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SUBJECT

TESTS AT SEA OF THE GENERAL MOTORS RADIANT HEAT DETECTOR IN TRACKING A DESTROYER

BY

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ABSTRACT

The General Motors Radiant Heat Detector with 12 inch mirror was mounted on a destroyer and used to detect and to track automatically a second destroyer in clear weather at night. Positive ranges of 10,000 yards were obtained with the sensitivity of the apparatus being such as to require a net flux of energy at the receiver of about 0.10 erg/cm^2sec for automatic tracking.

With a radiation telescope the temperatures were measured of the decks, vertical surfaces and stacks of the ship, and of the sea and sky.

Calculations from the temperature survey indicated that at 10,000 yards

(1) The calculated flux of radiation was in approximate agreement with the flux inferred from the known sensitivity of the receiver. This meant that from a temperature survey of a ship under way, or at rest, or in any condition, one can determine the radiant flux from the ship in any desired direction, with an accuracy dependent on the completeness of the temperature survey,

(2) The radiation from the hot stacks in the horizontal direction was several times that from the other vertical surfaces. This meant that the destroyer was tracked mainly by the radiations from the hot stacks and hence the tracking was not very dependent on the radiation temperature of the background.

[redacted]

CHAPTER 1

INTRODUCTION

Authorization. The tests were carried out under the authorization of the Bureau of Ships Project Order 2226/42 of 18 March 1942.

References: Pertinent references are:

(a) NRL ltr. C-S70-4(1) of 29 May 1942 to BuShips: Enclosure (A), General Motors Laboratories Report No. PI-54 of 18 December 1941.

(b) NRL Report No. H-2247, 29 February 1944, "Tests at Cove Point of the General Motors Radiant Heat Detector in Tracking Landing Craft," and references *infra*.

The present report describes tests at sea of an early model of the General Motors Radiant Heat Detector mounted on a destroyer and used to detect and track another destroyer. Previous experiments, described in reference (b), were made with the equipment on shore. The present experiments were the first with the equipment on a Navy ship at sea. The tests were carried out during the nights of February 7 to 8, 1944, in the sea area about 40 miles east of the Chesapeake Bay entrance. The destroyer was tracked to a range of about 10,000 yards.

By means of a radiation telescope measurements were made of the temperatures of various external surfaces of the destroyer, and of the sea and the sky. From these the thermal flux at a distance radiated by the destroyer was calculated and found to be in approximate agreement with that determined from the known sensitivity of the Heat Detector.

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CHAPTER 2

THERMAL TRACKING RANGE TESTS

The Radiant Heat Detector equipment was mounted on the U.S.S. CORRY, a new type destroyer, and used to detect a sister ship, the U.S.S. CARMICK. The equipment was the early demonstration model with 12 inch mirror delivered to the Naval Research Laboratory in January, 1942. It was described in reference (a), and needs only a brief description here. A photograph is shown in Plate 1. It can be operated to scan the horizon, to pick up automatically a target if the heat radiations from the target are strong enough, and thereafter to keep pointing at the target as the target moves across the scene. Thus, it is essentially a target tracking device. It consists of a thermopile at the focus of the mirror, the opposing junctions of the thermopile being connected through an amplifier to relays which actuated a reversible drive motor which turned the head of the Detector. When the image of the target fell on one set of junctions with sufficient intensity to operate the relay, the motor turned the head until the image fell on the other set of junctions thereby causing the motor to reverse and turn the head in the opposite direction. Thus the head continued to point at the target within about 2^o as the bearing of the target changed.

In order to obtain stabilization the head was mounted on the optical range finder at the starboard side of the gun director about 50 feet above the water. Due to the rather frail construction of the receiver housing (Balsa wood) it vibrated in the wind when the ship was under way, causing an erratic slight vertical scanning more or less across the horizon. This introduced thermal irregularities which precluded the use of the highest sensitivity of the Detector. The sensitivity used was such that a flux of energy of about 0.1 erg cm^{-2} sec^{-1} excess over the background flux was sufficient to operate the relays and cause tracking. The highest sensitivity of the Detector was about 16 times greater.

The wires to the Detector head on the range finder were led into the gun director and along its axis of rotation down into the chart house where the amplifier and relays were located. During a test the operator in the chart house permitted the head to scan the horizon, pick up a target and automatically track the target, the operator being apprised of the tracking by means of the red and green lights connected to the tracking relays. In the chart house he had no way of knowing that the tracking was correct, since all the usual ship inter-communication channels were in use, and had therefore to leave the chart house and inspect the scanning head in order to be certain that the signal received was that radiated by the CARMICK, and not by some part of the superstructure of the CORRY, as happened when the scanning was too far aft.

