NRL REPORT 3783

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FR-3783

AIRBORNE MEASUREMENTS OF THE THERMAL RADIATION FROM THE WAKE OF THE USS IREX

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

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ABSTRACT

The airborne equipment developed for measuring the thermal radiation from submarine wakes was designed to be flown at an altitude of 2000 feet at speeds of 30 to 60 knots. Operating with a noise input equivalent to 1.2×10^{-7} watts cm^{-2} $steradian^{-1}$, it is capable of measuring easily the difference in radiation between a wake and surrounding water when the temperature difference is only $\pm 0.005^{\circ}C$. With the equipment installed in the M-2 airship, thermal radiation from submarine wakes originating at depths down to 150 feet was measured at night at ranges up to 12,000 yards astern. For the first time, optical noise from the surface of the sea was observed with this type of equipment. Miles of sea were found to have optical noise levels equal to or less than that of the equipment, indicating that the signal-to-noise ratio can be increased still further.

PROBLEM STATUS

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

AUTHORIZATION

NRL Problem N03-19R
NL 430-014
BuAer Project No. TED-NRL-EL-8-A-345
(Established by BuAer Ltr Aer-EL-84, Serial 0655, 26 January 1949)

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AIRBORNE MEASUREMENTS OF THE THERMAL RADIATION FROM THE WAKE OF THE USS IREX

INTRODUCTION

The feasibility of detecting the approximate position of a submerged submarine by observing the thermal radiation from its wake [1] was demonstrated by a series of measurements made at night in the New London-Block Island area during September 1948.[2,3] Although carried out with makeshift equipment which proved itself unsuitable for airborne applications of this type, the measurements were quite successful and clearly indicated the potentialities of this method of detection.

As a result, a problem sponsored jointly by the Office of Naval Research and the Bureau of Aeronautics was established at this Laboratory for the purpose of developing more suitable equipment and, with it, investigating the thermal-radiation characteristics of submarine wakes. It was desired to determine the relationships between the magnitude of the thermal radiation from the wake and such variables as the submarine's depth and speed, the distance astern the submarine, the vertical temperature gradient in the water, sea states, and weather conditions.

New equipment was therefore developed and flown off the New Jersey coast and in the Key West area during May and June 1949. The operational signal-to-noise ratio of this equipment, although better than that of the earlier gear, proved to be inadequate.[4] Successful operation was achieved over New Jersey coastal waters but not over the Gulf Stream near Key West. The failure to measure wake radiation in the Key West area was attributed to very small, vertical, temperature gradients in the Gulf Stream, resulting in submarine-wake temperatures averaging 0.05°C colder than the surrounding water.[5] The

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[1] The first attempt by NRL to detect submarine wakes from the air was made early in 1942 from a blimp flying in the vicinity of Barnegat Light, N. J. The results were reported in an NRL confidential letter C-S70-4(1) dated 27 March 1942. It is reported that prior to that Dr. C. F. Kettering of the General Motors Corporation achieved some success in detecting steamer wakes with similar gear installed in an upper story window of a Miami hotel overlooking the water.

[2] Harvey, G. L., "The Detection of Schnorkelling Submarines by Infrared," U. S. Navy Underwater Sound Laboratory Report No. 101 (Confidential), 30 September 1948

[3] Clark, H. L., "Airborne Measurements of the Thermal Radiation from the Schnorkel and Wake of the USS DOGFISH," NRL Report N-3386 (Confidential), 22 November 1948

[4] Clark, H. L., "Airborne Measurements of Thermal Radiation from Submarine Wakes in the Key West Area," NRL Report 3606 (Secret), 4 January 1950

[5] West, H. L., "Surface Measurements taken on Thermal Wakes Generated by Submarines," U. S. NADC Report No. ADC-EL-50-50 (Confidential), 8 November 1949

measurement of such small temperature differences by radiometric means under the adverse atmospheric conditions encountered in the area was beyond the capabilities of the airborne gear. During this entire operation the equipment's signal-to-noise was determined by system noise rather than by optical noise from the surface of the sea. This was encouraging since it substantiated the choice of the optical system parameters and method of scan employed. It also proved that the gain of the optical system could be increased considerably before optical noise became a limiting factor and that many of the radiation signals missed during the operation could be measured. Consequently, this equipment was shelved.

A third set of measuring equipment was then developed. Its design was based on the Key West experience. Employing 24-inch-diameter mirrors and 1 x 1 inch thermopiles, it had sufficient optical gain to boost the signal-to-noise ratio of the system more than ten times. It was installed in the M-2 airship at Lakehurst, N. J., during the latter part of April 1950, and was flown for two weeks against surface vessels operating close to the New Jersey shore. Then, during the latter part of May formal measurements were conducted at night with a submarine in deep water 150 miles east of Atlantic City (longitude 71°W latitude 39°N approximately). Excellent results were obtained during these flights. The thermal radiation from the submarine's wakes originating from various depths down to 150 feet was measured easily up to 12,000 yards astern. For the first time, optical noise from the surface of the sea was observed with this type of equipment. Miles of sea were found to have optical-noise levels equal to or less than that of the equipment, indicating that the signal-to-noise ratio can be increased still further.

EQUIPMENT

General Characteristics

The operating principle of the third set of measuring equipment is similar to that of the earlier gear[6] with minor exceptions. It is designed to be flown at an altitude of 2000 feet at speeds of from 30 to 60 knots. The optical system scans at 34 rpm, the periphery of a 1000-yard-diameter circle (Figure 1) which is transformed into a tight spiral by the forward motion of the airship. Projected upon the periphery are the two halves of the optical system's field of view, each measuring 250 feet wide by 300 feet high with a 500-foot separation between adjacent edges. As the optical system sweeps around the circle and crosses a wake, first one and then the other section of the field of view encounters the wake. If the temperature of the wake differs from the surrounding water by more than $\pm 0.005^{\circ}$C and the atmospheric transmission is 30 percent or greater, the difference in the radiated thermal energy at the optical system will produce an easily measurable signal therein. This signal consists of a positive- and negative-lobed voltage pulse which is amplified, partially differentiated, and then presented on an oscilloscope and three different types of recorders (Figure 2). Identity of the polarity of the signal is maintained throughout the system so that it is possible to determine whether the wake is hotter or colder than the surrounding water.

The optical system (Figure 3) consists of two 24-inch, f - 0.4, stellite, parabolic mirrors, in the focal plane of which is mounted a special 1 x 1 inch Eppley thermopile. Each thermopile describes a theoretically rectangular, $6^{\circ} \times 6^{\circ}$ optical field of view which actually measures $5^{\circ} \times 5^{\circ}$ because of the parabola's off-axis comatic flare. Separation of the two fields of view is achieved by toeing the mirrors outward away from each other so

[6] Clark, H. L., loc. cit., footnote 4

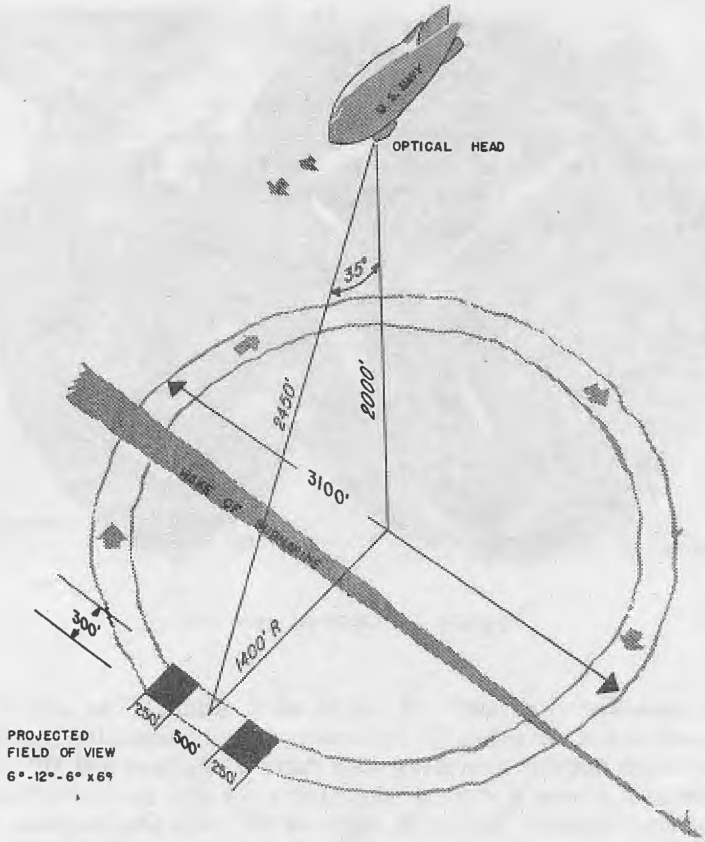

Figure 1 - Operating condition of detector

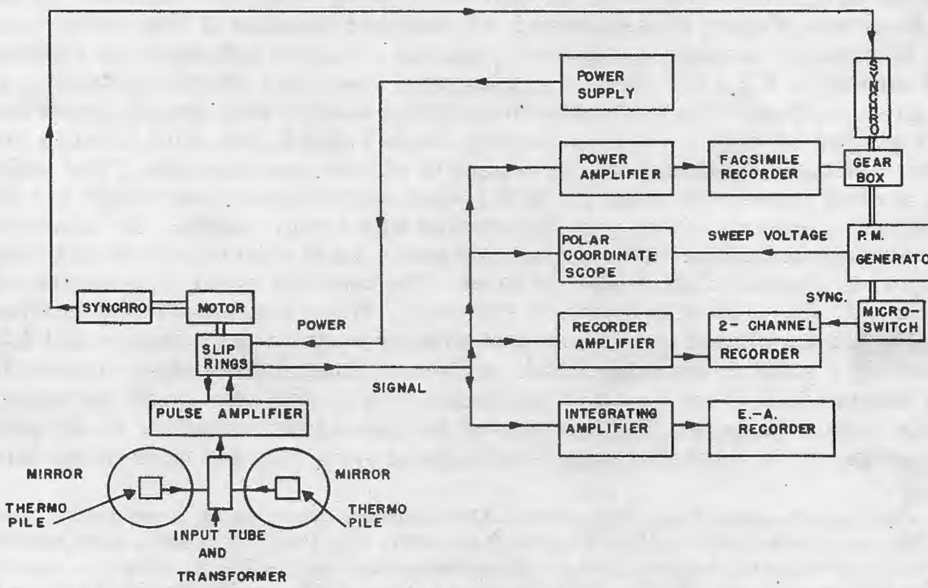

Figure 2 - Block diagram of equipment

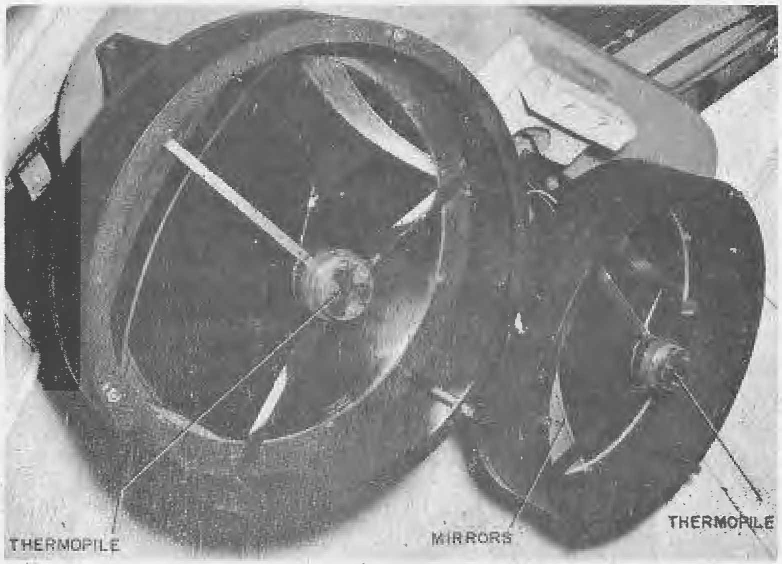

Figure 3 - Optical system

that their optical axes are at an angle of 15° to each other. (The use of two mirrors with a thermopile at each focus obviates the necessity of compensating for the off-axis aberrations encountered when both thermopiles with their 5° spread and 10° separation are employed at the focus of a single mirror.) Both mirrors are also tilted downward so that the optical axis of each mirror forms an angle of 35° with the vertical axis about which they rotate. In this manner, the operation depicted in Figure 1 is achieved.

The thermopiles are a tribute to the Eppley Laboratories of Newport, R. I. Basically designed by NRL, these units were worked out in detail and made practical by that company.[7] Each unit (Figure 4) measures 1 x 1 inch and consists of five series-connected banks of 50 parallel-connected receivers, making a total of 250 separate receivers. Each receiver measures 0.2 x 0.2 inch. The measured electrical characteristics of the entire unit are given in Table 1 together with those calculated by NRL before construction of the units was started by Eppley. As can be seen from Table 1, the units actually proved to be better than anticipated particularly in regard to signal-to-noise ratio. The units are mounted in steel cases with thick (3/16 in.) rock-salt windows over which are pressed thin (0.020 in.) sheets of silver chloride treated with silver sulfide. By combining the rock salt and treated silver chloride, an extremely rigid window with good transmission and weathering characteristics was obtained. The over-all spectral response of the thermopile with the window is shown in Figure 5 . When employed in the equipment these thermopiles are irradiated for 0.05 second when crossing a point source and 0.1 second when crossing a wake of the same width as the projected field of view. Hence, full output from the thermopiles is not realized in practice. A slower scan could result in greater thermopile output. However, the passband of the associated amplifier would be such as to reject improperly the unwanted signals introduced by the roll and pitch of the airship.

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[7] Three other companies, Bell Telephone Laboratories, Charles M. Reeder Co., and Farrand Optical Co., were also approached with the problem. The Bell Telephone Laboratories showed no interest in developing a thermister-bolometer of this size. The Reeder Co. supplied two relatively high resistance (2 ohms) thermopiles, one of which deteriorated before they could be used. Farrand Optical Co. stated that they were not in a position to build such thermopiles.

 [redacted]

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TABLE 1

Thermopile Characteristics

Characteristic	Calculated	Measured
D-C Sensitivity	0.020 v/w/cm^2 0.0031 v/w	0.022 v/w/cm^2 0.0034 v/w
Time Constant	0.1 sec	0.08 sec
Resistance	0.5 ohm	0.2 ohm

The two thermopiles employed are connected in series opposition so that only differences in radiation are observed. This arrangement minimizes the disturbances produced by mass variations in the background radiation from the sea and also makes the system selective for those targets which are comparable in size to the optical field of view projected on the sea.

Together the two thermopiles have a resistance of 0.4 ohm, which necessitated the development of a special input transformer. Construction of the transformer was relatively simple. It consists of 40 EI-28 (28 gauge) mu-metal laminations, 30 turns of No. 15 formex wire on the primary, 40,000 turns of No. 46 enamel wire on the secondary, and an electrostatic shield between primary and secondary. It was impregnated, baked, and potted in a heavy copper case which in turn was mounted in a cylindrical steel housing lined with five concentric layers of mu-metal. In this housing was also mounted the input tube and certain resistors (Figure 6). With the input tube connected across its secondary, the transformer exhibited good frequency response from 2 cps to 100 cps with an input impedance of $\frac{1}{2}$ ohm and an effective gain of about 700.

