than the others, and large portions of its deck are "invisible." Figure 6, which was recorded in the early evening in January, shows a cold cargo ship with one hot stack and several warm open holds. Figure 7 is an infrared picture of a warm ship, probably a destroyer, with two hot stacks. This picture was recorded in February, one-half hour after sunset, when the air temperature was 3°F colder than the sea temperature. The ship had apparently been warmed by the sun during the day.

Infrared pictures can provide information on size, shape, deck structure, and direction of travel of a vessel and the number and placement of its hot stacks. In Fig. 8 a cold ship with one hot stack on the after deck is shown. From its shape and the placement of its single hot stack, this ship may be tentatively identified as a tanker. Figure 9, which shows a destroyer patrolling the Straits of Florida during the

---

[7] A more detailed description of the AN/AAD-2 may be found in "Operation and Maintenance Manual AN/AAD-2 ( ) Infrared Mapping Set," Manual No. 247-M-1, HRB-Singer, Inc. ~~(CONFIDENTIAL).~~

United States quarantine of Cuba, was recorded several hours after midnight in November. The cool ship is marked by two hot stacks and several other hot areas. Figure 10 shows the same destroyer in the evening of the following day. The ship now appears quite cold, several of the hot areas apparent on the preceding picture are now gone, and several other areas now appear quite warm. The Commanding Officer of this ship, the USS VESOLE, has submitted to the NAVAIRDEVCEN an interpretation of the hot spots apparent on these two occasions, based on an analysis of the ship's log. In addition to the two stacks, the various hot spots have been identified as open hatches, deck areas above the fire rooms, and exhaust vents from various rooms. The forwardmost hot spot that appears in Fig. 9 but not in Fig. 10 has been identified as the exhaust vent from the ship's galley. The Commanding Officer of the VESOLE describes this spot as follows: "It appears in the picture photographed at 0145 R and not at 1950 R because it is the habit of the ship's baker to commence baking after the evening movie."

The appearance of surfaced submarines to an infrared mapper is more variable than the appearance of surface vessels. Several reasons can be given for this. First, the shape of a submarine cross-section is nearly circular whereas that of a surface vessel is nearly triangular. Accordingly, the apparent width of a submarine as viewed from above is dependent on the submarine's buoyancy condition. Such is not the case with a surface vessel. Second, since an infrared mapper cannot "see" well through even thin films of water, only the conning tower may appear on the infrared picture if the deck is very wet. Under certain conditions, the apparent temperature of the submarine deck may vary periodically between warm and cold with respect to the sea surface as (1) a wave washes over the deck producing a zero temperature contrast, (2) the water evaporates, producing a cooling effect, and (3) the dry deck surface warms again. Finally, a submarine that has just surfaced will exhibit for a short period of time the temperature of the water at its former operating depth.

A cold surfaced submarine is shown in Fig. 11. The approximate position of the conning tower is marked by a warm spot, while a portion of the after section of the hull where the engine rooms are located is marked by a hot area. Figure 12 shows the same submarine on the surface two hours later. The submarine, which had been submerged for two hours, now appears predominantly warm. The hot area near the engine rooms is still apparent. The raised wooden decks appear cool, probably because of the wood's low thermal conductivity and the enhanced evaporation of water from it. [redacted]

(b)(1) per E.O. 13526 Section 3.3(6)

V. INFRARED-GUIDED ANTI-SHIP MISSILES

The hot exhaust stacks of ships appear on their infrared pictures as bright spots, the sizes of which depend upon the spatial resolution of the infrared system. Since ships may appear warm, neutral, or cool with respect to the sea surface despite the intense radiation from the exhaust stacks, a relatively high spatial resolution would be required of any infrared guidance system for anti-ship missiles. Figure 14 is an infrared picture of a cool ship with one hot stack. This picture was recorded during mid-afternoon of an overcast September day. A warm ship with its single hot stack is shown in Fig. 15, which was recorded within 15 minutes of Fig. 14. Figure 16 is a striking example of the relative unpredictability of the average radiation from surface vessels. Although each of the three ships shows a hot spot for its exhausts, the average radiation appears to vary between quite cold and extremely hot.

