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A Technique for the Direct Measurement of Ocean Currents from Aircraft[1]

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ABSTRACT

A method for measuring surface and subsurface ocean currents from aircraft is described. Comparisons of measurements using this technique with those obtained from a ship are given and applications are discussed.

I. *Introduction.* This paper describes a method for measuring both surface and subsurface ocean currents from aircraft. In a sense, this method is a modification of the one described by Richardson and Schmitz (1965), but it has an advantage in that the precision-navigation system necessary for their method is not required. The method described here is for use from fixed-wing aircraft. However, the technique is equally usable with helicopters and surface vessels; indeed, it gives ships a capability in current measurement that they do not generally possess at the present time. Two collections edited by V. G. Zdanovich (1963, 1964) have described a similar device (somewhat cruder but operating on the same principles) for measuring surface currents.

II. *The Method.* There are several variations of the method that can be used; Fig. 1 depicts a simple form with which we have had considerable experience. An expendable probe is ejected from the aircraft and, on striking the water, a surface marker (SM) separates from it and dispenses fluorescein dye. The remainder of the probe carries two buoyant streamlined floats (F-1 and F-2) to the bottom. At a preset time (longer than the time required for the probe to reach bottom), float F-1 is released, and later, at a predetermined delay time, F-2 also is released. These floats rise under their own buoyancy and also dispense fluorescein dye at the surface.

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[1] Accepted for publication and submitted to press 13 December 1971.

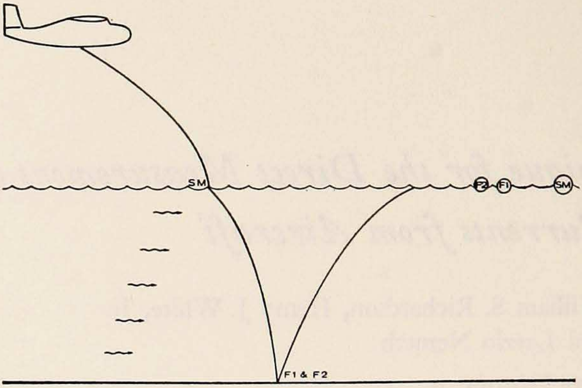

Figure 1. Schematic diagram of the method indicating the release points of the various parts of the probe and their ultimate disposition.

Consider, for the moment, floats 1 and 2. Assuming (i) that the average current from the surface to the bottom has not changed during the delay time between their releases and (ii) that they rise at the same rate, it is clear that

$$\vec{V}_s = \frac{\vec{R}_{21}}{t_D}, \tag{1}$$

where $\vec{V}_s$ is the surface current, $\vec{R}_{21}$ is their vector separation on the surface, and t_D is the delay time between their releases. It is important to remember that "surface current" is not a well-defined term; in this case it means the way in which these particular floats drift on the surface.

Consider now the separation ($\vec{R}_{S_1}$) between the surface marker and the first float to come up. If the timing starts at the surface contact (or effectively in the aircraft at drop), it is easily shown that the current averaged over the whole water column ($\vec{V}_{avg}$) is

$$\vec{V}_{avg} = \frac{P}{D(P+Q)}[Q\vec{R}_{S_1} + \vec{V}_s(D + t_0Q)], \tag{2}$$

where D is the depth, P is the fall rate of the probe with its floats, Q is the rise rate of the floats, and t_0 is the preset time at which float 1 is released. If R_{S_1} is measured and if the depth is known, V_{avg} can be computed from the known characteristics of the probe and floats. The transport per unit width of the water column is

$$\vec{T} = \int_0^D \vec{V} dz = D\vec{V}_{avg}. \tag{3}$$

The two separations, $\vec{R}_{21}$ and $\vec{R}_{S_1}$, can be readily determined by aerial photography, provided that the altitude and heading of the photographing aircraft and the focal length of the camera used are known. No additional navigational capability is required other than the general one of knowing where the measurements were made so that the depth can be determined from navigational charts. It is appropriate to obtain the photograph as soon as possible after all floats are on the surface so that local surface shears and turbulence do not disperse the floats from their original relative positions.