In order to minimize the induced emf's produced by rotating the transformer-input tube combination in the earth's magnetic field, it was necessary to mount the assembly symmetrically on the axis of rotation of the optical system (Figure 7). The remaining stages of the amplifier, which operate at higher signal levels, were mounted off axis behind the mirrors (Figure 7).

The amplifier itself (Figure 6) is an ordinary R-C unit employing under coupling between stages and plate-load shunting for tuning purposes. Coupled to the output end of this amplifier is an L-C filter network (Figure 8), which provides additional high-frequency attenuation. The over-all frequency response of the amplifier with the L-C filter is shown in Figure 9.

Power for the amplifier is provided by a separate unit (Figures 10 and 11) which operates from a 24-volt storage battery. Filament current is obtained directly from the battery through voltage-dropping resistors. Screen and plate supply voltages are generated by a dynamotor and regulated by both gaseous and vacuum tubes. In order to avoid feedback through the dynamotor, which might lead to an unwanted oscillatory condition, the high voltage for the first two stages of the amplifier is regulated independently of that for the last two stages. As an added precaution, regulator tubes are also employed in the amplifier to eliminate any "hash" which might be introduced into the high-voltage lines by the slip rings.

The filtered output of the amplifier is fed simultaneously to: a Dumont Type 275-A polar coordinate oscilloscope; a Brush Type BL-905 amplifier and Type BL-202 two-channel recorder; a power amplifier and facsimile recorder; and an integrating amplifier and Esterline-Angus recorder (Figures 11 and 12). All recording units, except the Esterline-Angus recorder, are synchronized with the optical scanner by means of a 50-speed synchro link. The facsimile recorder is driven directly. This same drive likewise rotates a permanent magnetic generator which provides the sweep voltages for the circular trace on the oscilloscope. In addition, the drive also trips a microswitch once per revolution of the optical scanner and thereby produces synchronizing marks on one channel of the two-channel Brush recorder.

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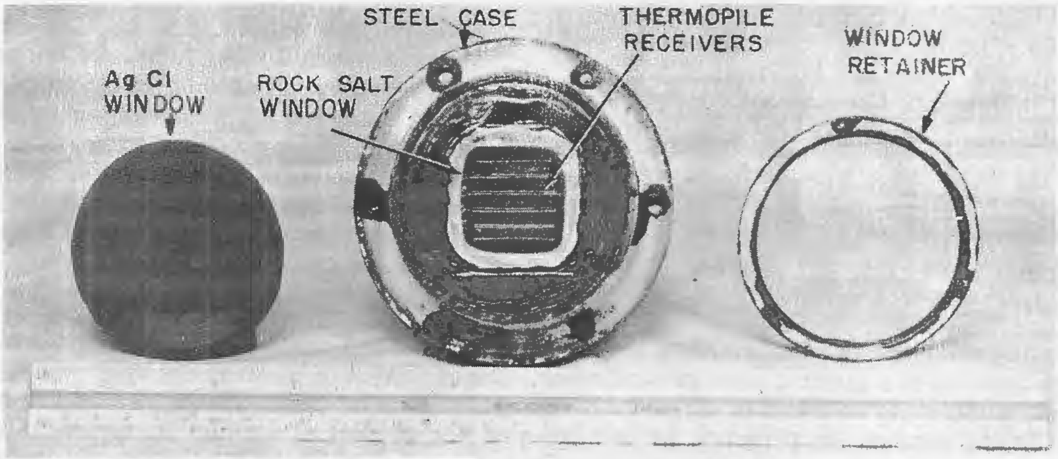

Figure 4 - Thermopile

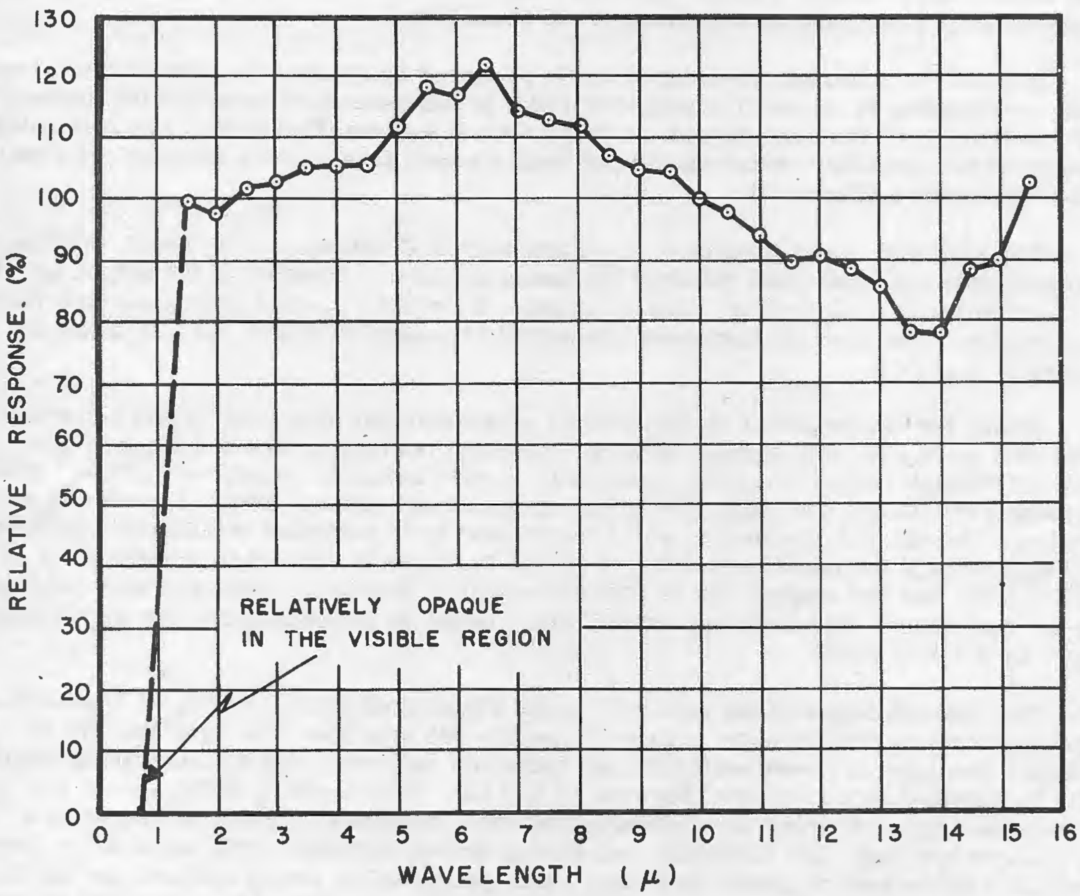

Figure 5 - Relative spectral response of thermopile and window

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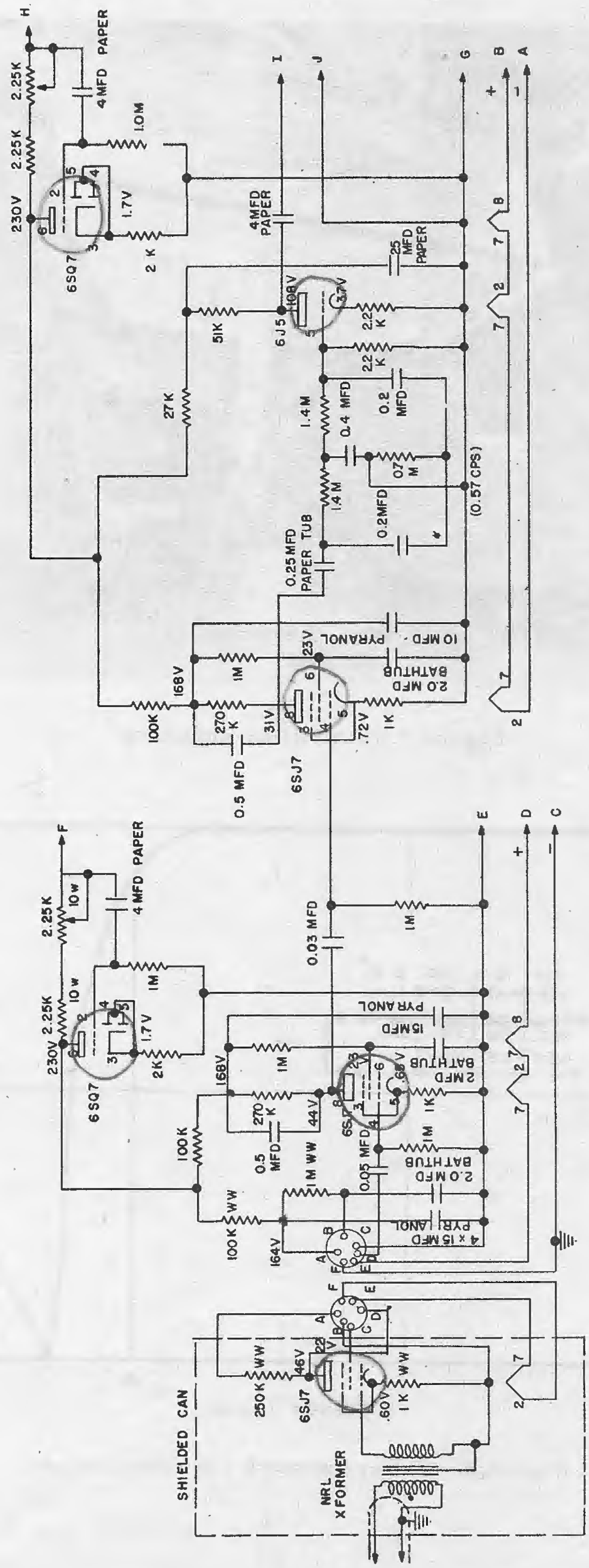

Figure 6 - Amplifier wiring diagram

[redacted]