In addition to its hot stacks, a ship may present several hot spots which might also serve as targets for heat-seeking devices. Figure 17 shows two cold ships with numerous hot spots and areas. Another cold ship with several hot spots is shown in Fig. 18.

Figure 19 shows a freighter with one hot stack viewed at an angle of 44^{o} from the vertical. The hot stack stands out prominently at this angle.

Occasionally, the infrared pictures of ships do not show bright spots marking exhaust stacks. These exceptions may be unpowered vessels such as barges or ships at anchor, diesel-powered ships (which often have no vertical stacks), or ships directing their exhaust gases into the water, or possibly ships employing exhaust-deflecting caps on their stacks. Figure 20 shows a small cold boat with one hot stack towing a cold barge. Figure 21 shows two ships. One, apparently at anchor, has no hot stack. Figure 22 is an infrared picture of a diesel-powered patrol vessel. No hot stack was apparent on any of the numerous pictures of this boat, which were recorded on several occasions.

VI. SUMMARY AND CONCLUSIONS

Classes of maritime vessels can be recognized from their infrared pictures. Identifying features are size, shape, deck structure of the ship, and the number and placement, or absence, of hot exhaust stacks. It is difficult to predict with reasonable accuracy whether a ship will appear hot or cold with respect to the sea surface. Since the most dependable characteristic of ships is the hot exhaust stack, a high spatial resolution is desirable for use in the infrared guidance systems of anti-ship missiles.

VII. ACKNOWLEDGMENT

The results described in this paper are the product of the efforts of a team consisting of P. M. Moser, [redacted] (b) (6) in addition to the author.

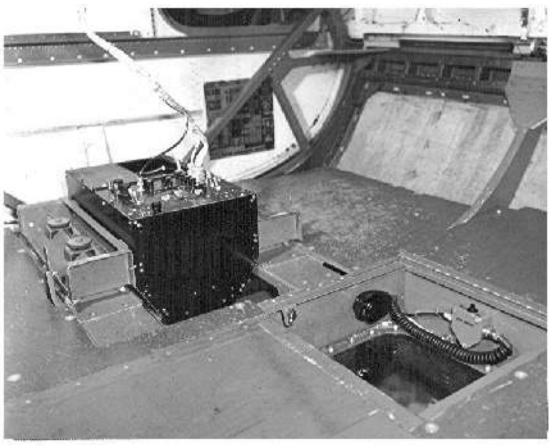

Fig. 1. AN/AAD-2 installed in modified bomb bay of SP-2E (P2V-5FS) aircraft.

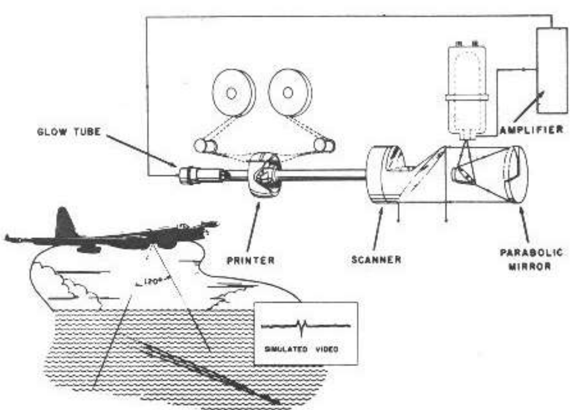

Fig. 2. Schematic of operation of AN/AAD-2.

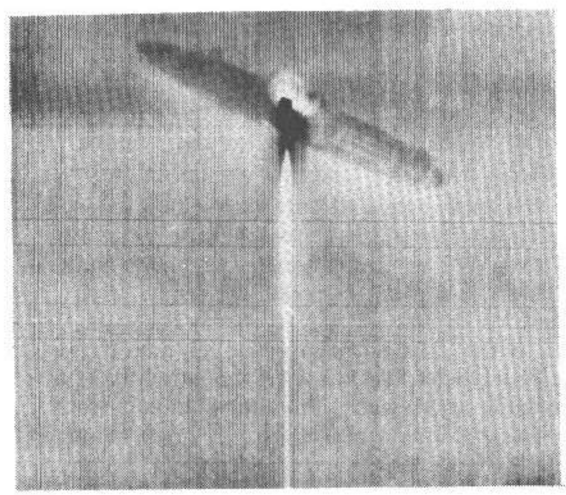

Fig. 3. Russian cargo ship carrying ballistic missiles from Cuba.