There are two situations in which a modification of the above approach may be desirable. For operation in deep water (>1000 m), the surface marker may have drifted for such a long time that its movement may not be very well represented by $\vec{V}_s$ as determined from $\vec{R}_{21}$. There are also cases in which $\vec{V}_s$ is much greater than $\vec{V}_{avg}$; in this case the three floats may be so separated that photographing them in a single picture is impossible. For these situations, the instrument is modified so that three floats go to the bottom with the probe, and no surface marker is used. At the bottom, floats 1 and 2 are released simultaneously, but float 2 is ballasted to rise at a slower rate (Q_2) than float 1 (Q_1). As before, float 3 is released after a fixed-time delay (t_D) and it rises at the fast rate (Q_1). In this case,

$$\vec{V}_s = \frac{\vec{R}_{31}}{t_D}, \tag{4}$$

and

$$\vec{V}_{avg} = \frac{Q_1 Q_2}{D(Q_2 - Q_1)} \vec{R}_{21} + \vec{V}_s. \tag{5}$$

When the floats are given appropriate rise rates, they will all arrive at the surface within a few minutes of each other and will not be widely dispersed. This method has the additional advantage that the initial time setting (t_0) and the rate of fall of the probe (P) are not involved in the computation of velocity.

In either of these methods, additional floats may be included which release at preselected mid-depths (times) as the probe falls to the bottom. Utilizing either equation (2) or (5), as appropriate, it is thus possible to obtain $\vec{V}_{avg}$ over the various depth intervals and thus current or transport vs. depth.

III. *The Instrument.* The expendable probe, which is simple and inexpensive (about $ 40), is shown in Fig. 2 in both assembled and exploded views. This particular unit is rigged for the first method described above. It consists of a clock to which the two floats are attached and a surface-dye package whose drift is similar to that of the two floats.

The floats are made by injection-molding two parts; a polyethylene nose cone and an acrylic cone. The nose cone accepts two thin-walled fiberglass balls that provide the required buoyancy. These balls are satisfactory to depths of 1200 m; for deeper work, a cylindrical block of syntactic foam is used for buoyancy. The fluorescein dye (typically 75 g) is contained in a conical cloth bag that fits snugly into the tail cone. The two parts snap together, and four holes are provided at the joining line to permit the soluble dye to escape. The tail cone has three helical fins molded on its end; these fins cause the cone to spin as it rises, thus stabilizing the run. A length of nylon monofilament with a nylon bead on its end is attached to the tail, thus providing the connection to the clock release.

The mechanism for the clock is from a standard kitchen timer. We use a 15-minute clock movement for depths to 2000 m and a 60-minute movement for greater depths. These timers run perfectly well in salt water for periods up to 2 or 3 hours; their rate in water is about 10% faster than in air. The accuracy of the clock when running in water is about 2%. Fixed to the face of the clock is a circular molded acrylic plate with 12 equally spaced holes near its circumference. Attached to the rotating clock shaft is another circular plate with a small notch in its circumference. The bead on the end of the float, fitted into whichever hole is selected in the fixed plate, is captive until the notch in the rotary plate passes over it, at which time the release occurs.

The two clock plates have small holes molded into them, and they align when the clock is fully wound. A pin attached to a lanyard is inserted into this hole so that the clock is stopped until the lanyard is pulled out at launching time.

The clock with its attached floats fits snugly into another molded nose cone that is attached by a 2-m lanyard to a 1600-g streamlined lead weight. Four dogs on this nose cone snap securely into the clock and are held in place by the protecting tube that slips over the entire mechanism. The surface-dye package is held in this tube by a small piece of soluble plastic film (polyvinyl alcohol), which dissolves in a few seconds when the probe hits the water and releases the dye package.

Excluding the weight and its lanyard, the probe is 94 cm long, 7.3 cm in diameter, and 1.5 kg in weight. The 1.6-kg weight gives it a fall rate in water of 3.60 m/sec, and the floats rise at 1.83 m/sec. The run-out of the floats, as determined from the surface separation of simultaneously released units, is less than 2 m/1000 m of depth.

In earlier models, it was necessary to launch the probe with a small parachute attached so as to prevent damage to the balance wheel of the clock. A minor modification, involving a deepening of the balance-wheel bearings, has cured this trouble, and the probes can be used without parachutes.