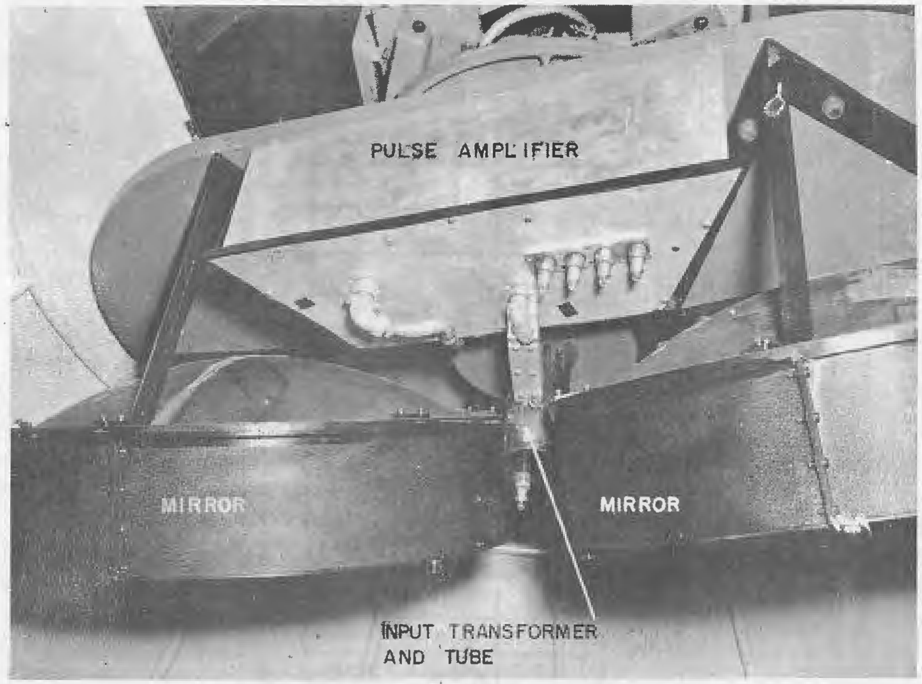

Figure 7 - Amplifier mounting

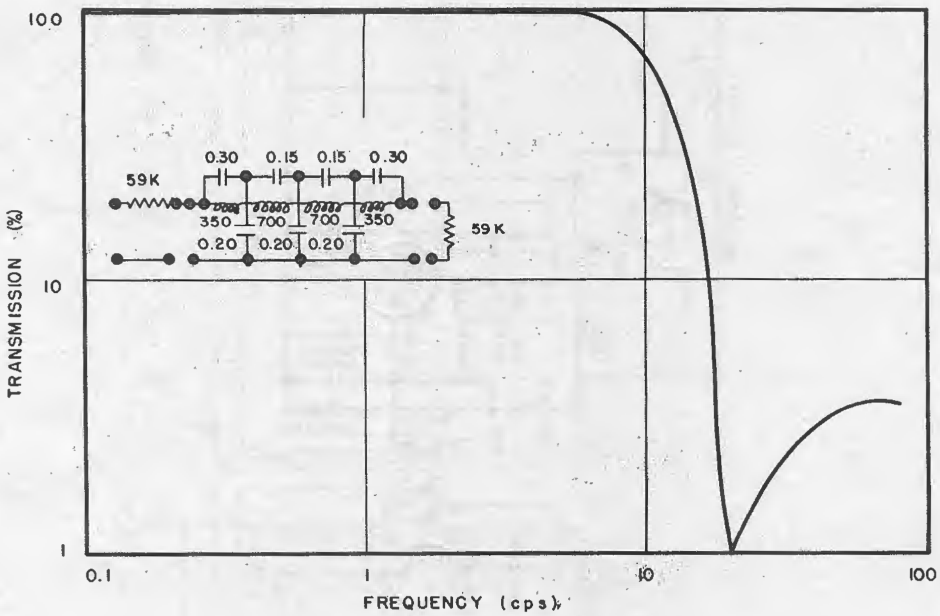

Figure 8. - Filter-network characteristics

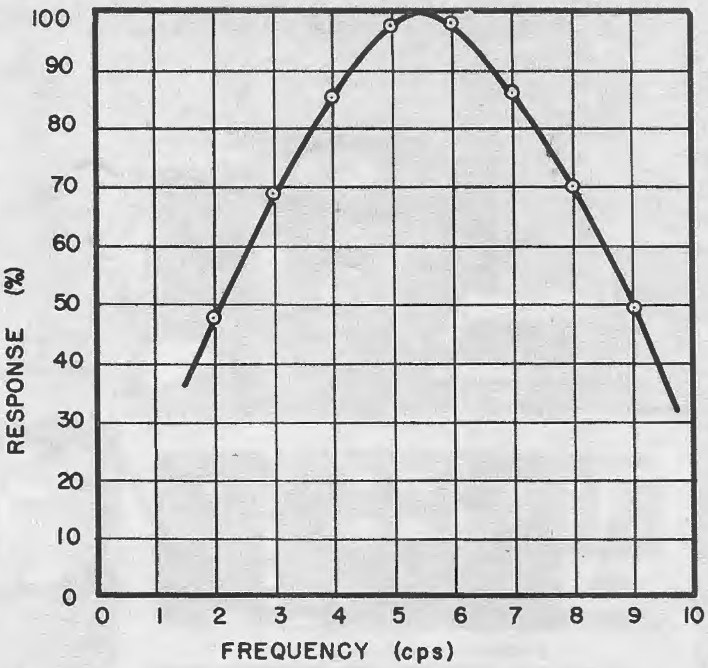

Figure 9 - Over-all frequency response of amplifier

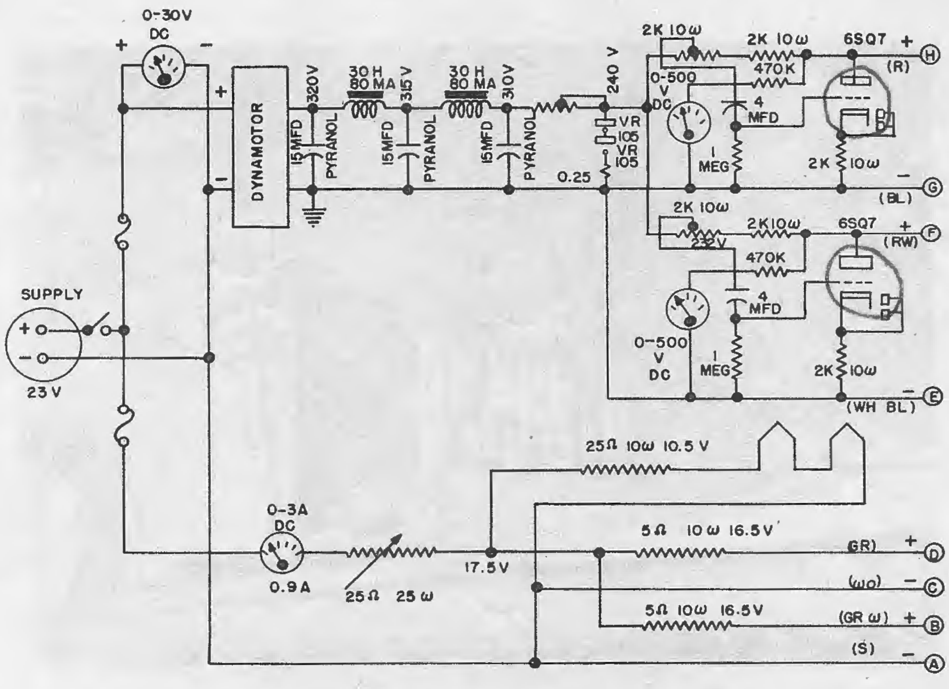

Figure 10 - Power-supply wiring diagram

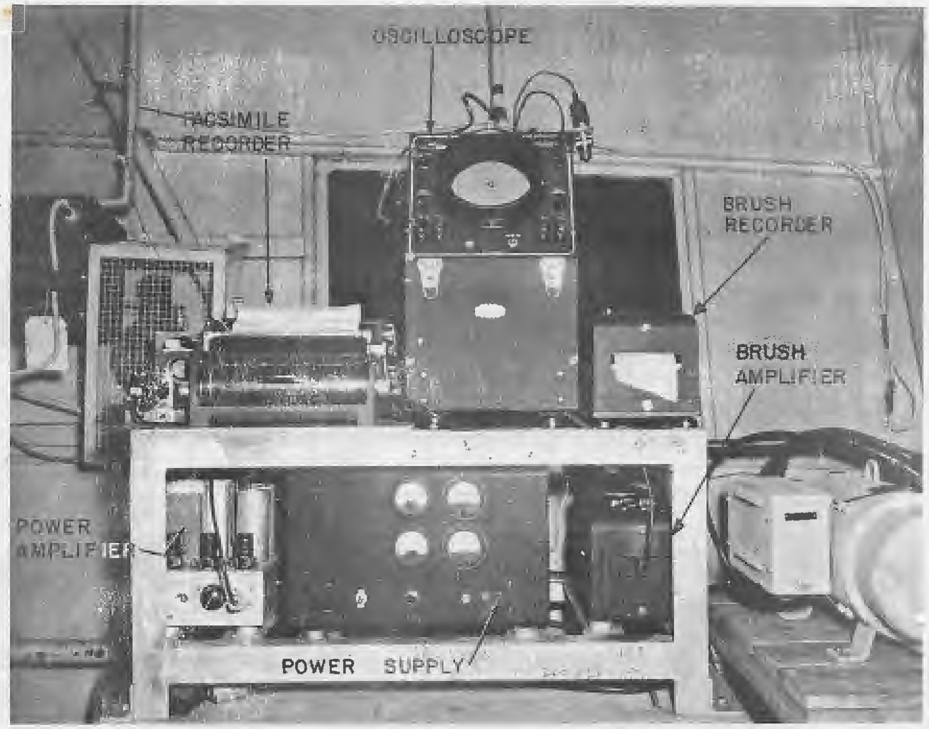

Figure 11 - Electronic console

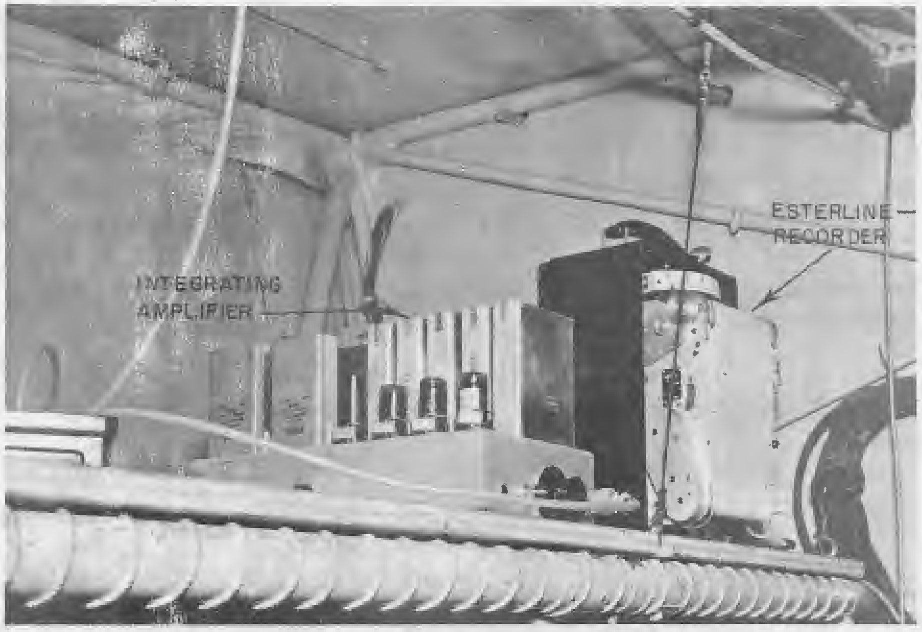

Figure 12 - Integrating amplifier and recorder

Signals appear on the Brush recorder as amplitude deflections from which the magnitude of the wake radiation can be deduced. As explained in the previous report,[8] the signal assumes the shape of a ram's head due to the differentiating action of the amplifier. If the ram's head is right side up, the wake is colder than the surrounding water; if up side down, warmer.

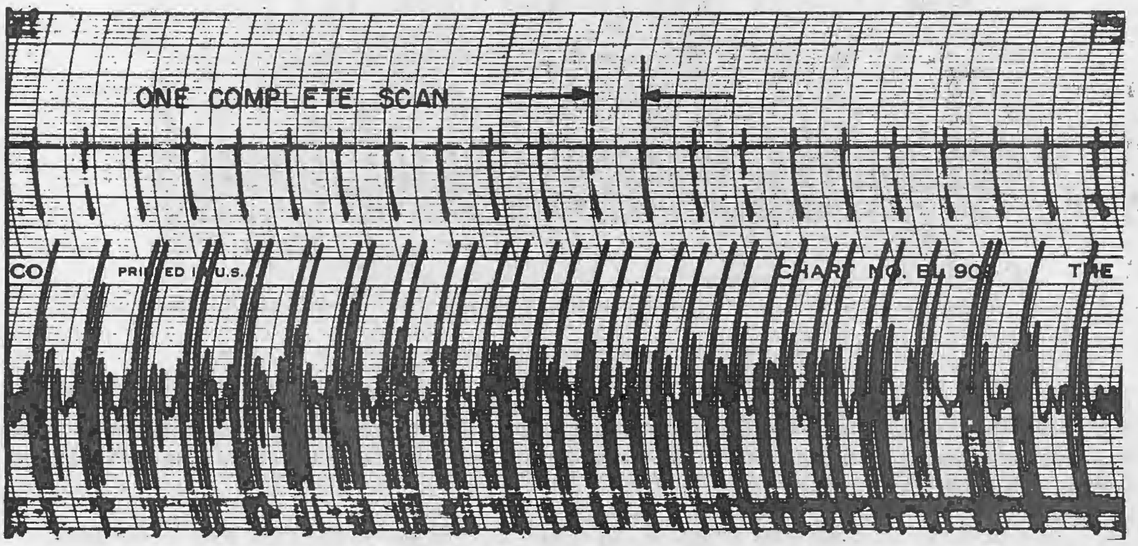

Figure 13 - Brush recording of 50-knot,right-angle wake crossing

A right-angle, 60-knot crossing of a wake produces approximately 30 such signals during the crossing interval. When a wake is approached under such a condition the leading edge of the scanning circle encounters the wake first. This results in a single pip per revolution of the scanner (Figure 13). As the two contact points appear they slip around the circle and finally merge as one at the trailing edge of the circle. The resulting pips on the recorder therefore start as one, split into two with ever increasing separation until the wake coincides with the great diameter of the scanning circle, then, decreasing separation, merge as one as the scanning circle leaves the wake. If the airship flies parallel to the wake, two signal pips of constant angular separation are generated for each complete revolution of the scanner (Figure 14). Wake crossings at other angles lead to variations of these two cases.

Signals presented on the facsimile recorder show this effect to a greater extent. The signal itself is presented as a dark trace bordered on either side by a white trace corresponding to the face and horns of the ram's head. A phase inverter incorporated into the power amplifier (Figure 15) permits inversion of the signal so that a dark-light-dark trace can also be presented. During the measurements made in these experiments, the light-dark-light trace was employed and corresponded to a cold wake. The recorder was synchronized with the scanner so that zero degrees relative to the airship or dead ahead occurred three-quarters of the way across the recorder paper. Zero to 90° extended from this point to the right edge of the paper and 90° to 360° from the left edge to the zero point again. Consequently, signals resulting from a right-angle crossing (Figure 13) appear in v-formation on the facsimile paper (Figure 16). A parallel flight results in

[8] Clark, H. L., loc. cit., footnote 4

[redacted]

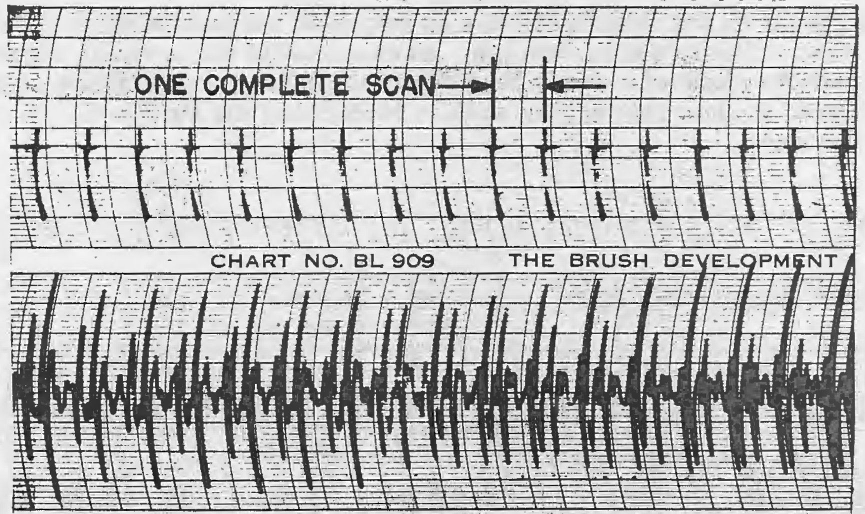

Figure 14 - Brush recording of a flight parallel to the wake

two parallel traces. A recorder with a circular printing mechanism synchronized with the scanner would eliminate all of this confusion, and such a recorder is being built for use in future work.

The integrating amplifier (Figure 17) takes advantage of the fact that a 60-knot, right-angle wake crossing consumes 30 seconds and that during this interval approximately 30 signal pulses are generated. The signals are amplified, rectified, and integrated with a long time constant R-C network before being presented on the Esterline-Angus recorder. The dynamic signal-to-noise ratio thus obtained is superior to that obtained with the Brush recorder or polar coordinate oscilloscope. Two integrating time constants, 2-1/2 seconds and 10 seconds, were available. The 10-second time constant was employed throughout the measurements. A typical example of the improvement in signal-to-noise ratio by integration is shown in Figures 18a and 18b. The dynamic signal-to-noise ratio obtained with the Brush recorder (Figure 18a) is four, but for the same case the dynamic signal-to-noise obtained with the integrating amplifier and Esterline-Angus recorder (Figure 18b) is twelve, or three times greater. Thus the useful measuring range of the equipment is improved by the integration process, a condition which is possible only through the slow air speed offered by the blimp.

All three recorders and their respective amplifiers are monitored by the polar coordinate oscilloscope which does nothing more than serve as a reference against which the recorder indication can be checked during the recording process.

Airship Installation

Installation of the equipment in the airships required the removal of existing gear from the forward bomb bay of the M-2 airship and the addition of a conical wind shield (Figure 19). The optical scanner was hung up inside the shield from special brackets. Directly above the scanner and inside the car, was mounted the electronic console and integrating unit.[9]

[9] All of this work was done by the Experimental Group at NAS, Lakehurst.

