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AN INEXPENSIVE AND RAPID TECHNIQUE FOR OBTAINING CURRENT PROFILES IN ESTUARINE WATERS[1,2]

By

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ABSTRACT

A current indicator, consisting of a confined submerged biplane-shaped drag and a device for reading the angle made by the suspending wire with the vertical, is introduced in theory and practice. It was designed for rapid determination of current velocities and directions at any depth from a vessel anchored in shallow water. A number of calibration runs made with the Drag and with a von Arx Current Meter indicate that the Drag is reliable and sufficiently accurate for the purpose for which it was designed. The gear proved to be rugged, easy to use, and inexpensive. It requires little time to make a number of observations from the surface down to 50 feet.

INTRODUCTION

A knowledge of the circulation is of prime importance in the study of the physical characteristics of estuaries. The circulation may be inferred indirectly from the distribution of chemical constituents, or perhaps from the distribution of suspended particles. It may be determined directly from a sufficient number of current velocity measurements, which must be made at various depths in order to arrive at vertical profiles of velocity. Also, they must extend over at least one tidal cycle at any location in order to take into account the variation with tide.

Since the Ekman current meter first became the standard oceanographic instrument for current measurements, numerous attempts have been made to produce instruments superior to that in operation. The majority of these attempts has led to the construction of only a few instruments of each design and to their use by only a few investigators. The Price meter, used widely in stream work, has found some application in lakes, estuaries, and the ocean. However, the inaccuracies inherent in a design of the Price meter type in relation to the roll of the

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[1] Contribution No. 2 from the Chesapeake Bay Institute.

[2] Results of work carried out for the Office of Naval Research of the Navy Department, the State of Maryland (Department of Research and Education), and the Commonwealth of Virginia (Virginia Fisheries Laboratories), under contract with The Johns Hopkins University.

boat or ship from which it is suspended are readily demonstrable (O'Brien and Folson, 1948). In addition to this, the Price type meter does not obtain subsurface current directions. Certain meters designed in Europe, notably the Ott current meters, have been used fairly extensively by European investigators. Americans, however, have used few of these.

Recently we were faced with the problem of outfitting several small vessels with means for measuring current speed and direction at surface and subsurface depths. The craft were to be used on an intensive study of an estuarine region involving relatively large tidal currents (up to two knots) and relatively shallow depths (50 feet and less). The work had to be carried out on a limited budget. Ekman current meters were not used because of their high cost and because the instrument must be brought to the surface for reading and resetting after each mesaurement.

William S. von Arx of the Woods Hole Oceanographic Institution has developed an excellent current meter which allows current speed and direction to be read on dials aboard the vessel; also, he has described a procedure for eliminating the effect of the vessel's swing on her anchor (von Arx, 1950). However, we were unable to obtain the necessary four instruments of this type within the time and budget allotted us.

Our requirements were: Availability, low cost, simplicity of operation, rapidity in obtaining measurements at all depths down to 50 feet, and dependability when used under tough field conditions. We did not feel that any commercially manufactured meter met all of these requirements satisfactorily.

One technique which met certain of our requirements involved the use of a free-drifting current drag. A current drag, or kite, with slight negative buoyancy is attached by a line to a buoy, the positive buoyance of which is just enough to support the drag. The line between the buoy and the drag is adjusted so that the drag is at the depth at which current measurements are to be made. The drag is made sufficiently larger than the buoy so that the observed movement of the buoy will reflect primarily the flow of water at the depth of the drag with but slight effect due to the action of surface current on the buoy. From the distance and direction of drift over a given time interval, the current velocity at a given depth can be determined. This technique is particularly valuable for very low velocities.

Although the free-drifting drag met certain of our requirements, we decided against its use in our work because of the difficulty in measuring accurately the distance of drift during a given time interval and because measurements at various depths require that the gear be