Further details on the construction of the probes are available from the authors.

IV. *Operational Procedures.* The launching of probes from an aircraft requires the installation of a 2-m-long launching tube at a rather flat angle

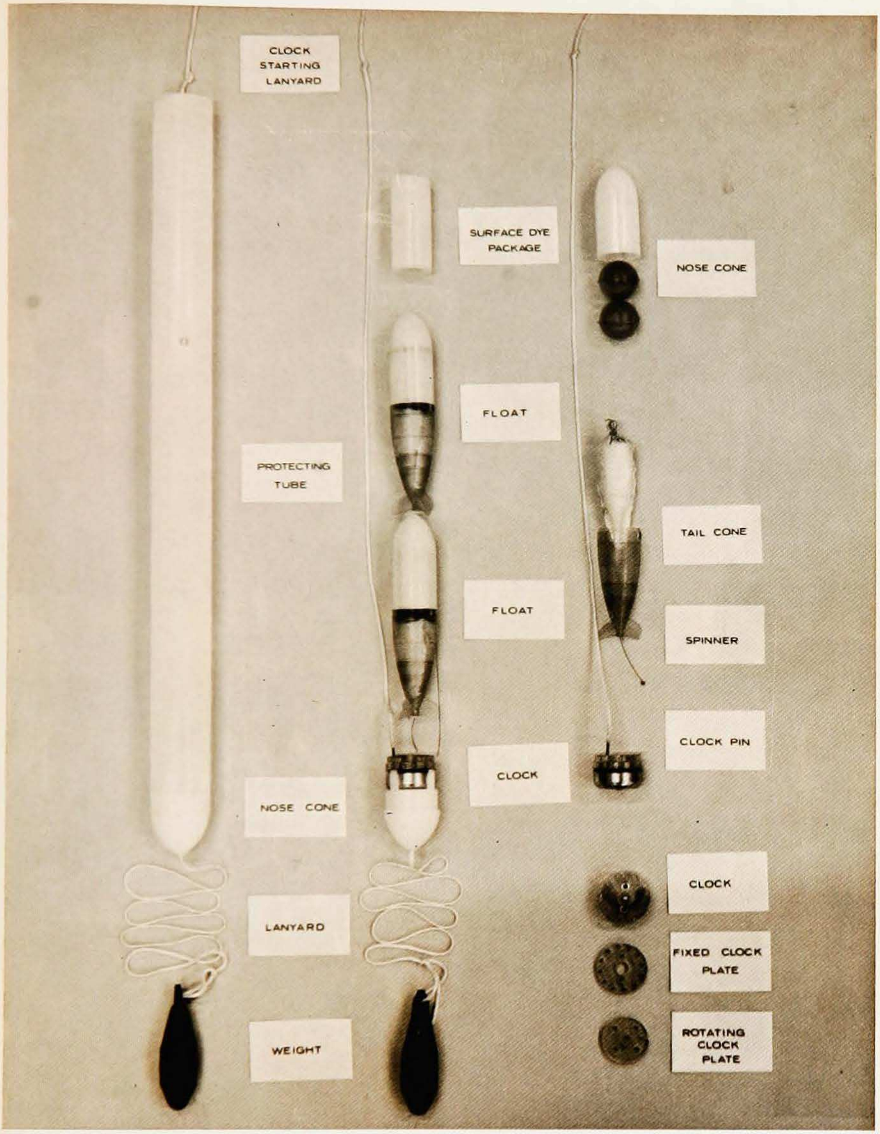

Figure 2. The expendable probe: left—assembled; center and right—exploded views.

(about 15° from the horizontal). If shorter tubes at steeper angles are used, the probes tend to jam in the tube as they enter the aircraft's slipstream. Since our interest is often in long sections of current measurements, we tend to use two aircraft. The first aircraft launches the probes and the second follows at the appropriate time to photograph the dye marks on the surface.