Date: 9 Nov 1962 Time: 0156 R
Aircraft altitude: 500 ft
Detector: InSb, 0.5 x 0.5 mm (photoconductive)
Ship: (USSR) VOLGOLES

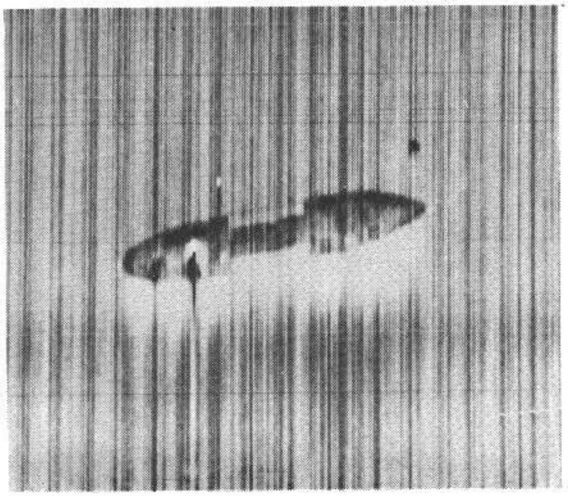

Fig. 4. Oiler in Key West Harbor.
Date: 10 Nov 1962 Time: 0351 R
Aircraft altitude: 500 ft
Detector: InSb, 0.5 x 0.5 mm (photoconductive)
Viewing angle: 16 degrees

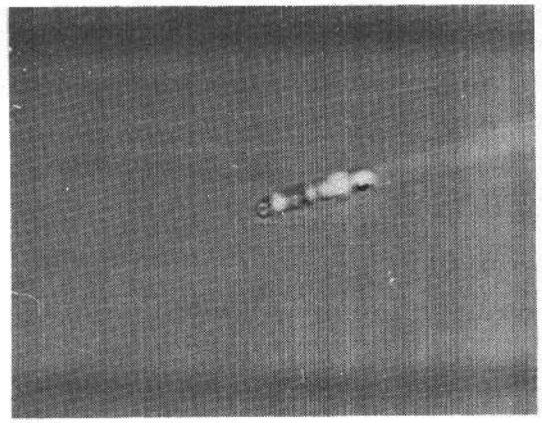

Fig. 6. Cold cargo ship with one hot stack.
Date: 18 Jan 1962 Time: 1927 R
Aircraft altitude: 2000 ft
Air temperature (at 2100 ft): 37°F
Detector: Ge:Hg, 2.8 mm diameter
Viewing angle: 4 degrees

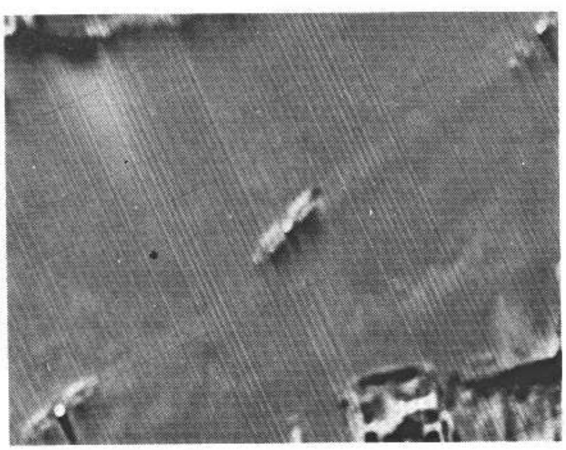

Fig. 5. Three warm ships with hot stacks.
Date: 26 Jun 1962 Time: 2033 R
Aircraft altitude: 2000 ft
Air temperature (at 2000 ft): 82°F
Detector: Ge:Cu, 2.8 mm diameter
Viewing angle: 8 degrees