The CARMICK was detected and tracked during three maneuvers of the two destroyers on the night of February 7. The plots of the runs are given in Plates 2, 3 and 4, based on course and radar range information from the plotting room. On all three runs, in order to establish the positiveness of the results, the Detector head was several times deliberately turned away from the target, then allowed to scan, detect and track the target.

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On Run 1, at 1916, the CARMICK steamed away from the CORRY to a distance of about 4000 yards. Then the two ships travelled on parallel courses, as shown on Plate 2, the CARMICK making about 20 knots and the CORRY just maintaining steerage-way. During the run the Detector tracked the CARMICK with certainty to a distance of 13000 yards.

Run 2 began at 2046 with the CARMICK about 16000 yards north northeast of the CORRY. The CARMICK ran at reduced speed and the CORRY closed in on her as shown on Plate 3. CARMICK was detected and tracked from a distance of 9000 yards.

Run 3 began at 2207 with CARMICK about 3500 yards to the east of CORRY. The ships followed the courses shown on Plate 4, and then CARMICK pulled away from CORRY at a speed of about 20 knots. She was tracked with certainty to a distance of 11000 yards.

The results are shown in Table 1.

Table 1. Tracking ranges.

	Approximate speed of CARMICK	Aspect of CARMICK	Tracking range
Run 1	20 knots	port quarter	13000 yards
Run 2	5	starboard bow	9000
Run 3	20	port quarter	11000

The weather during the runs was very favorable to the heat detector tests. The breeze was about 15 knots, the sea moderate, and there was little roll or pitch of the ship. The sky was cloudless and the lower atmosphere clear. There was a moon nearly full at an altitude above 40 degrees. The moonlight had no effect on the detector as long as the detector was not pointed directly at the moon or the moonpath.

As has been said, the Radiant Heat Detector was a laboratory demonstration model and had not been designed with the sturdiness requisite for shipboard installation. The experience with it during the shipboard tests served to emphasize certain obvious features which are probably essential in the design of this or similar types of equipment which are to be placed on shipboard and which scan the horizon and track or record the presence of thermal targets on or near the horizon. Two of the features are:

(1) The Detector head must be on a stable platform, the accuracy of stabilization being perhaps better than 5 minutes of arc,

(2) The Detector head must be as free from vibration as possible, such as the vibrations due to the motion

[redacted]

of the ship, impact of waves on the ship, wind on the Detector head, etc. Motions of the Detector head may cause irregularities and lowered sensitivity. It follows that tests on a vibration free land station of a particular type of equipment must be interpreted with reserve in estimating the effectiveness of the equipment on board ship.

<u>Unaided eye and binocular ranges</u>. It is of interest to record the ranges at which CARMICK was seen from the bridge of CORRY by experienced lookouts with the unaided eye and with 7 x 50 binoculars. The ranges are given in Table 2. CARMICK was painted with dark blue hull and haze gray superstructure. The values for the night of February 7 refer to an altitude of the moon about 50°.

Table 2. Eye and binocular ranges at night.

	Unaided eye	Binocular
February 7	3000 yards	7500 yards
February 8	3000	16000

and the bearing of CARMICK between 30° and 70° from the moon; those for the night of February 8 refer to the moon at an altitude of about 70°. Both nights were very bright and the lower atmosphere clear; the sky seemed to be brighter, due to upper altitude haze, on February 8 than on February 7. Conditions were excellent for seeing dark objects against the horizon sky. The lookouts were certain that at the ranges of Table 2 they would have picked up the ship even if they had not known it was there or where to look.

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CHAPTER 3

RADIATION TEMPERATURES OF VARIOUS AREAS

Radiation temperature measurements of various areas were made on the night of February 8 with a radiation telescope. The weather conditions, as air temperature, wind, state of sea and sky were closely the same on the nights of February 7 and 8. The radiation telescope had a field of view about 4 degrees in diameter; it was merely pointed at the area and the reading taken. The reading gave the radiation temperature, which is the same as the true temperature only if the area is radiating as a black body. The radiation temperatures were determined of various external surfaces of the CORRY while underway at a speed of about 20 knots, and of the undisturbed sea near the ship, the sea toward the horizon, and of the sky at several zenith distances. The values are given in Table 3, and were correct within about 0.5° centigrade.

