NRL Report 6222

Measurements of Marine Turbidity

[Unclassified Title]

J. D. Bultman and J. M. Leonard

Organic and Biological Chemistry Branch
Chemistry Division

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ABSTRACT

A towable apparatus for the *in situ* determination of the turbidity of sea water is described. This apparatus, which contains a sensor for detecting backscattered light, is capable of producing a continuous horizontal profile of turbidity at any depth down to several hundred feet. It differs, in addition to the towing feature, from other sea-going turbidimetric devices in that its signal is a function of the amount of light reflected by particulate matter rather than the attenuation of transmitted light caused by the presence of these materials.

In recent field trials in the Gulf of Mexico this device was used in attempts to detect the wake of a submerged submarine. Eighteen known wake crossings were made of which eight crossings were marked by an increase in sensor signal above that recorded in the out-of-wake water. This device is also being considered as a possible oceanographic tool for *in situ* mapping of the distribution of planktonic organisms in the sea.

PROBLEM STATUS

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

AUTHORIZATION

NRL Problem C02-18A
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MEASUREMENTS OF MARINE TURBIDITY

INTRODUCTION

The various possible means of nonacoustic detection of submarines have one element in common, namely that the vessel induces a localized change in the water through which it passes. This change constitutes a trail of the submarine; with an appropriate sensor it could serve as a means of detecting the passage of the vessel. Since the ocean is usually heterotropic with respect to one or more properties and the submarine screw imparts a rather effective stirring action, the change is primarily a homogenization of the water mass within the submarine's wake. Several physical parameters, such as temperature, could be used as useful indices of water mixing. Perhaps the planktonic particulate matter of the sea could also be used. The growth of phytoplankton is limited to that range of depth in which light intensity is favorable to photosynthesis and the grazing zooplankton are also responsive to light stimuli, with distributions of both being subject to density gradients of the sea, turbulence, internal waves, currents and other water movements. Because of these factors, the plankton are also heterotropically distributed in one or more dimensions, including time. It seems reasonable that some of this heterogeneity might be useful in detecting zones of thorough mixing. Measurement of turbidity in situ would, of course, be the most appropriate index.

Measurements of turbidity in the sea and in other natural waters will not be cited here. To the writers' knowledge, practically all in situ measurements have been made from a stationary platform, e.g., a ship lying dead in the water. Such measurements provide a vertical turbidity profile with station-to-station discontinuities. Joseph (1) describes a device for taking horizontal profiles of turbidity, but it is firmly affixed to the ship's hull, so it takes data at only one, relatively shallow depth. Earlier, Joseph (2) described a device he considered suitable for towing, but he later (1) indicated that it was beset with technical difficulties. In May-June 1963, a continuous "turbidity profile" was made between Portland, Maine, and Key West, Florida, in a manner somewhat like Joseph's hull-attached technique. Differences in turbidity were noted, but in the open ocean they were so gradual as to confirm all the other oceanographic observations made during the exercise, that the first several feet of ocean at that time was very well mixed indeed.

During March and April of 1964 personnel of the Chemistry Division accompanied personnel from the Sound and Radio Divisions of NRL in performing oceanographic experiments in the Gulf of Mexico in the general area around Key West, Florida, aboard the USNS GILLIS, AGOR-4. Field trials of a device fabricated by NRL for making turbidity measurements of ocean water were performed. The advantage of this instrument not enjoyed by the conventional sea-going turbidity measuring devices is one of mobility. It can make a continuous horizontal turbidity profile of the water while being towed over a wide range of towing depths and towing speeds, thus allowing large reaches of the ocean to be mapped quickly.

APPARATUS

Most turbidity devices measure simply a decrease in light transmission in the water. The authors have felt that for open ocean water a sensor responding primarily to light scattered by the suspended matter could be more sensitive. A second consideration was a well streamlined vehicle to carry the sensor. A first version of such a device has been described already (3).