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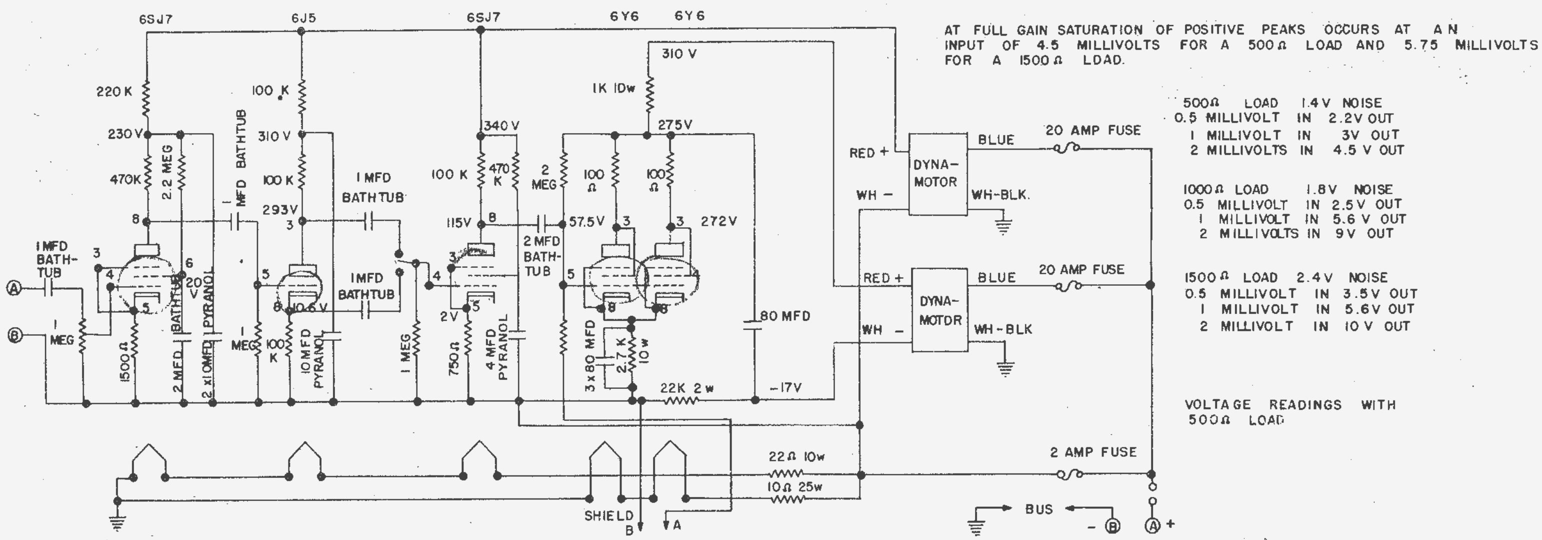

Figure 15 - Power-amplifier wiring diagram

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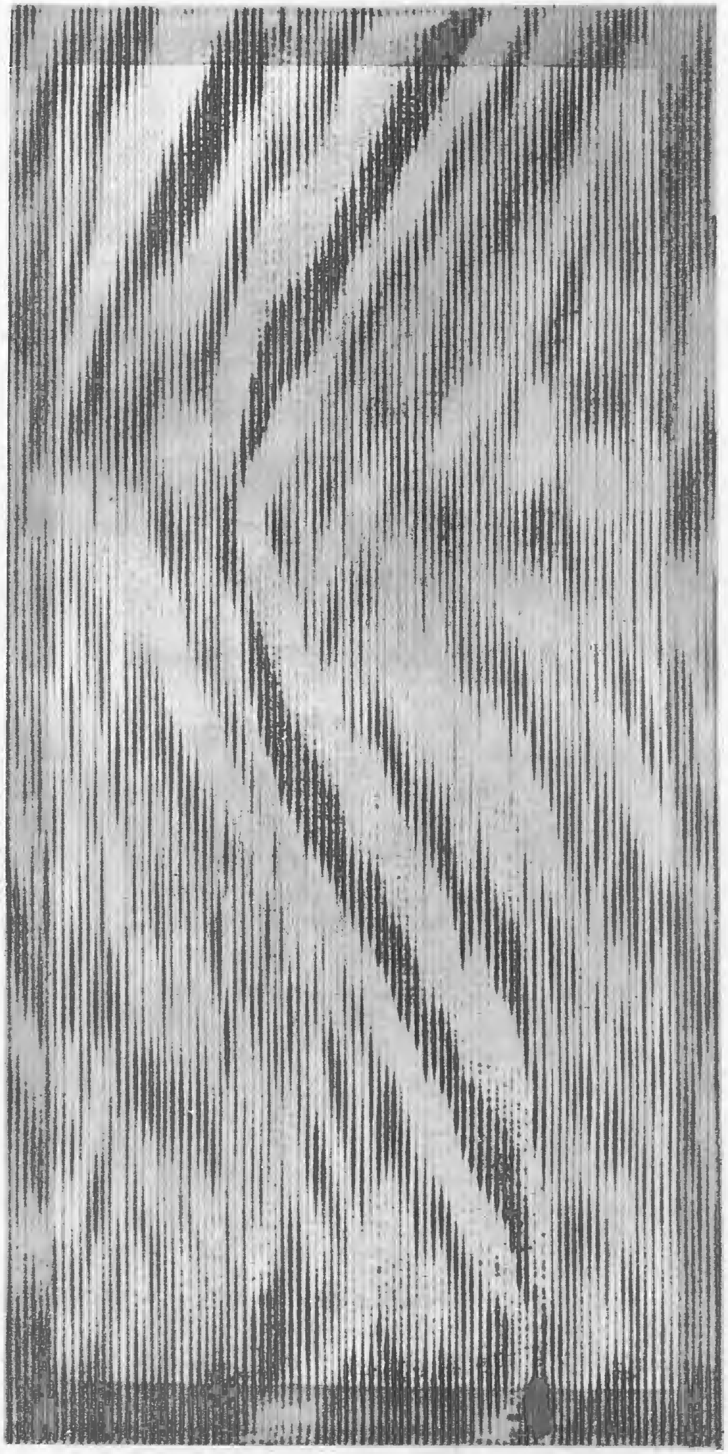

Figure 16 - Facsimile recording of a 50-knot, right-angle wake crossing

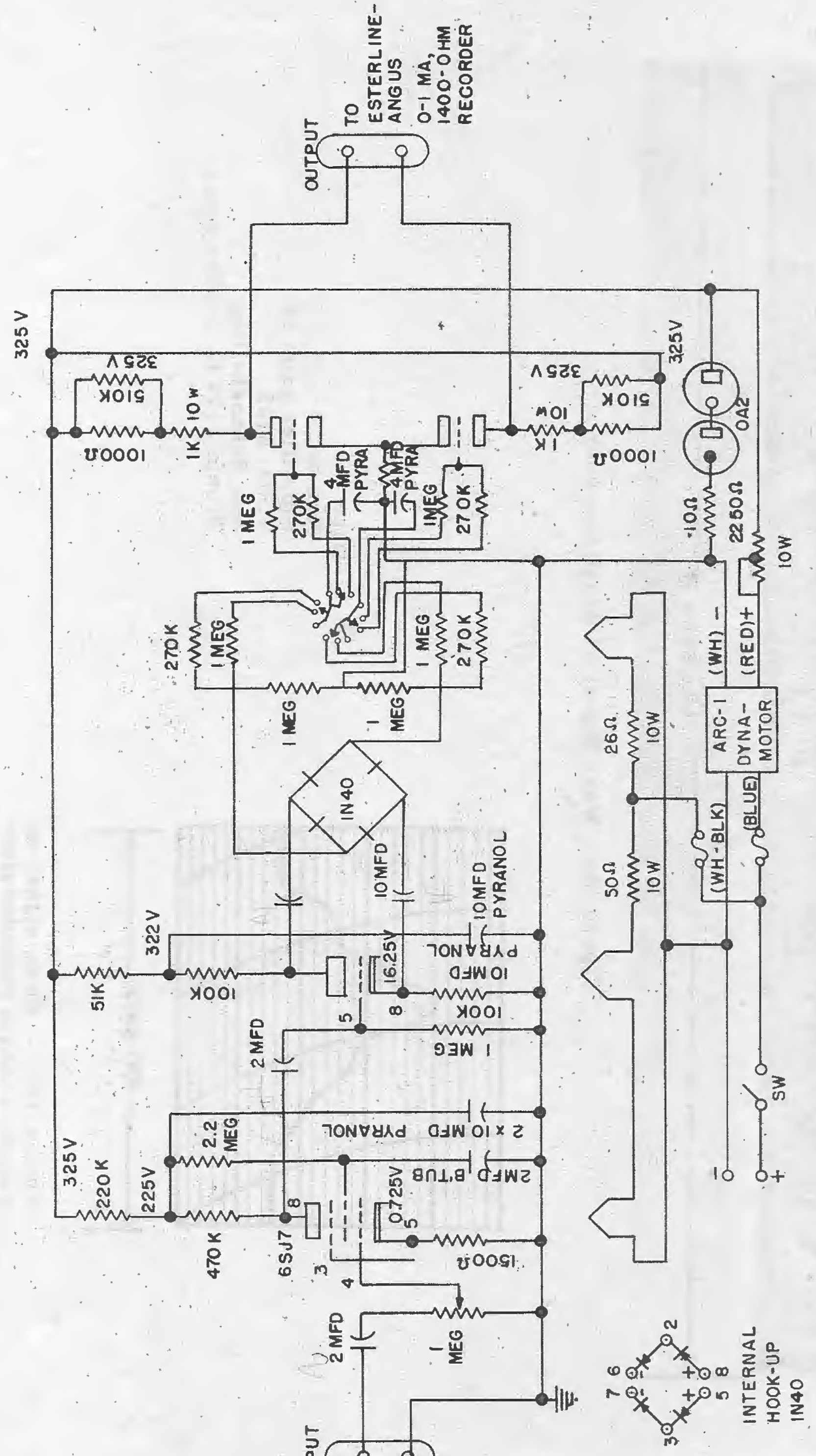

Figure 17 - Integrating-amplifier wiring diagram

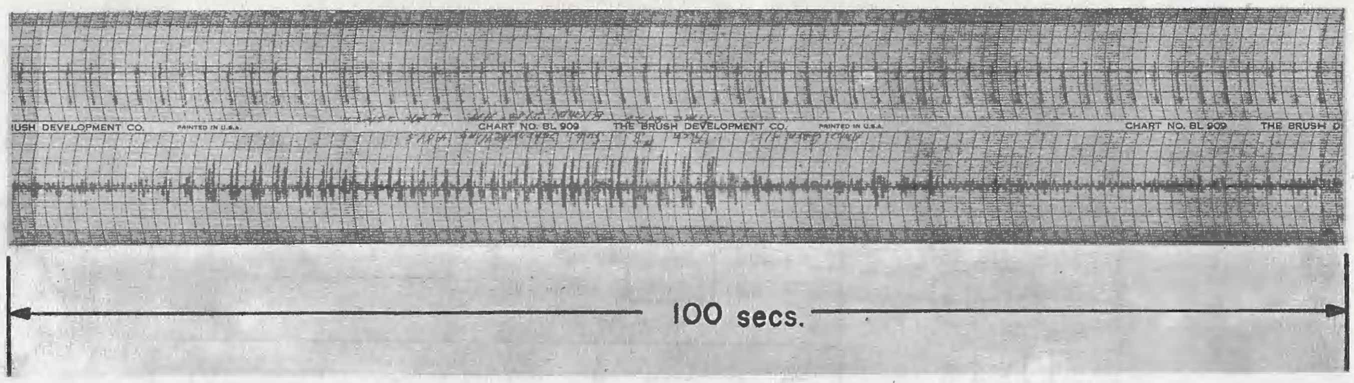

Figure 18a - Wake Signal on Brush recorder

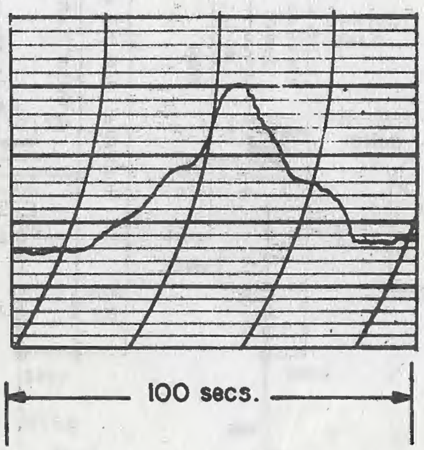

Figure 18b - Wake signal on Esterline-Angus recorder after integration

Data:
Run No. 3
Amplifier gain: 15
Time: 2128
Sub: Schnorkelling
Blimp: 2100 ft, 2 miles astern

[redacted]

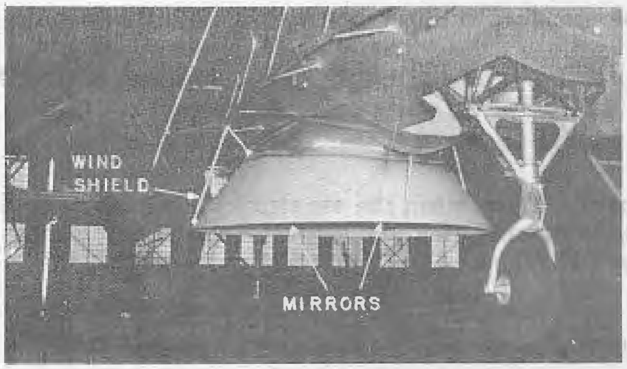

Figure 19 - Wind shield

Power for all units, except for the signal amplifier and its power supply which were battery powered, was supplied from the 27-volt d-c line on the airship. A 27-volt inverter was employed to provide 115-volt, 60-cycle power for the scanner motor and the various a-c operated instruments.

Minor modifications of the equipment were required after installation. The scanner proved to be dynamically unbalanced and swung the airship when rotating. This motion in the earth's magnetic field caused unwanted emf's to be induced in the thermopile circuit. Proper balancing eliminated the source of trouble. Some signal due to the rotation in the earth's field still remained, however. This signal was not evident when the scanner was operating on the steel-reinforced concrete deck of the hanger or the Laboratory. It appeared only when the scanner was suspended in the air. Elimination of this signal was brought about by inserting a magnetic compensating loop in series with the thermopiles. Connections were made so that the emf picked up by the loop bucked out that picked up by the thermopiles.

Operational Sensitivity

In the previous report[10] it was shown that, when the dimensions of the optical field of view projected upon the surface of the sea are equal to or less than the dimensions of a uniformly radiating wake, the radiation available at the optical system is

$$\Delta\phi = \alpha \beta D^2 \left(\frac{\Delta T}{T_0}\right)(\sigma T_0^4)\, \tau \text{ in watts,} \tag{1}$$

where
α = vertical dimension of the optical field of view (radians),
β = horizontal dimension of the optical field of view (radians),
D = diameter of collecting mirror (centimeters),
ΔT = difference in temperature between wake and surrounding water (degrees Kelvin or centigrade),
σ = Stefan-Boltzman constant (5.72×10^{-12} watts cm^{-2} deg^{-4}),
T_0 = temperature of surrounding water (degrees Kelvin), and
τ = total transmission of the atmosphere over the optical path between the wake and the optical system (percent).

When constructing a system for wake radiation measurements, the choice of the parameters α, β, and D should be such that the smallest possible ΔT and not merely $\Delta\phi$ can be measured. In other words the quantity

$$\frac{\Delta\phi}{\alpha \beta D^2} = \left(\frac{\Delta T}{T_0}\right)(\sigma T_0^4)\, \tau \tag{2}$$

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[10] Clark, H. L., loc. cit., footnote 4

should be minimized. Equation (2) can be modified slightly by multiplying both sides by $4/\pi$ giving

$$\frac{\Delta\phi}{\alpha\beta A} = \frac{\Delta\phi}{\alpha\beta\left(\frac{\pi D^2}{4}\right)} = \frac{4}{\pi}\left(\frac{\Delta T}{T_0}\right)(\sigma T_0^4)\,\tau \text{ in watts cm}^{-2}\text{ steradian}^{-1}, \qquad (3)$$

where A is the area of the collecting mirror. Thus, when the sensitivity, equivalent noise input, or minimum detectable signal of an instrument for use against an extended target such as a wake is stated, it should be given in terms of watts per area of mirror per steradian of field of view.

In practice, one measures the sensitivity, equivalent noise input, or minimum detectable signal (in watts per square centimeter) in the usual way and then must divide this quantity by the measured angular field of view (in steradians) to obtain the sensitivity figure. The radiation density at the mirror required to produce a signal-to-noise ratio of unity on the Brush recorder was found to be 4.5×15^{-10} watts cm^{-2}. The measured field of view was found to be $5^0 \times 5^0$ (0.087 x 0.087 radian) or 7.6×10^{-3} steradians. Thus the equivalent noise input of the system is 5.9×10^{-8} watts cm^{-2} $steradian^{-1}$. The figure is, however, approximately three times greater than that which could be realized from a system limited solely by Johnson noise from the thermopiles. The factor of three is due to the noise generated by the air inside the thermopile cases swishing over the thermopiles as the scanner rotates. Evacuated or helium-filled cases should have been employed but could not be fabricated in time for these measurements.