The air temperature, measured with a thermometer, was 39° F or +5° C. The radiation temperature of the white foam of the bow wave along side of the ship was +3° C, whereas that of the undisturbed sea surface (that is, undisturbed by the ship) next to the white foam was -3° C. An explanation of the higher radiation temperature of the white foam is not obvious. Calculation indicated that effects of the moonlight were inappreciable in this connection.

Table 3. Radiation temperatures of various areas.

SURVEY OF SHIP	
Exposed surfaces, vertical and horizontal of superstructure	+3° Centigrade
Surfaces of deck and gun turrets forward	+3°
Deck amidship, near stack	+5°
Stack, near deck	+59°
Stack, halfway up	+43°
Stack, near top	+36°
SURVEY OF SCENE	
Sea, upward radiation	-3°
Sea, toward horizon	+1°
Sky, near horizon	+1°
Sky, zenith distance 60°	-2°
Sky, zenith distance 30°	-4°
Sky, zenith distance 0°	-8°

[redacted]

CHAPTER 4

CALCULATIONS AND DISCUSSION

In an infra-red receiver containing a compensated thermopile, one set of junctions receives radiation from the background sky and the other set of junctions receives radiation from the target plus radiation from the background sky not obscured by the target. When the target is sufficiently distant to be a point source, it has been shown that the flux of energy f erg cm^{-2} sec^{-1} from the target falling on the face of the receiver is

$$f = \pm(j - j_o)a/\pi r^2 \qquad (1)$$

where

$$j = \sigma t^4 , \qquad (2)$$

$$j_o = \sigma t_o^4 . \qquad (3)$$

In (1) the sign is chosen to make f positive. t and t_o are the absolute temperatures of the target and the background, respectively; a is the area of the target in cm^2, r is the distance from the target to the receiver in cm, and $\sigma = 5.71 \times 10^{-5}$ is the Stefan constant of total radiation.

Putting (2) and (3) in (1) yields

$$f = \pm\sigma a(t^4 - t_o^4)/\pi r^2 . \qquad (4)$$

It is convenient to write (4) as

$$f = \pm 2.02 \times 10^{-6}(t^4 - t_o^4)a/r^2 , \qquad (5)$$

where a is in square feet and r is in yards.

At distances greater than 8000 yards a destroyer, even broadside, was approximately a point source to the Detector of Chapter 2. Then f may be calculated from (5) and the temperature data of Table 3 for various cases for a range of 10,000 yards. One finds,

Broadside view, vertical surfaces without the stacks	Bow or stern view, without the stacks	One stack
a = 330 x 17	a = 30 x 30	a = 16 x 25
= 5500 sq.ft.	= 900 sq.ft.	= 400 sq.ft.
t = +3° C	t = +3° C	t = +45° C
t_o = +1° C	t_o = +1° C	t_o = +1° C
f = 0.019	f = 0.0031	f = 0.037

[redacted]

Therefore at 10,000 yards for a broadside view with two stacks

$$f = 0.019 + 0.037 + 0.037 = 0.093 ,$$

and for a quartering stern view with two stacks

$$f = 0.003 + 0.037 + 0.037 = 0.077 .$$

These values of f should be reduced because of the absorption of the atmosphere in the 10,000 yard range, but perhaps not by more than 50 percent. Thus the values may be about 0.04 which is regarded as in agreement with the value about 0.1 stated, from laboratory calibration, as the flux on the Detector necessary for positive tracking, (probably a conservative statement.)

The calculated values of f are open to a little uncertainty because they were not obtained from temperature measurements of CARMICK during the runs when the tracking ranges were observed, but were obtained from measurements of CORRY the following night. Further, it is known that stack temperatures increase with the speed of a ship; therefore, f and the tracking ranges depend on the conditions of operation of a ship.

The calculation leads to two informative conclusions:

(1) The radiation from the hot stacks of the destroyer in the horizontal direction was several times greater than that from the other vertical surfaces. Therefore, the destroyer was tracked mainly by the radiations from the stacks, and hence the tracking range was not very dependent on the radiation temperature of the background. If there had been no artificial heat in the ship the tracking range would have been considerably less, and entirely dependent on the radiation temperature of the ship surfaces relative to the background.

(2) The agreement between the calibrated sensitivity of the Detector and the flux at a distance calculated from the temperature survey of the external surfaces of the ship indicated that one can determine the radiant energy flux in any direction from any type of ship by measurements aboard the ship with a radiation telescope while the ship is under way, or at rest, or in any desired condition. The accuracy with which one can make the radiant flux determination will depend on the detail and completeness with which the temperature survey were carried out.