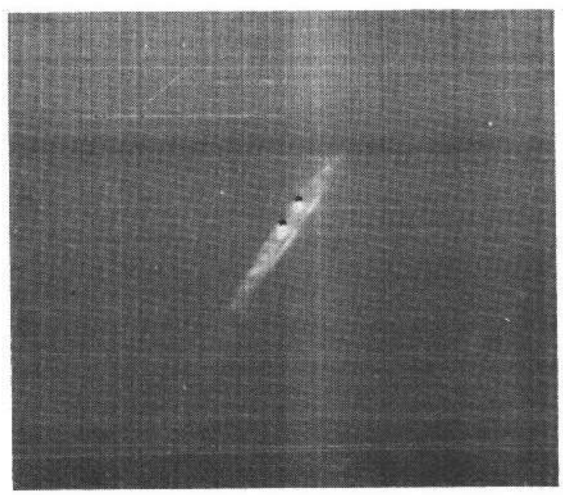

Fig. 7. Warm ship with two hot stacks.
Date: 27 Feb 1961 Time: 1815 R
Aircraft altitude: 1000 ft
Air temperature (on surface): 40°F
Water temperature: 43°F
Detector: Ge:Au, 1.0 mm diameter
Viewing angle: 14 degrees

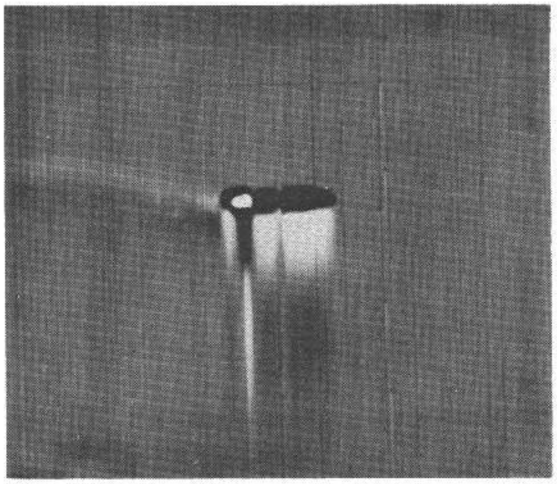

Fig. 8. Cold ship with one hot stack.
Date: 12 Jun 1962 Time: 2104 R
Aircraft altitude: 1500 ft
Detector: Ge:Hg, 2.8 mm diameter
Viewing angle: 2 degrees

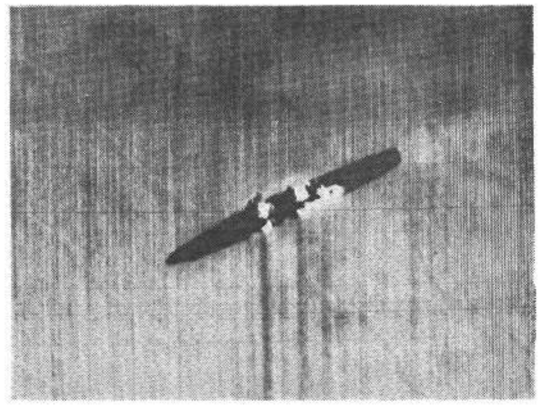

Fig. 10. Destroyer patrolling the Straits of Florida
Date: 10 Nov 1962 Time: 1950 R
Aircraft altitude: 500 ft
Detector: InSb, 0.5 x 0.5 mm (photoconductive)
Ship: USS VESOLE (DDR 878)
Viewing angle: 8 degrees