The present turbidimeter is composed of three separate units. They are the sensor, a vehicle for transporting the sensor through the water, and a simple electronic processing system aboard the towing vessel by which the sensor signal is translated into a recorder trace for permanent record. The sensing unit or "eye" of the turbidimeter is shown in Fig. 1. The sensor components, housed in a steel canister 6 inches in diameter by 8 inches in length, consist of a 12-volt dc, sealed-beam, automotive spot light, a mechanical biquadrant chopper (driven by a 12-volt, 2400-rpm, dc motor) which interrupts the light beam at the rate of 80 pulses/sec, and a Lucite cone machined so that the light passing through from apex to base is concentrated axially at a point in the water about three inches in front of the base. Centered in this base is a Western Selenium Photovoltaic cell (Model 856, Type RR) which is activated by the reflected light. Sea water is nearly opaque to red wavelengths, so the first model of the device used simply a red filter over the photosensitive element instead of a chopper to eliminate the effect of daylight. Some signal still remained.

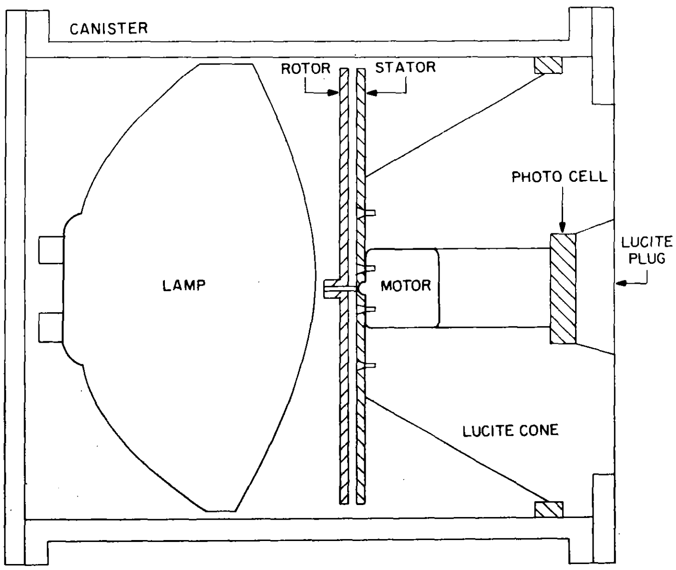


Fig. 1 - Cross section of sensing unit

To eliminate the undesirable background, the chopper mechanism was installed to provide a pulsating light field at a fixed frequency. The pulsating light, as reflected, produces a corresponding signal which is fed to an audio amplifier. The amplified signal is fed into a bandpass filter set to pass 80 cycles/sec, thereby eliminating all other undesirable frequencies, as well as the dc component generated by the ambient light. The output of the bandpass filter is fed into a rectifier circuit employing a Conant, Type B, copper oxide, full-wave meter rectifier. The output of the rectifier drives a model G-11A Varian recorder. A block diagram of the circuit is shown in Fig. 2. Because of this circuit change a red filter is no longer necessary in front of the photosensitive unit. Light intensity and chopper motor speed were reproduced by manually controlling the current flow through the circuit by means of a variable 26-ohm Cutler-Hammer motor controller and a dc ammeter. To assure full light intensity and motor speed, it was necessary to provide the sensor with 12-volts dc at 2.6 amps. Because of cable and other resistances in the circuit, this voltage level at the sensor required a 70-volt dc supply.