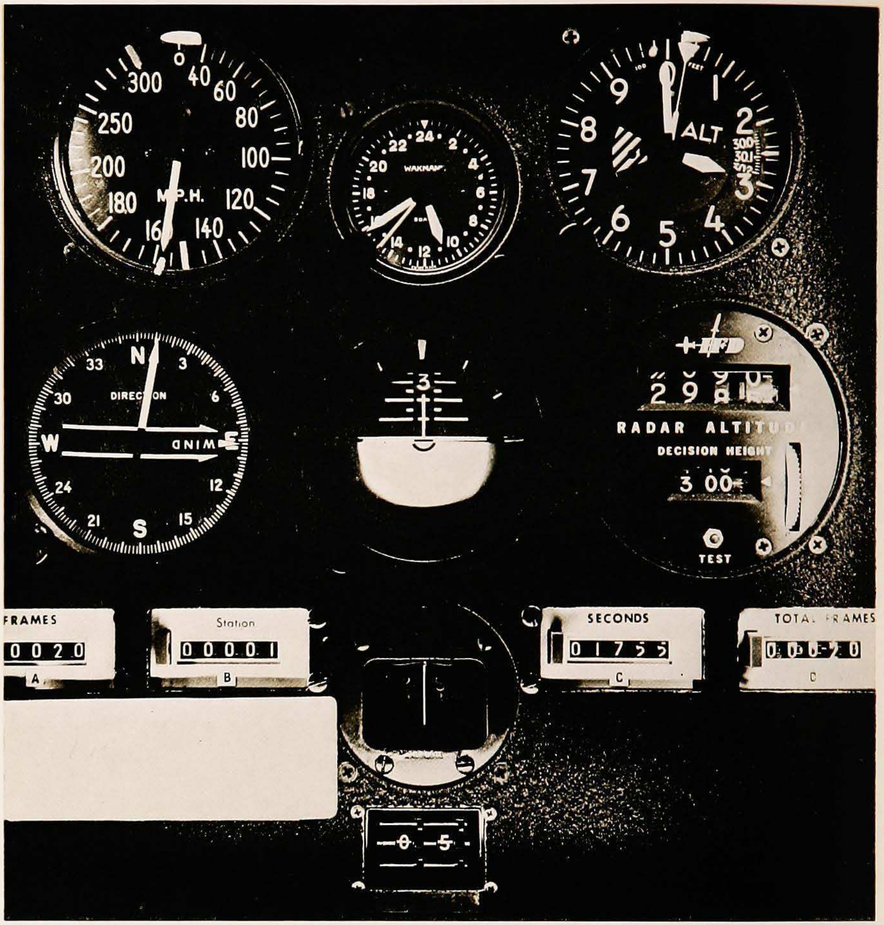

Figure 3. The data panel; the radar altimeter (right center) and the flux-gate compass (left center) are normally used in the data reduction.

The downwardly directed camera is equipped with a wide-angle lens and uses color film. Most photographic runs are at an altitude of 300–600 m (below the typical cloud base over the ocean). This aircraft is also equipped with a data panel (Fig. 3) that is photographed simultaneously with each photograph of the sea surface. This panel contains all of the necessary information for scaling and orienting the sea photographs. It is fairly easy for the pilot to fly directly over the dye traces, but, since downward visibility is not good in most aircraft, it is difficult to tell exactly when to photograph. For this reason, we take a short series of overlapping photographs (generally 3 to 5) on each probe. This usually gives a choice of two or three usable photographs for data reduction, and we select the best of these.

Figure 4a. Example of photographs of the dye patches. See text for discussion.

Figure 4b. Example of photographs of the dye patches. See text for discussion.

Figure 4c. Example of photographs of the dye patches. See text for discussion.

We have tried many different dyes in an effort to obtain different signatures from the three targets. To date, only fluorescein has given sufficient contrast to be visible in the photographs. However, with a little experience it is fairly easy to identify the surface marker and the two floats; Fig. 4 illustrates how this is done. In Fig. 4a the two floats are to the right. We see for each of them a bright portion, which is dye at or near the surface. The float itself is not visible, but since it is the source it must be at the end of the bright part. Trailing away from the bright part is a weaker tail, which is the dye trail at progressively greater depths; this is dye that leaked out as the floats rose, and it is probably visible down to a depth of about 20 m. The patterns indicate a complex shear structure in this layer, and since the two floats arrived at the surface about four minutes apart, this has opened up the trail from the first one. Therefore, the right-hand track is from the second float that surfaced from the bottom; the middle track is from the first float that surfaced; and the dye to the left, which has no comparable structure, is the surface marker.