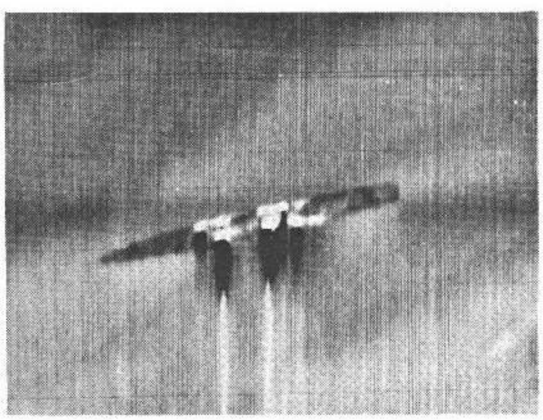

Fig. 9. Destroyer patrolling the Straits of Florida
Date: 9 Nov 1962 Time: 0145 R
Aircraft altitude: 500 ft
Detector: InSb, 0.5 x 0.5 mm (photoconductive)
Ship: USS VESOLE (DDR 878)

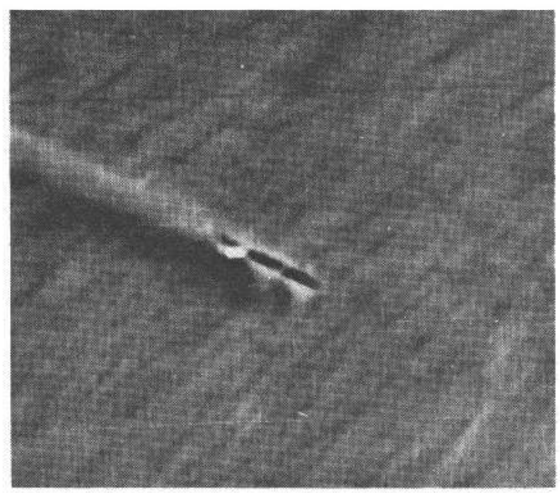

Fig. 11. Cold submarine on the surface.
Date: 15 Mar 1962 Time: 1912 R
Aircraft altitude: 1200 ft
Air temperature (at 1300 ft): 82°F
Water temperature: 76°F
Detector: Ge:Cu, 2.8 mm diameter
Submarine: USS GRENADIER (SS 525)
Viewing angle: 17 degrees

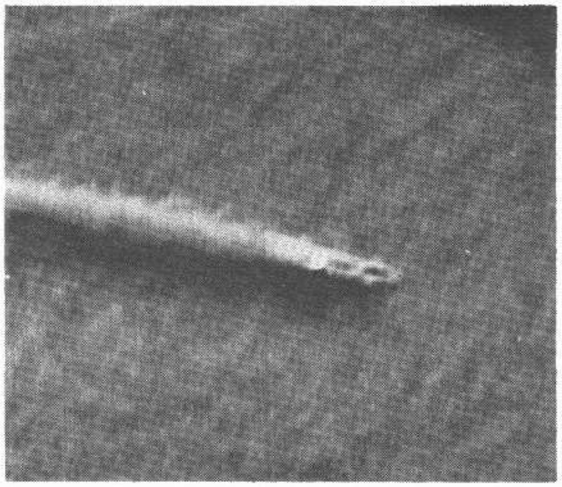

Fig. 12. Warm submarine on the surface.
Date: 15 Mar 1962 Time: 2127 R
Aircraft altitude: 1600 ft
Air temperature (on surface): 79°F
Water temperature: 74°F
Detector: Ge:Cu, 2.8 mm diameter
Submarine: USS GRENADIER (SS 525)
Viewing angle: 30 degrees

(b)(1) per E.O. 13526 Section 3.3(6)

[redacted]

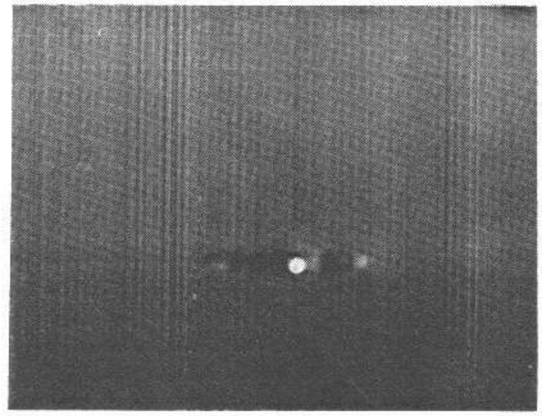

Fig. 14. Cold ship with one hot stack.
Date: 15 Sep 1961 Time: (mid-afternoon)
Viewing angle: 20 degrees