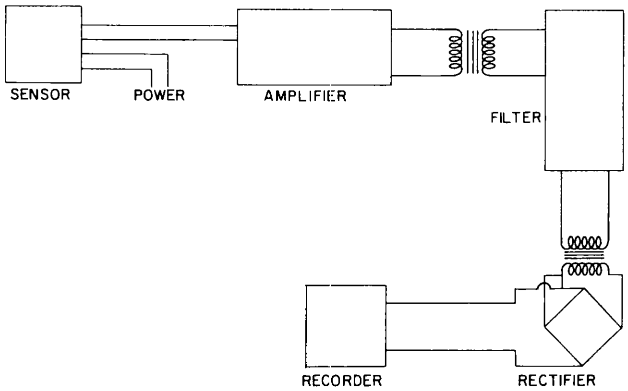


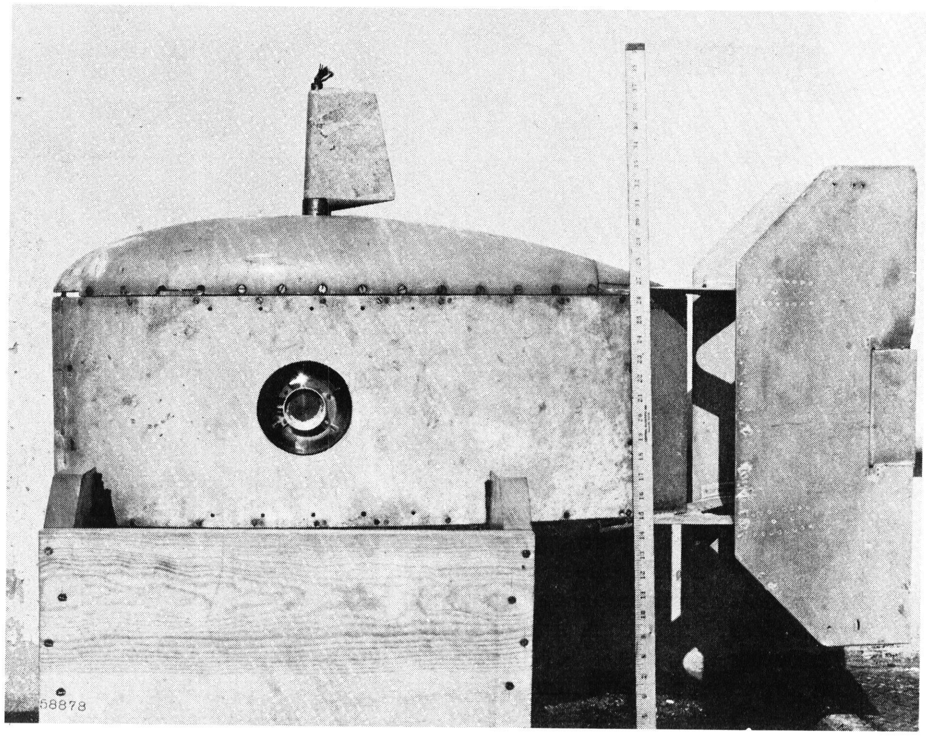
Fig. 2 - Block diagram of measuring system

The sensing unit is housed in a towing vessel obtained from the David Taylor Model Basin (Fig. 3). This vessel, a scale model (1/3) of a Trilby Fish, was ballasted to weigh 150 pounds submerged. It is so streamlined as to be free of reflection-producing cavitation. The sensor housing is mounted within the towing vessel so that it is side-looking through a circular window cut in the vessel's port wall. The fish was towed by a 0.300-inch stainless steel, armored, multiconductor electrical cable (3-H-1, modified) supplied by the American Steel and Wire Co. During experimental runs it is very important to be able to adjust the towing depth of the fish to the operating depth of the submarine. On the basis of the known weight and drag characteristics of fish and cable, this towing depth can be calculated as a function of the ship's speed and length of cable paid out (4). For convenience of operation, families of curves relating these variables were prepared.