In actual flight, the noise level increased by another factor of two due to vibration and sway in the earth's magnetic field. Thus the operational equivalent noise level of the system became 1.2×10^{-7} watts cm^{-2} $steradian^{-1}$.

From Equation (3), the temperature difference corresponding to the operational equivalent noise input can be calculated, assuming an atmospheric transmission of 30 percent and a sea surface temperature of 300°K. It amounts to 0.002°C for the present system. Hence an easily measurable temperature under such conditions is 0.005°C or greater.

Since the equivalent noise input of a system is a direct indication of the temperature differences which it can measure, it is interesting to compare the above values with those obtainable with earlier equipments under the same conditions. The gear employed in the Key West area had an operational equivalent noise input of 10^{-9} watts cm^{-2} and a field of view of $5^0 \times 5^0$ or 1.2×10^{-6} watts cm^{-2} $steradian^{-1}$, which is equivalent to a temperature difference under the above conditions of 0.02°C. The gear employed in the New London area had an operational equivalent noise input of 3×10^{-9} watts cm^{-2} and a field of view of $3^0 \times 1^0$ or 3.3×10^{-6} watts cm^{-2} $steradian^{-1}$, which is equivalent to a temperature difference under the above conditions of approximately 0.06°C. In other words, the present equipment is 10 times better than the Key West gear and 30 times better than the New London gear.[11] The most recent tests show that another improvement of at least twenty times is advisable.

[11] BuAer specifications for the development of similar gear by the Servo Corporation of America, for use in heavier-than-air craft, call for an ENI (Equivalent Noise Input) of 6×10^{-11} watts cm^{-2} and a field of view of $1^0 \times 1^0$ which will yield 2×10^{-7} watts cm^{-2} $steradian^{-1}$. This is equivalent to a temperature difference of 0.004°C for a 300° K sea and a 30-percent atmosphere.

 [redacted]

[redacted]

SHAKEDOWN TESTS

Because of bad weather, only two shakedown flights were undertaken. These were made at night off the New Jersey shore east of Asbury Park, and did not extend more than 20 miles seaward. Low hanging haze was present during both nights and the absolute humidity was 1.5 cm ppt. H_2O per sea mile.

The area chosen for the trials included steamship lanes so that wakes from passing traffic could be employed as targets. The thermal background in this area was moderately noisy. The sea appeared to be covered with long thermal streaks which were probably remanents of old wakes. Those wakes which could be identified were tracked 7 or 8 miles astern the vessels producing them. Figure 16 shows a typical wake signal observed at a point 7 miles astern the vessel which generated it.

Oil slicks gave good signals and, like the wakes, appeared to be colder than the surrounding water. Figure 20 shows a trace obtained from an oil slick. A good trace (Figure 21) was also obtained from the wake of a can buoy anchored five miles offshore in a running sea. The fact that signals were obtained from the wake of a can buoy, and particularly from an oil slick, leads one to believe that the generation of such signals can involve differences in emissivities and reflectivies of the water surfaces as well as temperature differences.

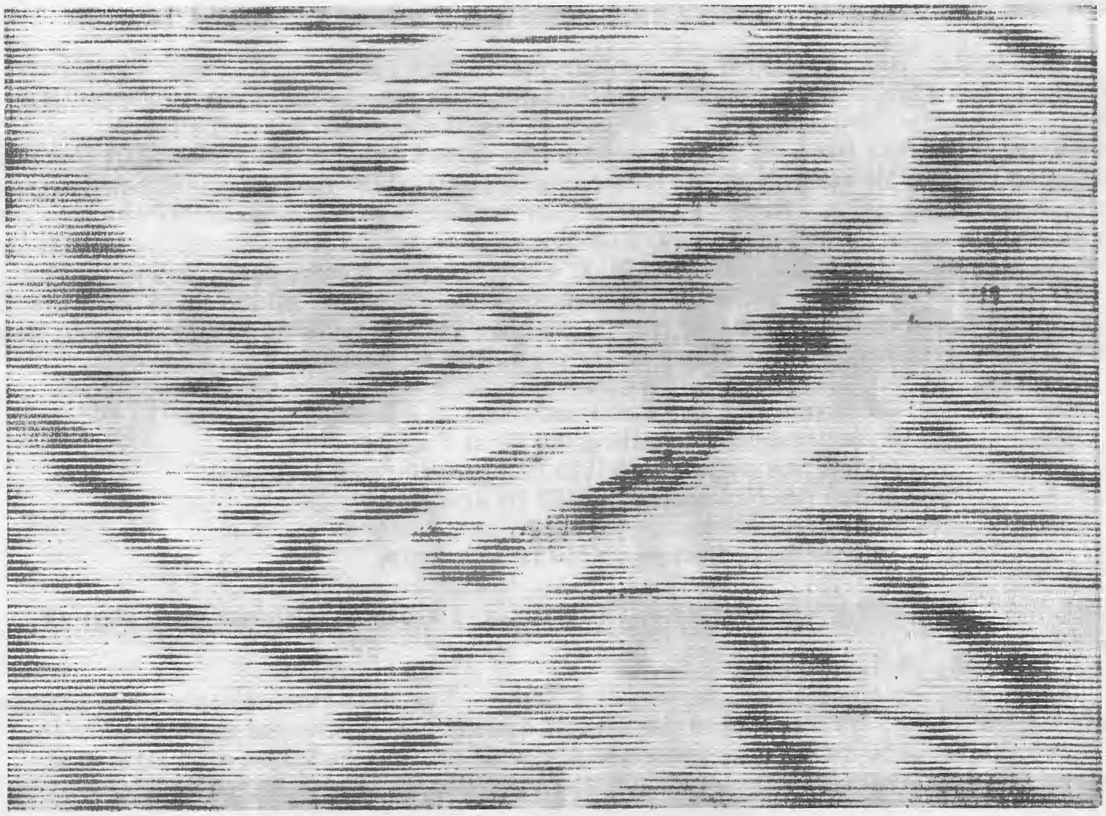

Figure 20 - Oil slick

[redacted]

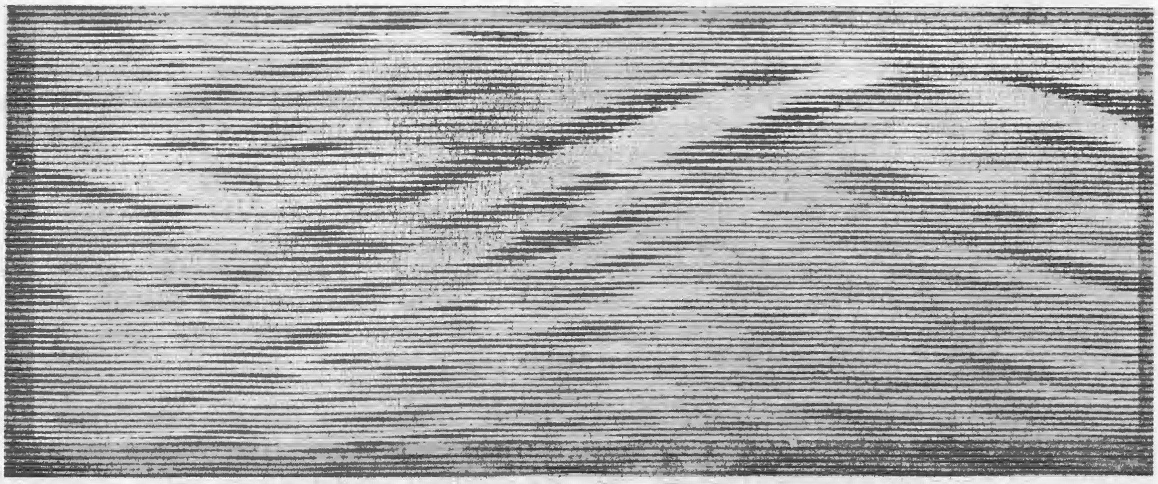

Figure 21 - Wake from a can buoy

EXERCISES WITH USS IREX

Airborne Measurements

The site chosen for the formal measurements with the submarine was located off the Continental Shelf in deep water approximately 150 miles east of Atlantic City, New Jersey. Five successive nights, 22 through 26 May 1950, were set aside for the measurements. The USS IREX was designated as the target and the USS PEREGRIN (AM) was assigned the task of making the surface contact temperature measurements with a group from NADC, Johnsville. The M-2 airship carried NRL's airborne gear. It was intended to have the submarine proceed at various depths down to 300 feet and at speeds of from 2 to 6 knots while the PEREGRIN and M-2, employing the tactics described in the previous report,[12] made the necessary measurements. However, on the third night the NRL gear failed due to a frozen bearing in the scanner and the tests were discontinued. Nonetheless, excellent data were obtained under the following conditions:

(a) Submarine surfaced and underway at 6 knots
(b) Submarine schnorkelling (60 ft) at 6 knots
(c) Submarine submerged (150 ft) and underway at 6 knots
(d) Submarine schnorkelling (60 ft) at 4 knots
(e) Submarine periscope up (60 ft) at 4 knots
(f) Submarine periscope up (60 ft) at 2 knots.

In addition, data concerning optical noise from large areas of open sea were also obtained.

Submarine Surfaced and Underway at 6 Knots - The first run attempted was intended to orientate the groups involved in the measurements and to iron out any "bugs" in the test procedure. The submarine remained surfaced and proceeded on a straight-line course at 6 knots with the blimp marking the resulting wake with flares at intervals of

[12] Clark, H. L., loc. cit., footnote 4

2000 yards. Numerous passes were made over the wake during the early part of the run and a number of airborne measurements were made. The results are presented in Table 2. This section of the wake was later investigated by the Johnsville group from aboard the PEREGRIN. After a sufficient length of wake was generated by the submarine, a flight along the wake was made. These results are plotted in Figure 22. During these measurements the blimp approached the submarine bow-on and flew down the wake a distance of 9000 yards, at which point it was necessary to turn off the wake to avoid the surface vessel. At the turn-off point the wake was 45 minutes old. It is not known how far the wake could have been followed had the surface vessel not been in the way. The results shown in Figure 22 have been expressed in terms of radiant intensity. No attempt has been made to convert these values into temperature differences at the surface of the water because the Johnsville group observed no temperature difference at all with their gear during this run. The signals appear to be due to differences in reflectivities and emissivities between the wake and surrounding water. The wake signal, in this case, appears to decrease slowly with age or distance astern the submarine but local variations, apparently due to variations in water condition, have an equally great effect on the signal. This is borne out more strongly in later measurements.

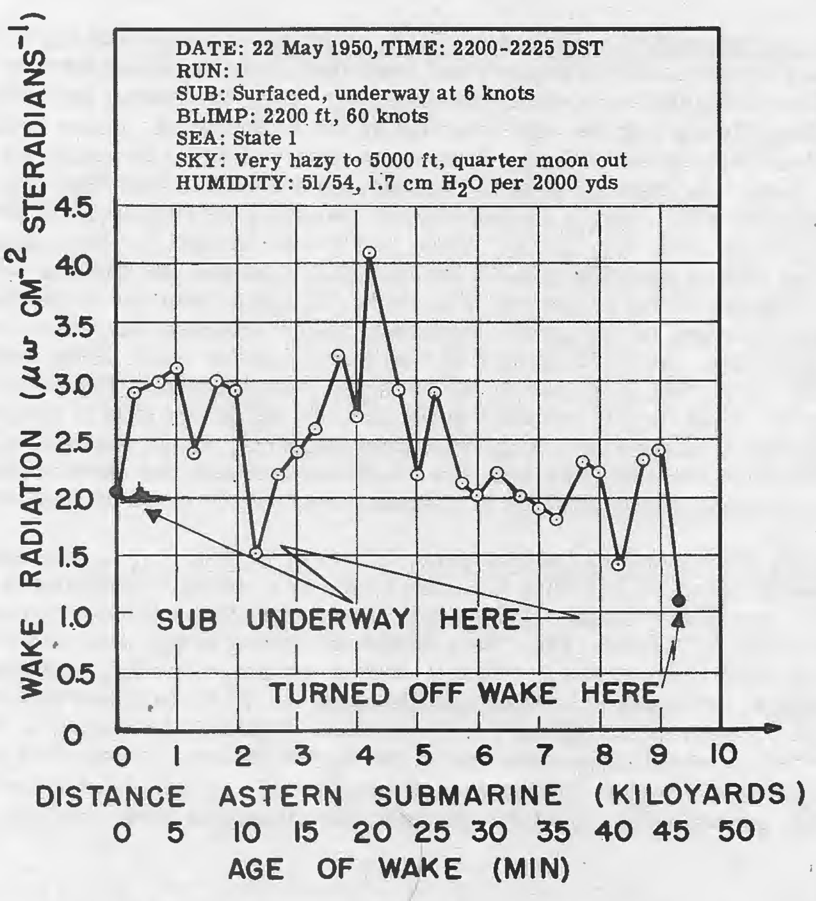

Figure 22 - Wake radiation from submarine underway on surface at 6 knots

TABLE 2

Radiation from First Section of Wake Generated by Submarine Underway on Surface at 6 Knots

Time (hr, DST)	Distance Astern (yd)	Age (min)	Signal (μw cm^{-2} steradian^{-1})
2054	500	2½	1.9
2056	1500	7½	0.8
2120	500	2½	3.2
2121	1500	7½	1.0
2135	2000	10	0.7
2150	2000	10	0.9
2202	3000	15	1.2
2207	2500	12½	2.3
2210	4000	20	1.8

Date: 22 May 1950
Run: 1
Blimp: 2200 feet altitude
Sea: State 1
Sky: Very hazy to 5000 feet, quarter moon out
Humidity: 51/54, 1.7 cm H_2O per 2000 yards

Submarine Submerged to 60 Feet and Schnorkelling at 6 Knots – At the completion of the first run, the submarine moved to a new and unmarked operating area; dove to 60 feet (screw depth); and proceeded at 6 knots while schnorkelling. After the submarine had gone about 5000 yards the blimp flew along the wake starting at the diving point. Some results are shown in Figure 23 and others in Table 3. This same area was later investigated by the Johnsville group. Near the conclusion of the submarine's run a second flight was made along the wake, starting with a bow-on approach and swinging off 10,000 yards astern to avoid the surface vessel. The results are shown in Figures 24 and 25. Here again it is not known how far astern the wake could have been followed had the surface vessel not been in the way. The facsimile recording, Figure 24, is a poor one due to the improper setting of the gain control on the power amplifier, which consequently overdrove the chemical paper, but does show the entire length of that portion of the wake being investigated. Signal amplitudes, obtained from the Brush recorder, are plotted in Figure 25. The time required for the wake to mature after generation by the submarine is clearly shown although somewhat masked by a local variation occurring in the same area. Any decrease in the magnitude of the radiation with age or distance astern the submarine is not evident. Local variations predominate and mask any general trends if such exist.