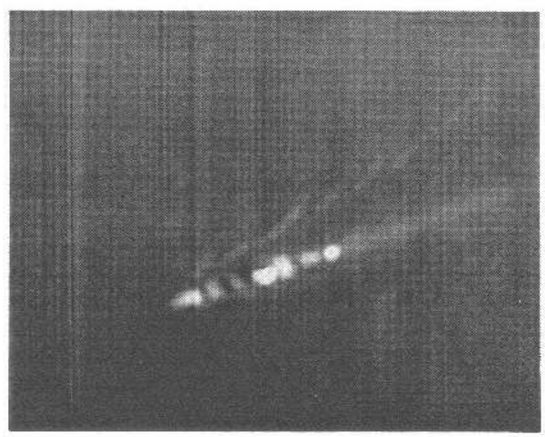

Fig. 15. Warm ship with one hot stack.
Date: 15 Sep 1961 Time: (mid-afternoon)
Viewing angle: 20 degrees

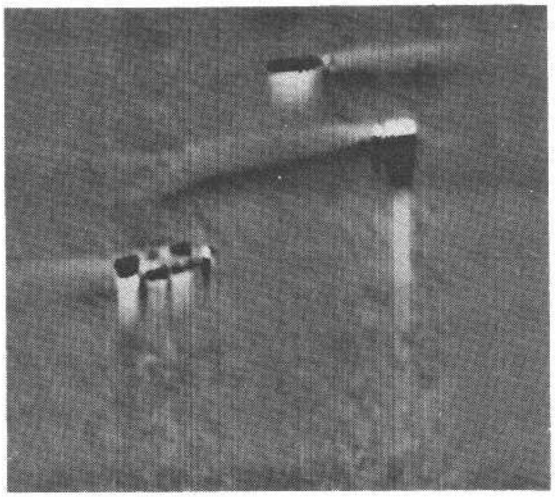

Fig. 16 A cold ship, a hot ship, and a ship with hot and cold temperature structure.
Date: 26 Jun 1962 Time: 2034 R
Aircraft altitude: 2000 ft
Air temperature (at 2000 ft): 82°F
Water temperature: 78°F (estimated)
Detector: Ge:Cu, 2.8 mm diameter
Viewing angle: 16 degrees

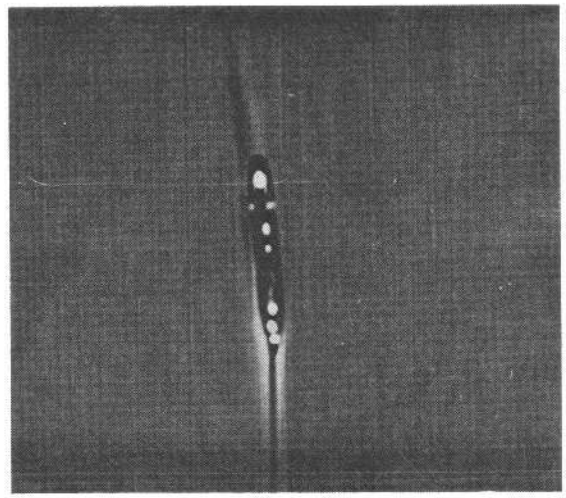

Fig. 18. Cold ship with hot spots.
Date: 18 Jan 1962 Time: 2003 R
Aircraft altitude: 2100 ft
Air temperature (at 2100 ft): 37°F
Detector: InSb, 2.8 mm diameter (photovoltaic)
Viewing angle: 6 degrees