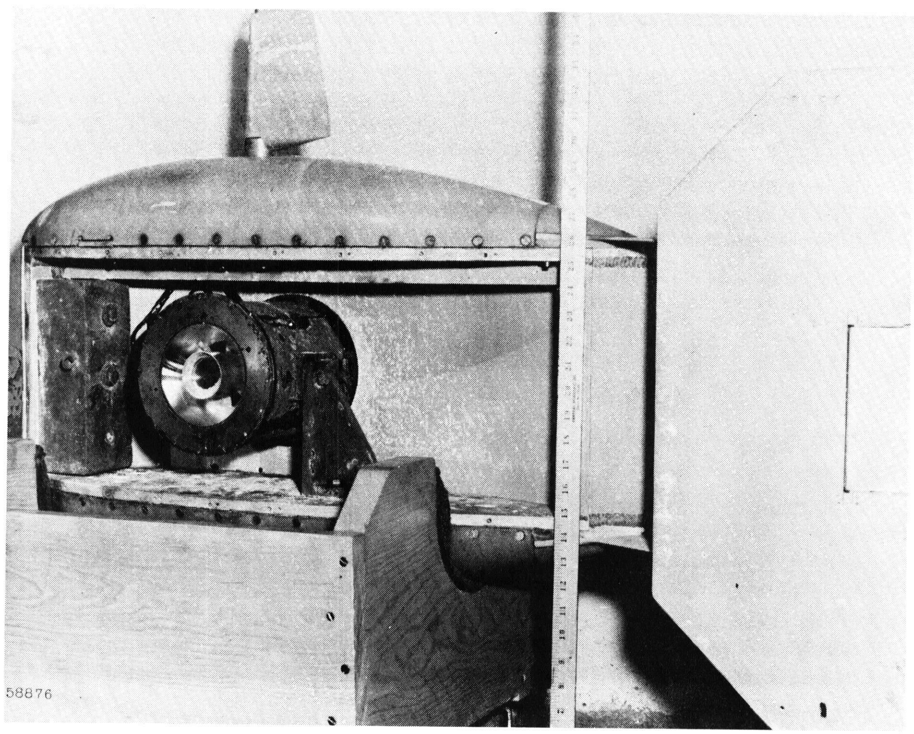
The device would not discriminate between one large "particle," e.g., a fish, and a very small, dense cloud of plankton. But it would be helpful indeed if the signal gave some expression of the numbers and sizes of the scattering particles. In the laboratory, one could measure the sensor signal as a function of the absolute quantity of light falling upon it. Also, calibrations with standardized suspensions (e.g., silica particles) are feasible. But neither method adequately portrays the oceanographic situation. In the May-June, 1963 voyage, calibrations were sought by taking samples of sea water close to the sensor for determinations of particulate matter. However, the present turbidimeter is so different as to invalidate comparisons of data. Circumstances of this last trip prevented the taking of water samples; these will be taken in the future.

EXPERIMENTAL PROCEDURE

With one exception, all turbidimeter towings were made at night, partly because of the convenience of using lighted buoys to mark the submarine's course and partly because of the anticipated plankton movements. The submarine operated at speeds of 4 and 8 knots and keel depths of 100 and 190 feet. The Trilby Fish model containing the sensor unit, was towed at the appropriate depth at a speed of 5 knots. The basic maneuver employed for each exercise is depicted in Fig. 4. The submarine executed a straight course, releasing flashing marker buoys at approximately 15-minute intervals. The surface vessel followed a serpentine course, crossing the submarine wake at right angles, and as nearly as possible, bisecting the distance between adjacent marker buoys. After four wake crossings each exercise was terminated. The time of each wake crossing and the corresponding submarine wake age were determined by the ship's bridge and relayed to the recorder station.



(a)



(b)

Fig. 3 - Vehicle and sensor (a) Side view (b) Closeup of sensor, side panel removed