Submarine Submerged to 150 Feet and Underway at 6 Knots – The last run[13] during the first night's exercise was with the submarine on a straight-line course at a depth of 150 feet and a speed of 6 knots. During this run the blimp made only right-angle or near right-angle crossings of the wake. No attempt was made to fly along the wake. The results of these passes are given in Table 4, with a typical recording in Figure 26. The wake radiation under these operating conditions is two to three times smaller than the wake radiation observed during the first two runs. The data presented in the Johnsville report,[14] which covered measurements in the Key West area, shows that any wake generated at a depth of 150 feet and older than 4 minutes will exceed 250 feet in width. Hence all of the data presented in Table 4 represent radiation from only a portion of the submarine's

[13] This, the seventh planned run, was executed during the first night.

[14] West, H. L., loc. cit.

[redacted]

TABLE 3

Radiation from First Section of Wake Generated by Submarine Submerged to 60 Feet and Schnorkelling at 6 Knots			
Time (hr, DST)	Distance Astern (yd)	Age (min)	Signal (μw cm^{-2} steradian^{-1})
2330:00	4000	20	3.6
2330:10	3700	18½	3.6
2330:20	3300	16½	3.7
2330:30	3000	15	3.5
2330:40	2700	13½	3.1
2330:50	2300	11½	3.0
2331:00	2000	10	3.0
2331:10	1800	8½	3.2
2331:20	1300	6½	3.4
2331:30	1000	5	3.5
2331:40	700	3½	3.4
2331:50	300	1½	3.5
2332:00	0	0	3.6

Date: 22 May 1950
Run: 2
Blimp: 2300 feet altitude
Sea: State 1
Sky: Very hazy to 5000 feet, quarter moon out
Humidity: 51/54, 1.7 cm H_2O per 2000 yards

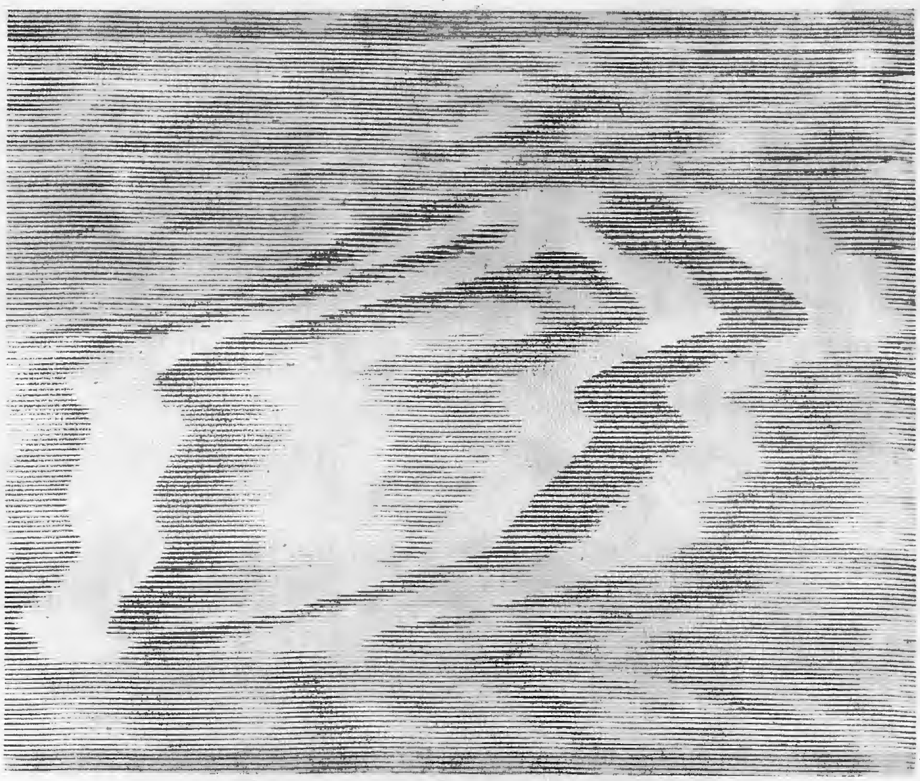

Figure 23 - Wake from newly submerged submarine schnorkelling at 6 knots

[redacted]

wake and not from an entire cross-sectional slice. Thus, a 20- or 30-minute old wake, which may measure 800 feet or more in width, is three times wider than the projected field of view of the airborne gear and will consequently yield only one third the signal realizable with an 800-foot-wide field of view. This may or may not account for the smaller radiation observed during this last run.

Figure 24 - Wake from submarine schnorkelling at 6 knots observed 0-5 miles astern

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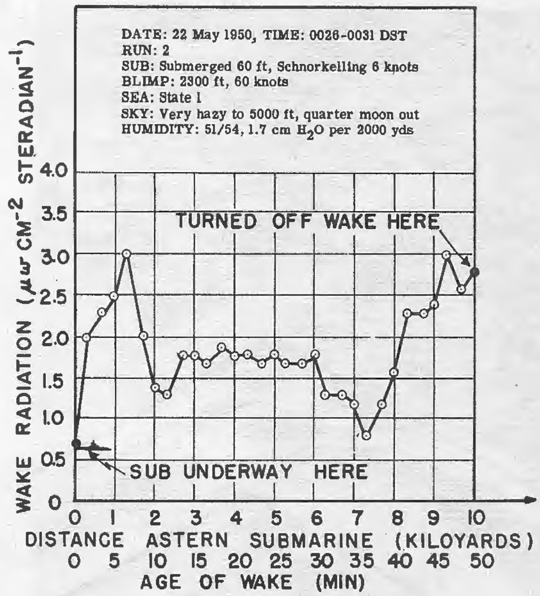

Figure 25 - Wake radiation from sub schnorkelling at 6 knots

TABLE 4

Radiation from Wake Generated by Submarine Submerged to 150 Feet and Underway at 6 Knots

Time (hr, DST)	Distance Astern (yd)	Age (min)	Signal (μw cm^{-2} steradian^{-1})
0226:00	3000	15	1.0
0226:30	2000	10	1.1
0227:00	1000	5	0.6
0231:00	2000	10	0.7
0231:30	3000	15	0.6
0235:00	5500	27	0.7
0235:30	6000	29½	1.0
0236:00	6500	32	1.2
0236:30	7000	34½	1.3
0237:00	7500	37	0.7
0248:00	2000	10	0.7
0248:30	2500	12½	0.8
0249:30	3500	17½	1.0
0250:00	4000	20	1.0
0253:30	4000	20	0.8
0254:45	5000	25	1.2
0255:00	6000	30	1.0
0304:00	6000	30	1.0
0304:30	5000	25	1.1
0305:00	4000	20	1.0

Date:	23 May 1950
Run:	7
Blimp:	2000 feet altitude
Sea:	State 1
Sky:	Slight haze to 500 feet, quarter moon out
Humidity:	51/54, 1.7 cm H_2O per 2000 yards

[redacted]

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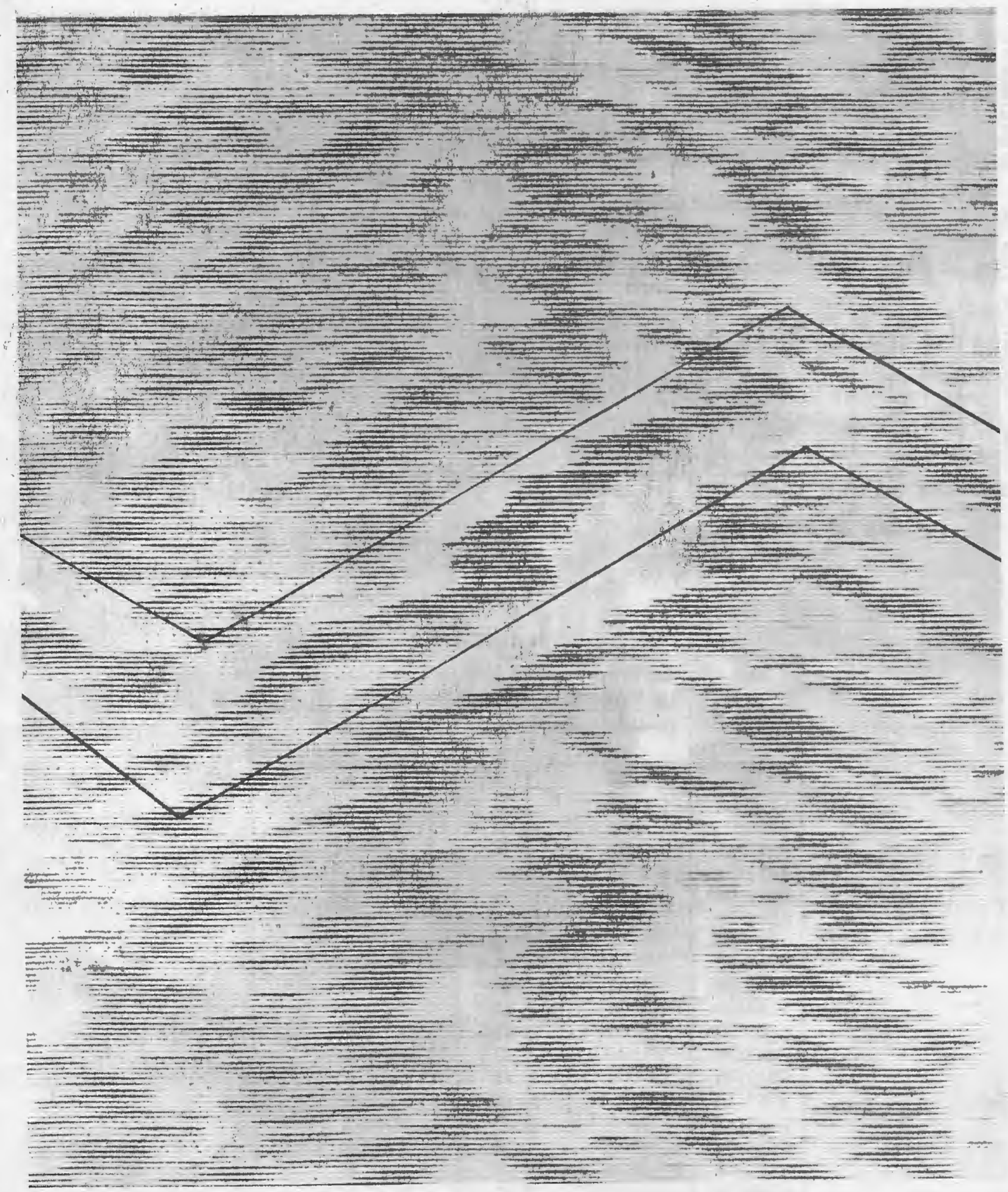

Figure 26 - Signal trace from a right-angle crossing of the sub's wake generated at 150 feet at 6 knots

 [redacted]

Submarine Submerged to 60 Feet and Schnorkelling at 4 Knots — The first run undertaken on the second night was with the submarine schnorkelling at a depth of 60 feet at a speed of only 4 knots. The first portion of the wake was investigated in a random fashion as the marker flares were placed in position. The results of these measurements are given in Table 5. This area was later investigated by the Johnsville group. After all marker flares were dropped and while the submarine was still underway, a flight was made along the wake starting at the submarine and veering off near the surface vessel. The results are shown in Figure 27. The magnitudes of the wake radiation observed during the flight are plotted in Figure 28. Local variations again predominate in this plot. However, the time for the wake to mature behind the submarine is clearly evident. Also evident is the slow decrease in wake radiation with age or distance astern the point of maturity. An average decrease of only 30 percent in 12,000 yards is evident. Since it was necessary to fly off the wake at the 12,000-yard point to avoid the surface vessel and its relatively cold wake, it is not known in this case how far the wake could have been traced had the surface vessel not been present and had the submarine's run been longer.

Submarine with Periscope Up, Submerged to 60 Feet, and Underway at 4 Knots — At the completion of the 4-knot schnorkel run, the submarine surfaced and proceeded to a new area for the next run. It then dove to 60 feet and, with only its periscope extended, maintained a straight-line course at 4 knots. Sample measurements were taken all along the wake and are given in Table 6. During this run advantage was promptly taken of an opportunity to fly the whole length of the wake without interference from the surface vessel. The resulting facsimile recording and the radiation magnitudes obtained during this

TABLE 5

Radiation from Wake Generated by Submarine Submerged to 60 Feet and Schnorkelling at 4 Knots

Time (hr, DST)	Distance Astern (yd)	Age (min)	Signal (μw cm^{-2} steradian^{-1})
2042:00	500	4	1.2
2042:30	700	5	1.1
2043:00	900	7	1.0
2056:00	2000	15	2.9
2056:30	1500	11	2.6
2057:00	1000	7½	2.6
2115:00	1000	7½	3.1
2115:30	2000	15	3.7
2120:00	700	5	2.0
2120:30	1700	13	3.4
2138:00	4000	30	1.9
2138:30	5000	38	2.4
2134:00	6000	45	1.6
2134:30	5000	37	1.2
2135:00	4000	30	1.9
2135:30	3000	22	2.5
2136:00	2000	15	2.2
2136:30	1000	7½	1.8
2137:00	0	0	0.8

Date:	23 May 1950
Run:	3
Blimp:	2000 feet altitude
Sea:	State 1
Sky:	Slight haze to 5000 feet, quarter moon out
Humidity:	54/58, 1.8 cm H_2O per 2000 yards

flight are presented in Figures 29 and 30. Both figures show the submarine's surface wake, the relatively large disturbance created by its dive, and, of course, the wake from the submerged run. This submerged run was exactly like the previous one except that the schnorkel was retracted. A comparison of Figures 28 and 30 shows that retraction of the schnorkel reduced the wake radiation considerably. In other words, the schnorkel made the wake colder and not warmer as one might expect. This could be due to the fact that the schnorkel increases the turbulence in the wake and thereby causes the emissivity and reflectivity of the wake to change so that it appears colder. On the other hand, the difference in signal level between Figures 28 and 30 may be due to differences in the vertical temperature gradient in the waters of two areas.