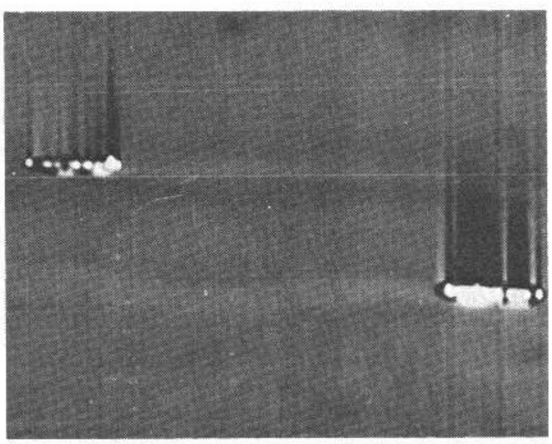

Fig. 17. Two ships in Delaware Bay.
Date: 18 Jan 1962 Time: 1949 R
Aircraft altitude: 2100 ft
Air temperature (at 2100 ft): 37°F
Detector: InSb, 2.8 mm diameter (photovoltaic)
Viewing angle: 10 degrees

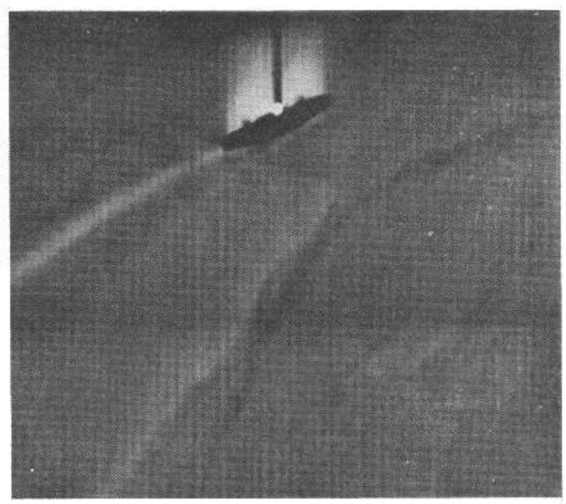

Fig. 19. Freighter with one hot stack.
Date: 7 Nov 1961 Time: 2013 R
Aircraft altitude: 1100 ft
Air temperature (on surface): 52°F
Water temperature: 59°F
Detector: InSb, 2.8 mm diameter (photovoltaic)
Viewing angle: 44 degrees

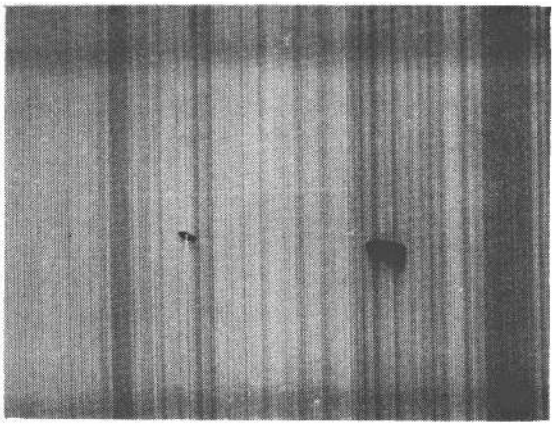

Fig. 20. A barge towed by a cold boat with one hot stack.
Date: 30 Nov 1960 Time: 2121 R
Aircraft altitude: 2400 ft
Air temperature (on surface): 40°F
Water temperature: 51°F
Detector: PbSe, 0.5 x 0.5 mm
Viewing angle: 2 degrees

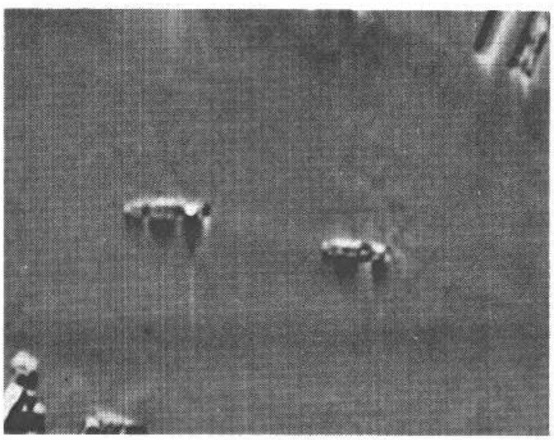

Fig. 21. A ship with one hot stack and a ship, apparently at anchor, with no hot stack.
Date: 26 Jun 1962 Time: 2033 R
Aircraft altitude: 2000 ft
Air temperature (at 2000 ft): 82°F
Water temperature: 78°F (estimated)
Detector: Ge:Cu, 2.8 mm diameter
Viewing angle: 6 degrees