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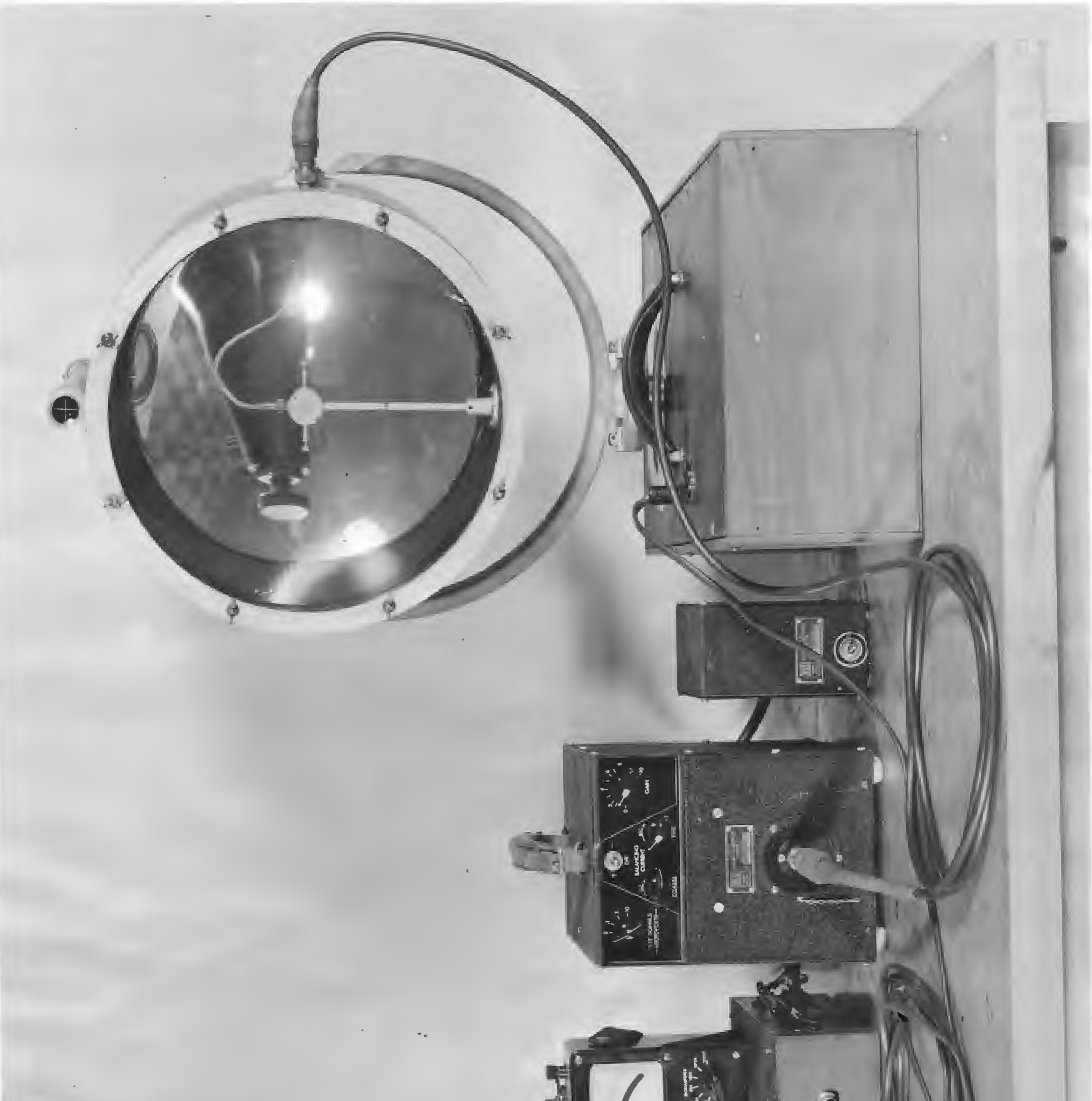