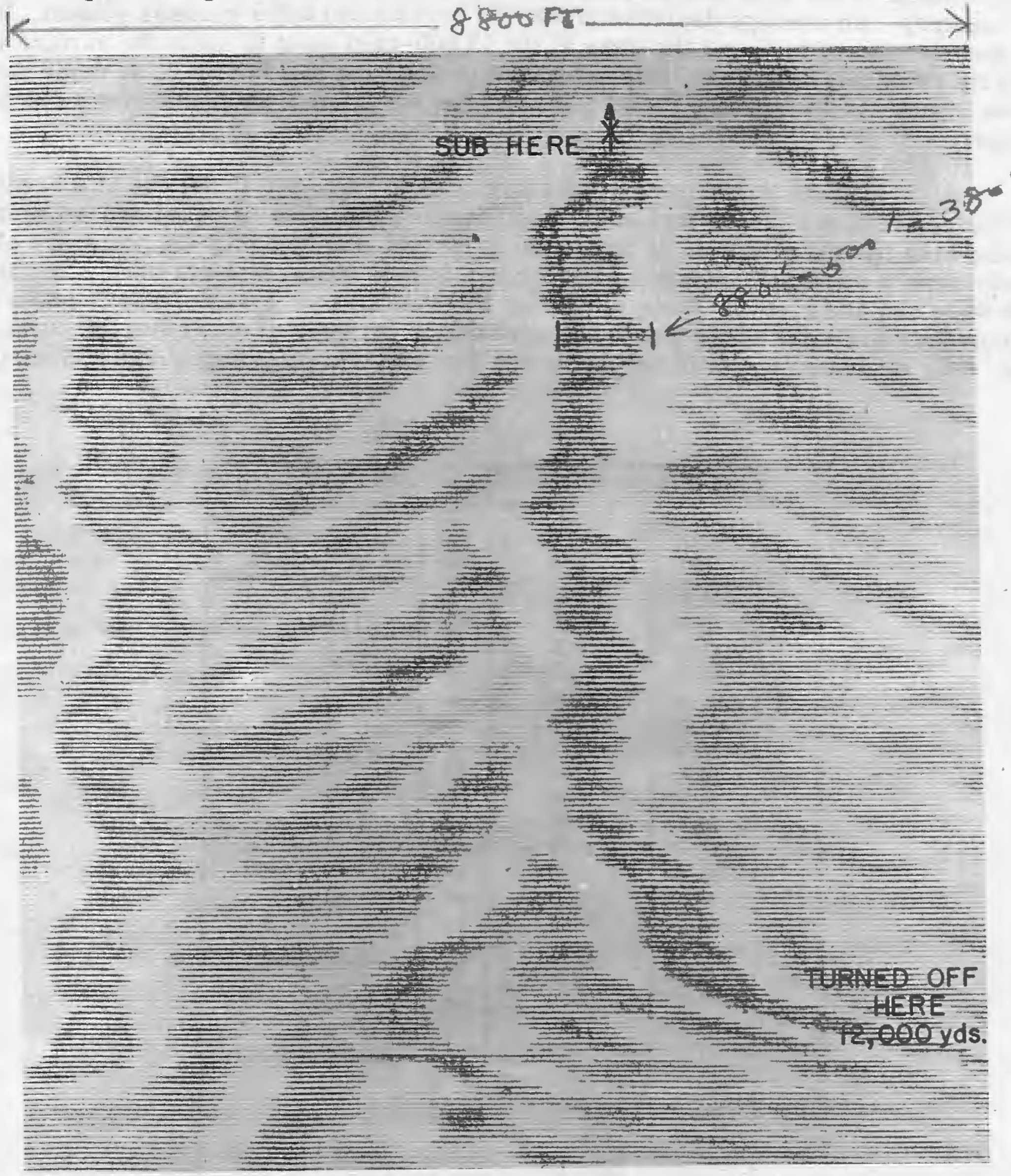

Figure 27 - Wake from sub schnorkelling at 4 knots observed 0-6 miles astern

TABLE 6

Radiation from Wake Generated by Submarine Submerged to 60 Feet and Underway at 4 Knots with Periscope Up			
Time (hr, DST)	Distance Astern (yd)	Age (min)	Signal (μw cm^{-2} steradian^{-1})
2242:00	500	4	2.0
2242:00	1500	11	4.2
2244:00	1500	11	2.9
2244:00	500	4	2.2
2249:00	100	1	1.2
2249:00	1100	8	2.5
2250:00	200	1½	0.9
2251:00	1200	9	1.2
2312:00	1000	7½	2.1
2312:00	2000	15	2.2
2315:00	5000	38	1.1
2315:30	4000	30	1.2
2324:00	500	4	1.0
2324:00	1500	11	1.2
2341:00	3000	23	1.4
2341:00	4000	30	1.1
Date:	23 May 1950		
Run:	4		
Blimp:	2000 feet altitude		
Sea:	State 1		
Sky:	Hazy to 5000 feet, quarter moon out		
Humidity:	54/58, 1.8 cm H_2O per 2000 yards		

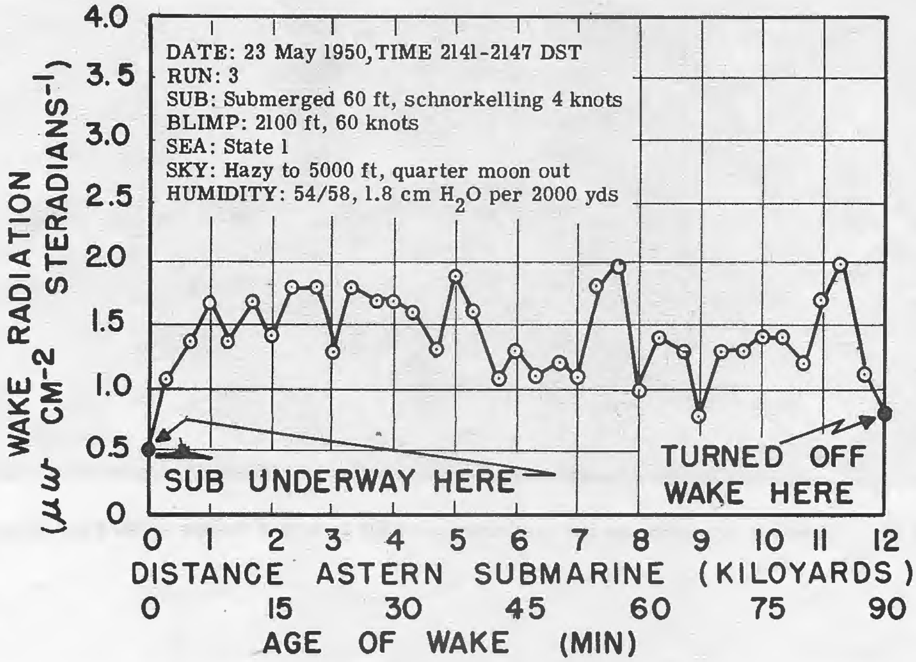

Figure 28 - Wake radiation from sub schnorkelling at 4 knots

[redacted]

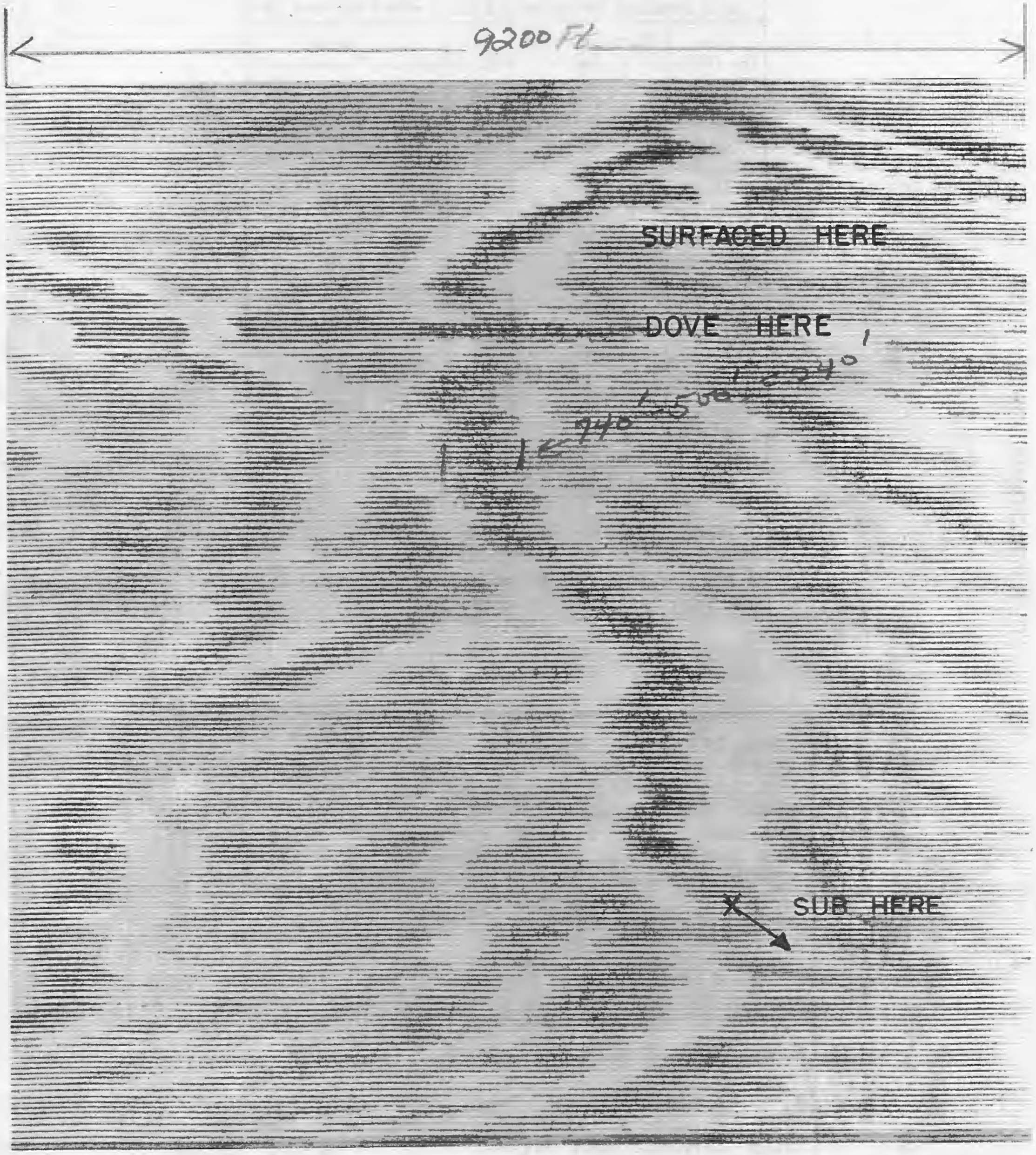

Figure 29 - Wake from submarine underway at 60 ft and 4 knots with periscope up

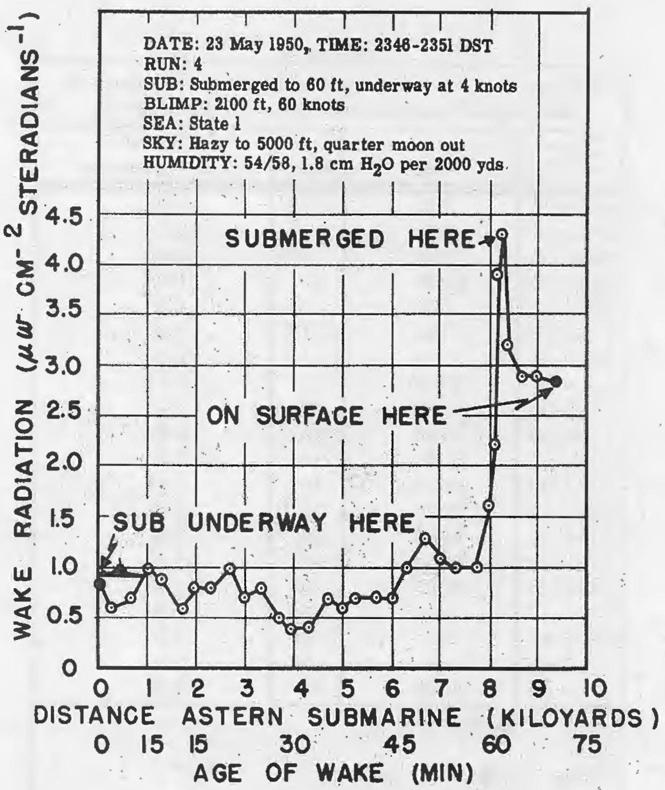

Figure 30 - Wake radiation from sub underway at 60 feet and 4 knots with periscope up

Submarine with Periscope Up, Submerged to 60 Feet, and Underway at 2 Knots — The last run executed before the airborne gear broke down was with the submarine underway at only 2 knots at a depth of 60 feet with its periscope extended. Sample measurements were made along most of the submarine's wake. Attempts were made also to fly along the wake in an effort to obtain a continuous plot of the wake radiation. However, the submarine's course was not straight and proved difficult to follow continuously with the airship. Right-angle or near right-angle crossings were therefore made. The results are tabulated in Table 7 and a sample recording is shown in Figure 31. Near the end of the submarine's run, signals from another wake of unknown origin appeared. It is surmised that this new wake came from a freighter which passed close to the operating area earlier in the run and that the wake drifted across the submarine's course, thus allowing the submarine to run into it. It was still possible to identify the submarine's wake in the presence of the other wake as long as the two did not coincide. The problem of identifying or even locating a submarine's wake in the presence of colder wakes from surface vessels appears to be a difficult one. If they can be resolved, the chances are that the weakest wake belongs to the submarine.

A comparison of the data from all six runs has been made in Table 8. The average value of the wake radiation for each run is presented. Readings taken closer than 1000 yards to the submarine and readings which are not representative of that particular run are not included. From the table, it is obvious that the wake radiation decreases with decreasing speed and increasing depth. Also, the wake radiation decreases with increasing streamlining. In other words, a submarine operating at a slow speed at great depths with its schnorkel and periscope retracted generates a wake which radiates the least at the surface relative to the surface water.