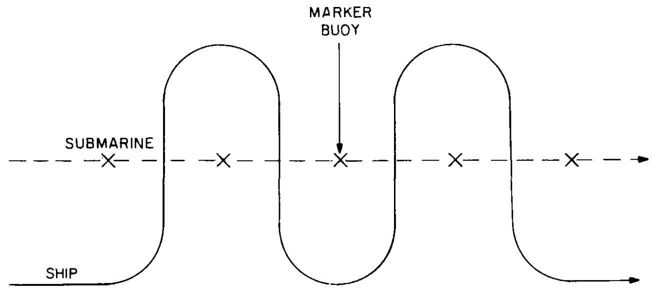


Fig. 4 - Ship - submarine maneuvers

RESULTS

Five towings–for a total of 18 wake crossings–were made. Of these 18 crossings, eight crossings were marked by an increase in sensor signal from that recorded in the out-of-wake water. In some instances, however, this signature was marginal and many more such crossings and background measurements are needed for a judgment on the significance of the signals of this magnitude. The most successful run occurred on the night of April 4th. A reproduction of the recorder trace is shown in Fig. 5. During this exercise the submarine was operating at a keel depth of 190 feet and a speed of eight knots. A strong signal, approximately 30 percent over background, was recorded during the first, third, and final wake crossings. During the first response, the increased signal began about six minutes prior to the crossing and persisted for another nine minutes which, at the five-knot towing speed, represents a towing distance of 2500 yards. The signal associated with the third crossing began only two minutes prior to the estimated crossing time and persisted for only five minutes or through a towing distance of about 830 yards. In this instance the wake age was 23 minutes. The signature for the final crossing also began two minutes prior to the crossing time and persisted for nine minutes for a towing distance of 1500 yards. The wake age, by then, had increased to 36 minutes. Close inspection of the recorder trace will reveal that at the recorded crossing time for two of the three positive events there was a momentary decrease in signal. It could have been caused by a mixing in of clearer or plankton-poorer water. And decreases in signal are just as reasonable as increases. The duration of this signal would be more in keeping with the expected width of the submarine wake.

DISCUSSION

If is assumed, first of all, that there is enough particulate matter present in the water to produce a sensor response, and secondly, that the passage of a submarine does have an effect on local particulate matter distribution, then one would expect a sensor signal obtained from in-wake water to differ from one obtained in out-of-wake water. Such differences have been observed during this exercise. It would be very difficult, however, to predict the direction and magnitude of this change because of the nature of the local pattern of plankton distribution. A submarine passing along the periphery of a plankton patch might leave a trail characterized by a decrease in signal resulting from the influx of clearer water from the adjacent water mass; the reverse mechanism could also operate. Intuitively one would expect signal oscillations to be smoothed out as a result of the homogenizing action of the submarine. Such a response was not observed, however, in any of the eight events in which a signal change occurred simultaneously with a wake crossing. Instead, each crossing was marked by a succession of discrete signal pulses, deviating in magnitude but always in the same direction with respect to the out-of-wake background