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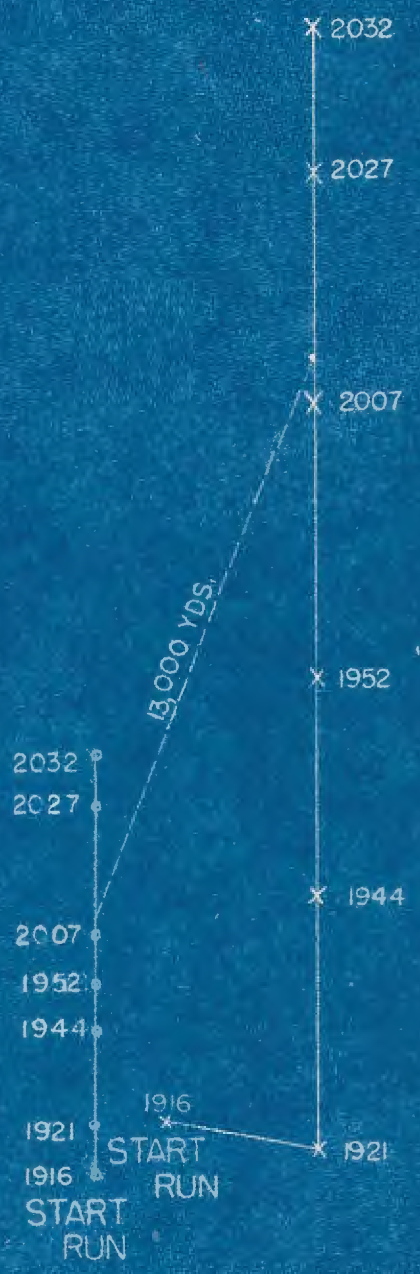
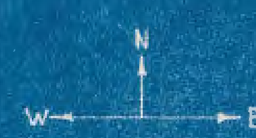
PLATE I