TABLE 7

Radiation from Wake Generated by Submarine Submerged to 60 Feet and Underway at 2 Knots with Periscope Up

Time (hr, DST)	Distance Astern (yd)	Age (min)	Signal (μw cm^{-2} steradian^{-1})
0036:00	100	1½	1.0
0042:00	100	1½	2.1
0046:00	100	1½	1.9
0053:10	1000	15	1.0
0053:30	500	7½	1.1
0054:00	100	1½	1.3
0059:00	100	1½	1.2
0059:00	1000	15	0.7
0106:00	2000	30	1.2
0106:00	3000	45	0.8
0115:00	1000	15	1.0
0131:00	4000	60	1.4
0131:30	5000	75	1.2
0136:00	6000	90	0.8
0137:00	4000	60	0.9
0138:00	2000	30	1.2
0138:00	500	7½	1.4
0139:00	0	0	1.8
0145:00	0	0	2.0
0146:00	2000	30	1.2

Date:	24 May 1950
Run:	5
Blimp:	2200 feet altitude
Sea:	State 1
Sky:	Hazy to 5000 feet, quarter moon out
Humidity:	54/58, 1.8 cm H_2O per 2000 yards

TABLE 8

Comparison of Average Wake Radiation for Various Operating Conditions of the Submarine

Screw Depth (Feet)	Speed (Knots)	Operating Condition	Average Wake Radiation, ψ (μw cm^{-2} steradian^{-1})
15	6	Surfaced	2.1
60	6	Schnorkelling	2.3
60	4	Schnorkelling	1.7
60	4	Periscope up	1.1
60	2	Periscope up	1.0
150	6	Buttoned up	0.9

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[redacted]

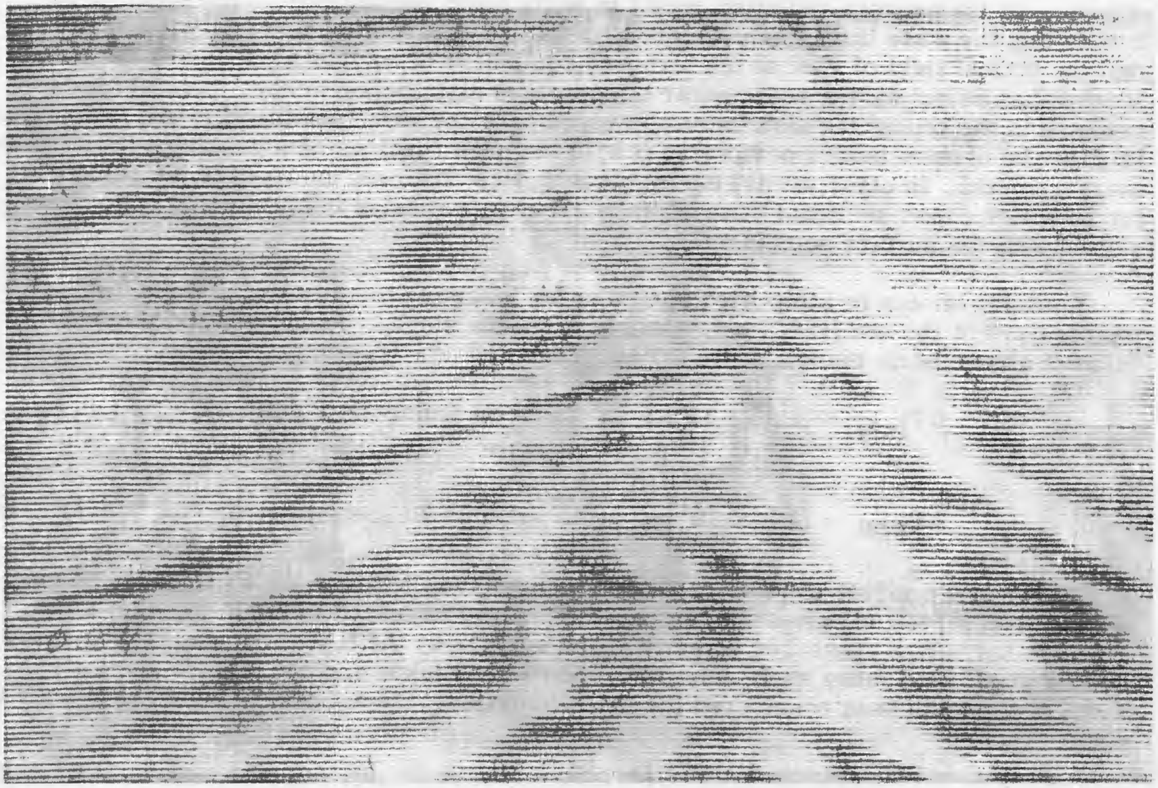

Figure 31 - Signal trace from right-angle crossing of wake of sub underway at 60 feet and 2 knots with periscope up

Correlation of Airborne and Surface Measurements

Accurate correlation between the contact temperature measurements made from the surface vessel and the radiation measurements made from the airship is not possible because it was not feasible to have both sets of measurements taken simultaneously at the same location. As an alternative, a comparison of the data averaged over an entire single run would give more accurate results provided that enough values were recorded to yield a good average in the presence of the relatively large local variations along a given wake. The fact that the average wake signal decreases very little with distance astern the target is a good argument in favor of handling the data in this manner. Practically, the great difference between the maneuverability of the surface vessel and airships introduces difficulties. For example, during the time which the airships took to take anywhere from 10 to 20 good readings, the surface vessel was able to obtain only 1 to 5 good readings. Lack of longer submarine availability made it necessary to operate in this manner. In the absence of a better method, correlation of the air and surface data averaged over an entire run must be made.

From Equation (3), the apparent difference in temperature between the wake and surrounding water is given by:

$$\Delta T = \frac{\pi}{4}\left(\frac{T_0}{(\sigma T_0^4)\ \tau}\right) \psi \text{ in } ^\circ C \qquad (4)$$

[redacted]

where ψ is the average radiation signal in watts cm^{-2} steradian^{-1}. This equation assumes that the wake has a rectangular temperature distribution across its width and that the optical field of view of the airborne equipment is completely filled by the wake. Most wakes do not have a rectangular temperature distribution across their width. More common is the triangular distribution in which case the value obtained for ΔT in Equation (4) must be doubled before comparing it with the peak readings obtained from the surface measurements. In other words, the airborne device observes an average temperature for an entire cross sectional slice of wake. It cannot resolve the peaks and valleys observed with the surface equipment.

Equation (4) can be simplified somewhat by inserting the numerical value for the temperature of the sea (13°C) as measured from the surface vessel and the assumed value of atmospheric transmission (30%). Thus

$$\Delta T_{peak} = (1.95 \times 10^4)\ \psi \text{ in } ^\circ C \quad \text{(rectangular distribution)} \qquad (5)$$

or

$$\Delta T_{peak} = (3.9 \times 10^4)\ \psi \text{ in } ^\circ C \quad \text{(triangular distribution).} \qquad (6)$$

The average values of wake radiation, ψ, are given in Table 8. Using these values in Equations (5) and (6) gives the temperature values tabulated in Table 9. Also tabulated are the values measured directly at the surface by the NADC people.[15] The agreement is good. Had more surface measurements been taken and had a more accurate model of the wake been considered for the calculations, the agreement would undoubtedly be closer.

OPTICAL NOISE

Daytime Operation

At the present time, the operation of this gear during daylight hours is impossible. As shown in Figure 5, the spectral response of the system is essentially uniform down to one micron and, hence, is very receptive to the short wavelength radiation present in the sunlight reflected from the water. Measurements made during the daylight hours have shown that daytime optical noise is of two types. The least bothersome is that due to sunlight reflected from moving whitecaps and proves to be of a random nature. This noise is usually greater than the total optical noise observed at night. Worse by far, however, are the orderly wake-like signals derived from the sun's path on the surface of the water. These signals are several orders of magnitude greater than any noise observed at night and will probably make daylight application of this type of gear impossible.

It is realized that there are better filters available than those now being employed. Steps have been taken to procure several of the Eastman Kodak type which have a short wavelength cutoff at about 4 microns. Nonetheless, if it were possible to eliminate all of the radiation below 4 microns, the 8-to-13-micron radiation in the reflected sunlight would still provide a very high optical noise level. Measurement of the exact magnitudes involved will have to await receipt of the filters at which time the problem will be thoroughly investigated.

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[15] NADC Conf. Ltr. Rpt. ADC-EL31J-HLW:ms, Serial 01607, dtd. 26 December 1950

[redacted]

TABLE 9

Comparison between Measured and Calculated Temperature Difference between Wake and Surrounding Water (Average of all Measurements Taken)

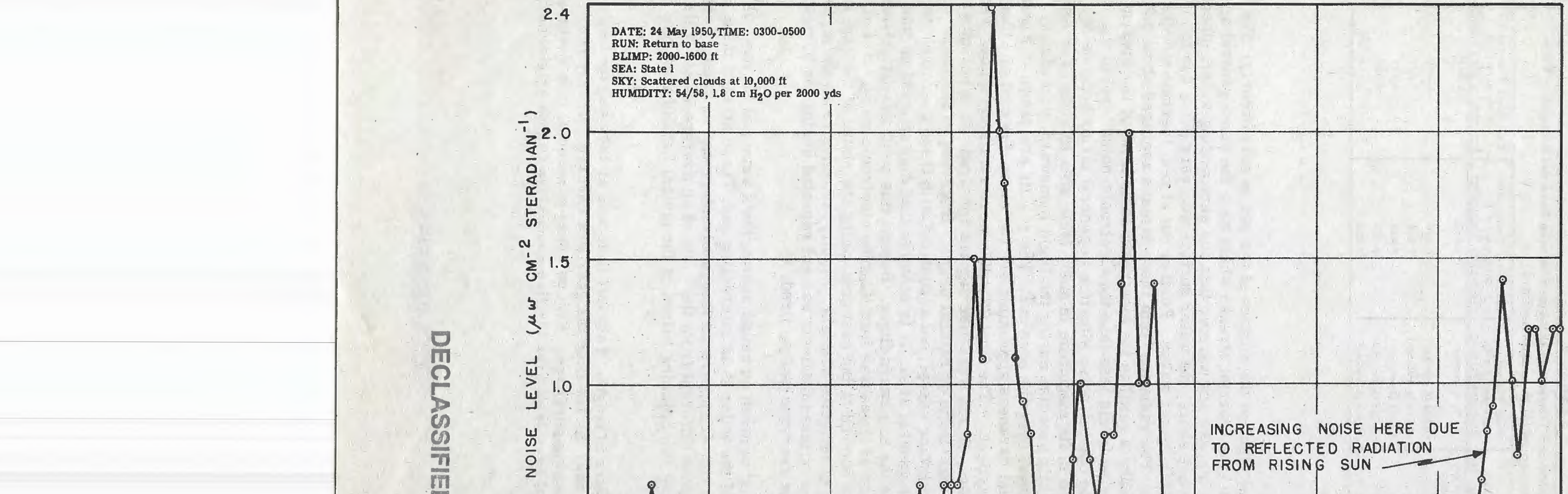
Screw Depth (Feet)	Speed (Knots)	Operating Condition	Wake Width (Feet, Average)	Peak Temperature Difference (°C) Measured Directly	Calculated Temperature Difference (°C) Triangular Distribution	Calculated Temperature Difference (°C) Rectangular Distribution
15	6	Surfaced	No indication from surface	No indication	(-0.082)	(-0.041)
60	6	Schnorkelling	156	-0.054 (4 readings)	-0.090	-0.045
60	4	Schnorkelling	247	-0.135 (4 readings)	-0.066	-0.033
60	4	Periscope up	188	-0.075 (2 readings)	-0.043	-0.022
60	2	Periscope up	254	-0.025 (5 readings)	-0.039	-0.020
150	6	Buttoned up	825	-0.011 (1 reading)	-0.035	-0.018

Nighttime Operation

The optical noise observed at night on the surface of the sea is very orderly. The ocean appears to be covered with long thermal streaks which have the same general appearance as wakes. Some of the streaks are warmer than the surrounding water; others are colder. Close to the New Jersey shore, the water surface was very noisy due to presence of a large number of old freighter wakes. Further out at sea, thermal streaks of a natural origin predominated. The radiation from these streaks averaged about 0.2 microwatts cm^{-2} $steradian^{-1}$ or about equal to the electronic noise level of the present gear. Some areas had optical-noise levels less than the electronic-noise level of the gear. It is difficult to discuss the optical-noise situation in general terms because of the extreme fluctuations observed in its magnitude in going from area to area. For example, at the end of the first night's exercise during the flight homeward, recordings were made of the optical-noise level over the open sea. The results are shown in Figure 32. Measurements started in total darkness approximately 150 miles due east of Atlantic City, N. J., and continued until daylight. The first 30 miles were relatively quiet. Then, between 120 and 100 miles offshore, steady wake-like signals appeared. It is not known whether these signals were of a man-made or natural origin. However, on the next flight outward, a submarine and surface vessel, not associated with these exercises, were found to be operating in the same general area. It is possible that they churned up this area on the night before, prior to the homeward flight. Beyond this point the optical-noise level again returned to normal and at times was less than the electronic-noise level of the system. Then, as a pink glow showed in the east announcing the rising of the sun, the noise level slowly increased due to reflected sunlight. Finally, 70 miles from shore, the gear was turned off. This series of measurements was not repeated during the homeward flight on the second night because everyone was so tired.[16]

The problem of differentiating between an actual submarine's wake and the natural thermal streaks of the surface of the water is an interesting one. These streaks must be investigated thoroughly from the air. It appears as though advantage can be taken of the fact that their widths are sometimes different from the width of an average wake. This can be realized by matching up the two opposing halves of the optical field of view to a

[16] These flights were over 18 hours in length. Take-off time was at 1400 and landing time was after 0800 on the next day. By the time the gear was checked out, only two hours remained each day for sleeping purposes. With no relief personnel, it is doubtful whether the NRL personnel could have lasted for the five successive flights originally planned.


DATE: 24 May 1950, TIME: 0300-0500
RUN: Return to base
BLIMP: 2000-1600 ft
SEA: State 1
SKY: Scattered clouds at 10,000 ft
HUMIDITY: 54/58, 1.8 cm H_2O per 2000 yds
NOISE LEVEL (μw CM^{-2} STERADIAN^{-1})
2.4
2.0
1.5
1.0
INCREASING NOISE HERE DUE TO REFLECTED RADIATION FROM RISING SUN

[redacted]

greater degree, by making the field of view sharper through the use of better mirrors and by making the associated amplifier more selective for the signal pulses obtained from the wake. Since the optical noise is so close to the electronic-noise level of the present gear and since the magnitude of the optical noise will decrease with poorer atmospheric transmission, these modifications will have to be accompanied by another major increase in the signal-to-noise ratio of the system.

It therefore appears advisable to develop still another system for measuring purposes. This system must have an equivalent radiation input, corresponding to a signal-to-electronic noise ratio of unity, of less than 10^{-8} watts cm^{-2} steradian^{-1}. To achieve this figure, mirrors measuring 9 feet in diameter must be employed. For good off-axis quality, an f-number of 0.7 is suitable which automatically dictates the use of a 7 x 7 inch thermopile to generate a $5^0 \times 5^0$ field of view. In the light of the experience gained during the development of the present system, this larger unit appears quite feasible.

SUMMARY AND CONCLUSIONS

(1) The detection of submarine wakes with airborne radiation-sensitive equipment has been successfully accomplished at night in deep water 150 miles east of Atlantic City, N. J.

(2) The thermal radiation from the wake of a submarine underway on the surface at 6 knots was measured easily at distance up to 9000 yards astern the craft.

(3) The thermal radiation from wake of a submarine schnorkelling at 60 feet at both 6 and 4 knots was measured easily at distances up to 10,000 and 12,000 yards, respectively, astern the craft.

(4) The thermal radiation from the wake of a submarine underway at 60 feet at both 4 and 2 knots with only its periscope elevated was measured easily at distances up to 8000 and 6000 yards, respectively, astern the craft.

(5) The thermal radiation from the wake of a submarine underway at 6 knots at a depth of 150 feet was measured easily at distances up to 7500 yards astern the craft.

(6) It is not known how far astern the submarine's wake could have been tracked under each of the above conditions had the submarine's runs been longer.

(7) It is not known how deep the submarine could have travelled and still have its wake radiation detectable had the airborne gear continued to operate throughout all of the runs planned.

(8) The basic limitation to this type of detection appears to be the wake-like radiation from long thermal streaks on the surface of the water whihh are of a natural origin. In heavily travelled areas, surface vessel wakes present an even greater limitation.

RECOMMENDATIONS

(1) It is recommended that measurements with the present equipment be continued until all the factors effecting the problem of wake detection are thoroughly understood.

[redacted]

(2) It is recommended that a measurement system with an equivalent noise input of less than 10^{-8} watts cm^{-2} $steradian^{-1}$ be developed for the purpose of exploring the optical noise from the surface of sea.

(3) It is recommended that an airborne, towed, temperature-measuring device be developed by the Bureau of Aeronautics so that surface contact temperature measurements can be made at all times from the airship without the hindrance of a surface vessel.

ACKNOWLEDGMENTS

The success of these measurements was possible only through the splendid efforts of C. R. Detwiler, L. H. Ethridge, C. T. Jeffrey, and T. C. Miller, all members of the Applied Optics Branch of this Laboratory.

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NAVY-DPPO PRNC, WASH., D.C.