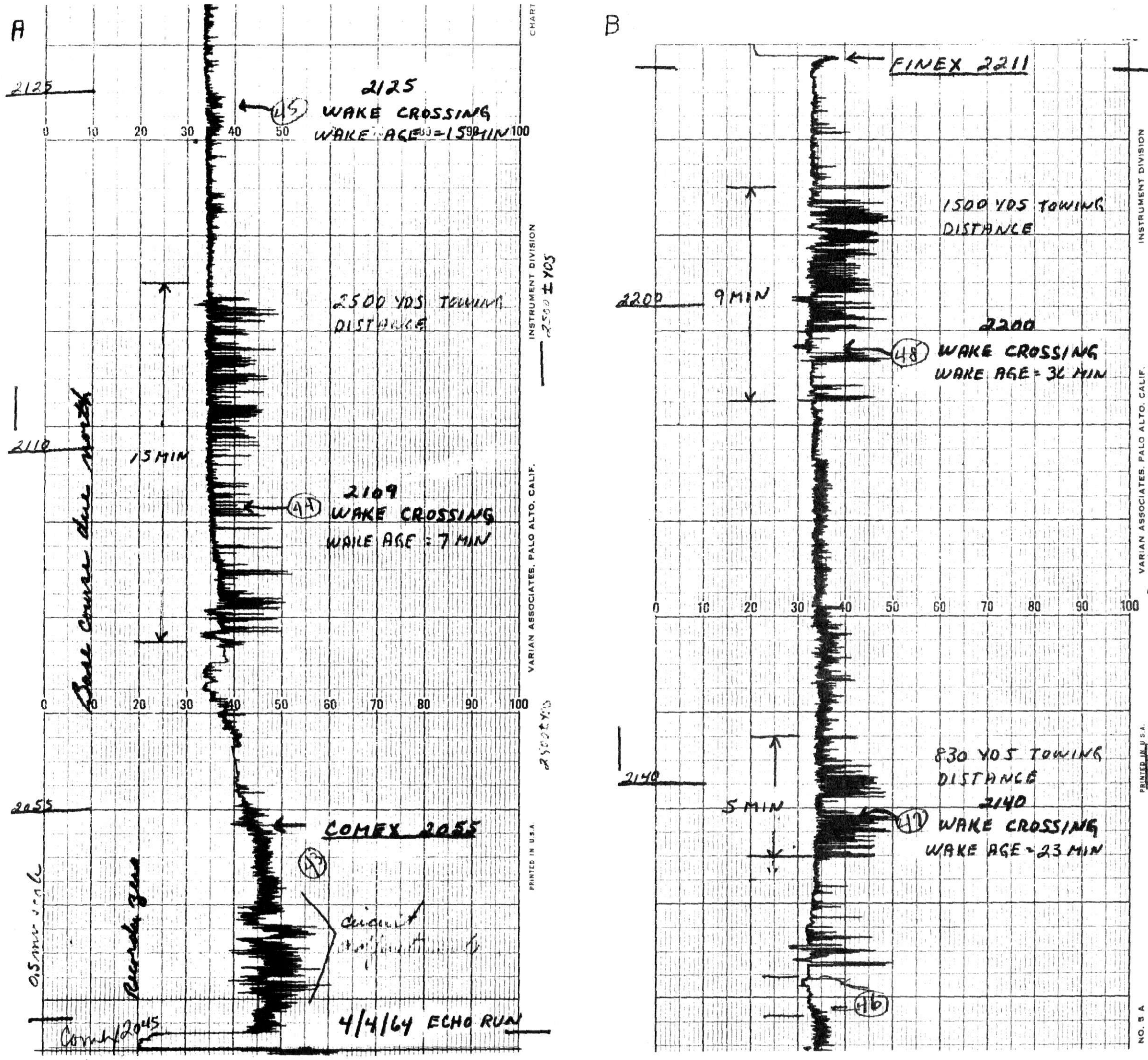


Fig. 5 - Reproduction of recorder trace from night operations of April 4th

signal. This behavior suggests that other particle distribution mechanisms may also be operating. Certainly before any wake detection could be claimed, many hours of measurement without a submarine and under a variety of operating conditions are needed to establish the normal turbidity signatures of the ocean. Turbidity readings taken at known wake crossings could then be compared with the normal signatures. Because of the lack of this background data no definite claims for wake "detections" can be made.

Obviously, the disadvantage of this device for wake detection is the necessity of relying on the natural occurrence of particulate matter. Plankton and planktonic debris constitute most of this material; however, distribution and local concentration are not uniform. Time of day, season, enrichment of the water by the appropriate nutrients, and other oceanographic factors, all exert an influence. In very clear water such as that which was encountered on this field trip, where Secchi disc readings of more than 90 feet were recorded, there would be very little particulate matter in the water and hence a very low sensor signal. Even in richer waters there is no means to determine beforehand a submarine course that would pass through regions of high plankton concentration, much less to have these plankton-rich regions appropriately located at points of intersection with the ship's course.

If one wishes simply to study wake patterns, the dependence on the naturally occurring particulate matter could be eliminated by having the submarine deliberately leave a "dirty" wake by discharge. But for such experiments, present techniques of ejecting radioactive salts or fluorescent dyes appear preferable.

CONCLUSIONS

The utility of this device for wake detection is limited but as an oceanographic tool it would have wide applicability. Difficulties relevant to the present study would no longer have significance since the prime function would be the detection of local concentrations of plankton, rather than the detection of alterations in their concentration resulting from the passage of a submarine. Wide areas of the ocean could be rapidly mapped with respect to plankton distribution and migration, particularly if the device were used in conjunction with plankton nets. Results obtained from the towing of plankton nets are summations of organisms collected over the towing distance. Since the entire collection of organisms from a single tow could have been taken over a small part of this distance, only a gross estimate of the horizontal concentration profile of the particulate matter can be made. Simultaneous towing of the turbidimeter in close proximity to the collecting net should provide data which would be helpful in assessing such a profile.

ACKNOWLEDGMENTS

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