COMPLETE RUN



RUN ONE

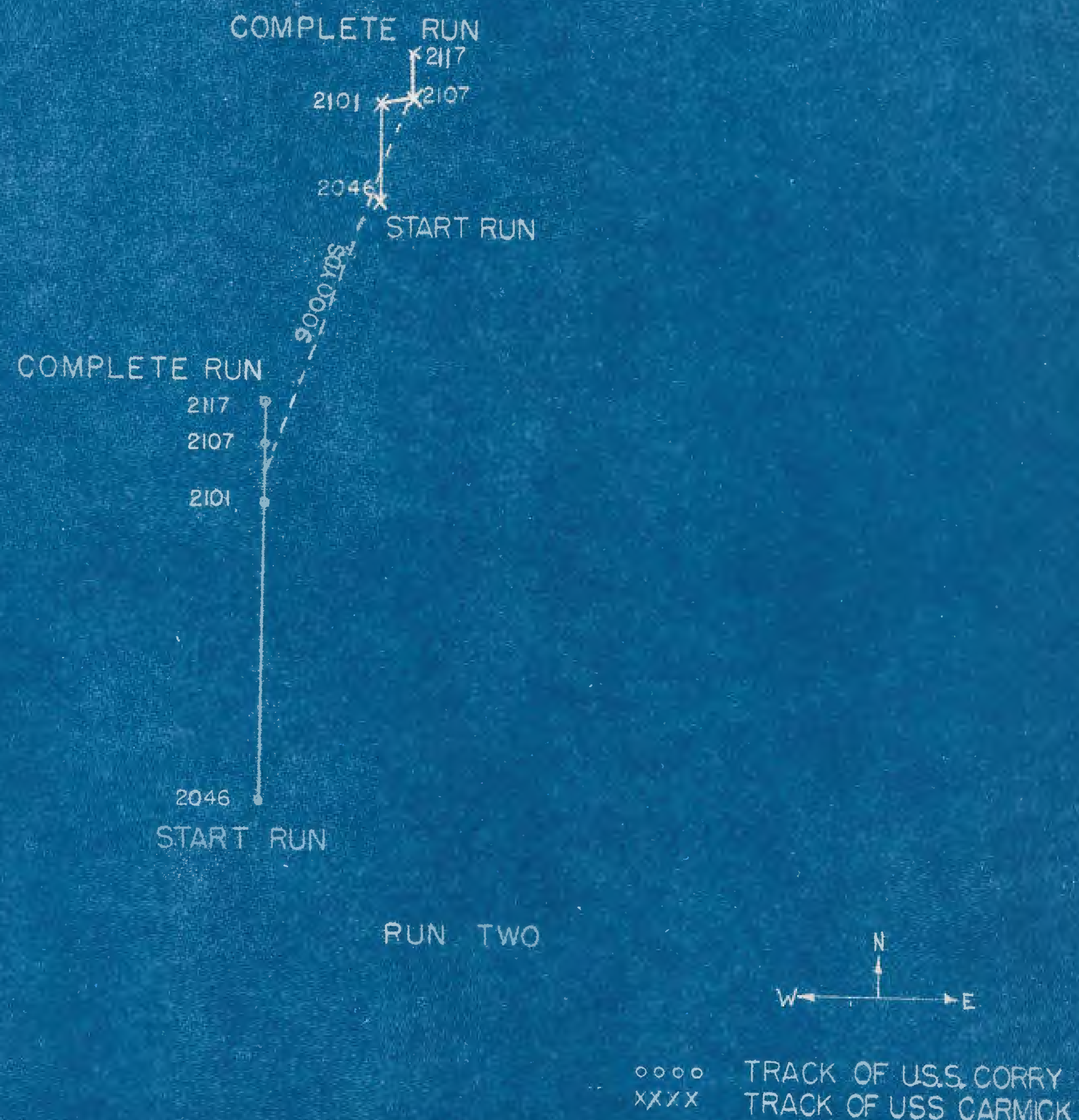


oooo TRACK OF U.S.S. CORRY

xxxx TRACK OF U.S.S. CARMICK

SCALE 1" = 4000 YARDS

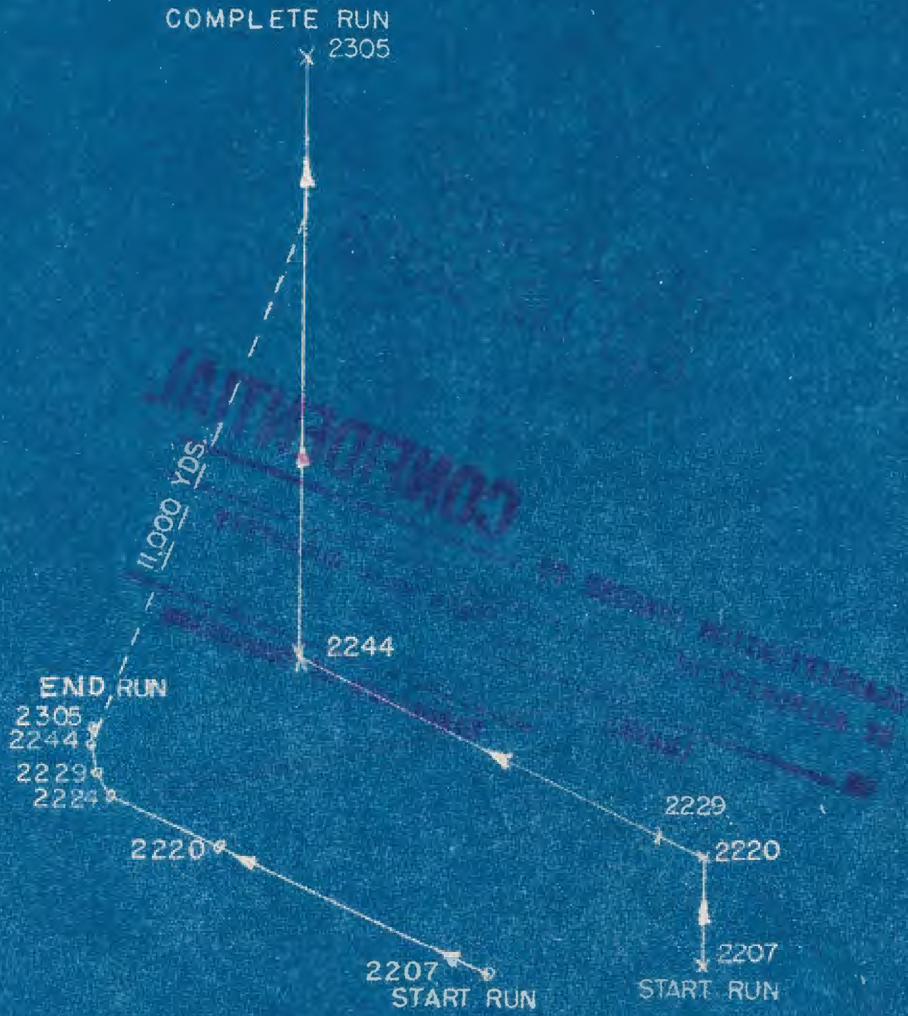
PLATE 2



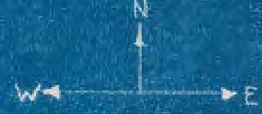
RUN TWO

SCALE: 1" = 4000 YARDS

PLATE 3



RUN THREE



o o o o TRACK OF USS CORRY
x x x x TRACK OF USS CARMICK

SCALE: 1" = 4000 YARDS

PLATE 4