The same arguments apply to the patterns shown in Fig. 4b, which was a station about 10 km distant from the station used in Fig. 4a. The water depth in both cases was about 1000 m. Notice the sharp break in the smoothly curved trails at the fading end. Similar complex shears near the sea surface have been described by Sharikov (1969).

Fig. 4c is a case in which both the surface and average currents were much smaller, and the surface marker is between the two floats. Again, the shorter and more-intense underwater trail is associated with the second float. It is rare for the photographs to be too ambiguous to interpret, but it does occasionally happen.

We have used this method for current measurement with winds up to 25 kn; the pictures were perfectly readable despite extensive whitecaps. It is not known, at present, what wind speed and sea state is limiting.

V. *Comparisons with Ship Measurements.* Is is difficult to intercompare various types of current measurements, because different techniques almost always involve differing space and time scales. For measuring surface currents by the above method, the time scale of the measurement is the delay time (t_D) between the release of the two floats. This is typically set at a few minutes. Using precision navigation (Decca Hi-Fix), we have tracked floats from R/V GULF STREAM to measure the surface current for periods equal to t_D while aircraft drops were made close to the vessel. The results of one such intercomparison near the axis of the Florida Current in a depth of 290 m off Fort Lauderdale, Florida, are given in Table I(A). The measurements covered a period of about 30 minutes; the depth-averaged current was not measured, since diversion of the vessel to pick up its dropsondes would have destroyed the simultaneity of the two sets of measurements.

The intercomparison shown in Table I(B) is for a region of weaker currents about 30 miles north of the island of Walker's Cay in the Bahamas, in a depth of 1030 m. In this case, the four trials are drops made over a period of about 10 minutes at the corners of a square that were one mile north, west, south, and east of the vessel. The measurements were not exactly simultaneous, since the ship's dropsonde falls and rises at slower rates than do the aircraft probes, but all the drops had some overlapping running time.

In both cases, the agreement is good, as one would expect it to be, considering the similarity of the ship and aircraft techniques.

VI. *Applicability.* With a little practice, this technique is simple and straightforward. In a recent experiment involving about 150 probes, we had good data from 80% of them. The failures were attributable to a variety of causes, including malfunction of the parachute (then in use), malfunction of the probe itself (presumably the clock), poor photographs, interfering rain squalls, and an inability to differentiate unambiguously among the dye patches. Presumably, as more experience is gained and the probes are further refined, the level of successful performance can be improved.

Because of its ability to traverse the ocean rapidly and inexpensively, the fixed-wing aircraft is an attractive vehicle for this type of work. However, the probes can be launched from a ship, and the dye patches can be clearly seen from the deck. On a ship, there is the advantage of having an accurate knowledge of the depth and of being able to predict quite precisely the surfacing times of the various parts. The ship can determine the separation of the floats with

Table I. Intercomparison of aircraft and vessel current measurements (cm sec^{-1}/degrees true).

Trial	Aircraft		Vessel	
	Surface Current	Average Current	Surface Current	Average Current
A				
1	171/000	not measured	174/002	not measured
2	185/002	not measured	177/359	not measured
3	176/356	not measured	176/358	not measured
Average	177/359		176/000	
B				
North	43/038	30/348		
West	35/047	26/332		
South	36/034	30/326		
East	44/033	33/346		
Average	39/038	29/338	35/042	26/332

reasonable accuracy by simply using dead reckoning from one to another. This capability of quickly measuring surface and subsurface velocities in the open sea is not generally available on research vessels.

Acknowledgments. Many contributions to the development of this method and of the probe were made by our colleagues at Nova University. In particular, Robert Yager worked out many of the operational and data-reduction problems. F. P. Burke, Jr., and Jerome Erich, as pilots, have been of great help in advising us as to what can and cannot be done with airplanes. Financial support from the Office of Naval Research (Contract N00014-67-A-0386) is gratefully acknowledged.

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