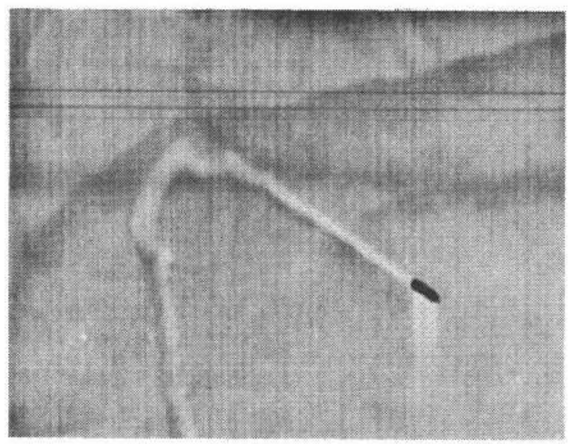

Fig. 22. Diesel-powered patrol vessel in Chesapeake Bay.
Date: 15 Nov 1961 Time: 2021 R
Aircraft altitude: 1000 ft
Air temperature (on surface): 52°F
Water temperature: 54°F
Detector: InSb, 2.8 mm diameter (photovoltaic)
Ship: U. S. Patrol Vessel (YP-654)
Viewing angle: 9 degrees

D I S T R I B U T I O N   L I S T

REPORT NO. NADC-AW-6421

WEPTASK NO. RUDC4B000/2021/WS-031

	Copy No.
BUWEPS, DLI-31	1 thru 10
(Copies 1, 2 for retention)	
(Copies 3, 4 for RUDC-43)	
(Copy 5 for R-56)	
(Copy 6 for FFRD)	
(Copy 7 for RAAV)	
(Copy 8 for RRRE)	
(Copy 9 for RT)	
(Copy 10 for RM)	
ONR	11 thru 15
(Copy 11 for 402C)	
(Copy 12 for 406T)	
(Copy 13 for 407T)	
(Copy 14 for 463)	
(Copy 15 for 466)	
CNO	16 thru 23
(Copies 16, 17 for Op-03EG)	
(Copy 18 for Op-07T)	
(Copy 19 for Op-71)	
(Copy 20 for Op-0714)	
(Copy 21 for Op-717)	
(Copy 22 for Op-352)	
(Copy 23 for Op-724D)	
NRL, Washington	24 thru 28
(Copy 24 for 5300)	
(Copy 25 for 5437)	
(Copy 26 for 6100)	
(Copy 27 for 7300)	
(Copy 28 for 7350)	
BUSHIPS	29 thru 32
(Copy 29 for 2011)	
(Copy 30 for 362C)	
(Copy 31 for 374)	
(Copy 32 for 681B)	
NEES, Anapolis	33
NMC, Point Mugu	34
CIA	35
NOTS, Pasadena Annex (P-80833)	36
NOTS, China Lake	37
COMOPTEVFOR	38
AIRDEVRON ONE	39

Continued on
inside cover

DISTRIBUTION LIST (Continued)

	Copy No.
Scripps Institution of Oceanography, Applied Oceanography Group	40
NEL, San Diego	41
NUSL, New London	42
David Taylor Model Basin, Washington	43
NUOS, Newport	44
Applied Physics Lab, University of Washington	45
Woods Hole Oceanographic Institution	46
Ordnance Research Lab, Penn State University	47
Hudson Lab, Columbia University	48
NOL, White Oak	49
NAVAIRTESTCEN, WST Div	50, 51
AFSC STLO-NADC	52
SEG (SEFRR) WPAFB	53
NAVTRADEVCEN	54
LANTFLTASWTACSCOL	55
NAVPHOTOINTPRCEN	56
NAVPHOTOCEN	57
ASWFORLANT	58
ASWFORPAC	59
RTD (RTH) Bolling AFB	60
IDA (Contract SD-50)	61
DDC	62 thru 81