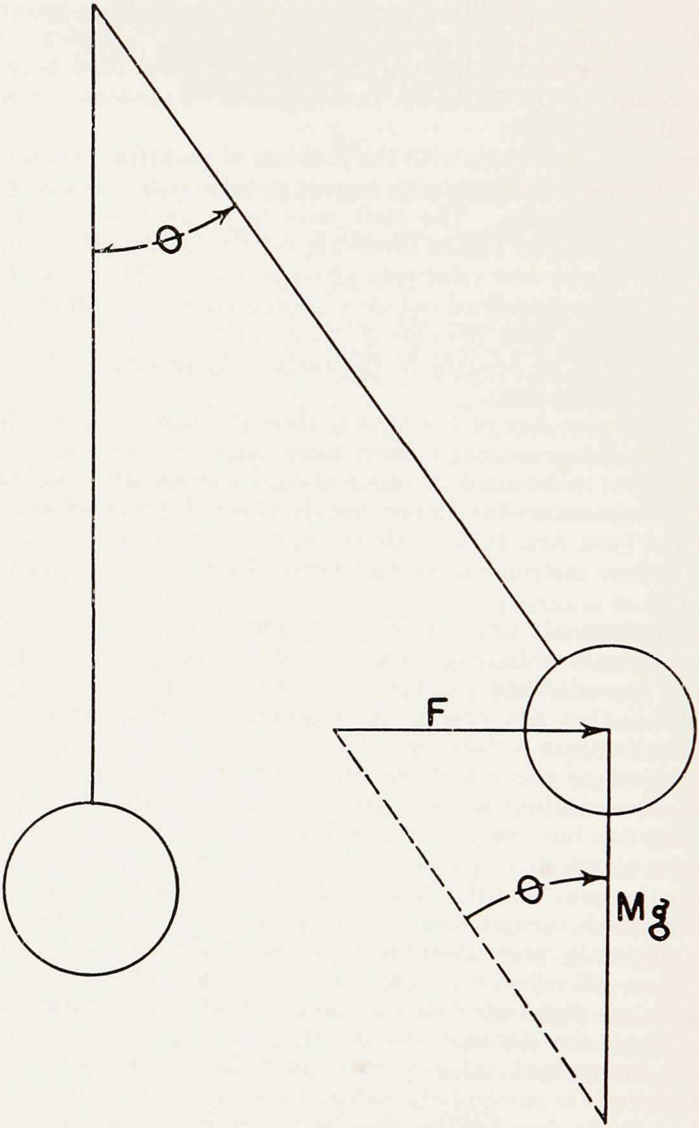

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Figure 1. The balance between the frictional drag, F, of water flowing past a confined submerged sphere and the restoring force of gravity, Mg.

recovered and that the length of the line be changed between drag and buoy. Another disadvantage is the possibility of fouling when working in fish trap areas or near the bottom of a narrow channel.

However, the technique which we finally decided to try does make use of the submerged drag, but instead of letting the drag drift freely, it is attached directly to the hydrographic wire, without a buoy; the force of the water motion on the drag is then obtained by measurement of the wire angle at the surface.

THEORY OF THE CONFINED SUBMERGED DRAG

Consider a submerged body with a negative buoyancy suspended as a pendulum in the water. This is illustrated in Fig. 1 as a sphere, but the theory also holds for bodies of other shapes. A flow of water past the submerged body will result in a force on the body, the magnitude of which is given by the expression

$$F = C_D A \rho v_0^2/2\,, \tag{1}$$

where C_D is the coefficient of drag, A the cross-sectional area of the body taken in a plane perpendicular to the flow direction, ρ is the density of the fluid, and v_0 is the velocity of the free fluid (Rouse, 1946).

This force will cause the body to swing out in the direction of flow until a vector balance is reached between this force and the restoring force of gravity. From Fig. 1 it can be seen that

$$\tan\theta = F/Mg = C_D A \rho v_0^2/2Mg\,, \tag{2}$$

where M is the mass of the body and g is the force of gravity per unit mass of the body. Solving for v_0, the velocity of the free fluid, we have

$$v_0 = \sqrt{2Mg/C_D A \rho}\,\sqrt{\tan\theta} = k\sqrt{\tan\theta}\,. \tag{3}$$

Thus it is seen that the velocity of the fluid is proportional to the square-root of the tangent of the angle made by the supporting line with the vertical. The proportionality factor, k, given by

$$k = \sqrt{2Mg/C_D A \rho}\,, \tag{4}$$

can readily be computed for any particular drag, provided the coefficient of drag, C_D, is known.

The coefficient of drag is a function of the Reynolds number, R, and of the shape of the submerged body. Its value has been determined experimentally for a great variety of body shapes. For all bodies, C_D decreases rapidly with increasing Reynolds number until this latter parameter reaches a value between 10^2 and 10^3. For a sphere or a cylinder, C_D varies only slightly for Reynolds numbers between 10^3 and 3×10^5. Near the higher value there is a sharp drop in C_D with increasing R due to a change in the character of the surface turbulance.

In the case of a flat plate or of a body composed of flat plates, such as the biplane shown in Fig. 2, the drag coefficient becomes independent of the Reynolds number for values of R greater than 10^3. Because of this property, together with the ease in construction, this type of drag, rather than the sphere or cylinder, was chosen for our study.

METHOD OF USING SUBMERGED DRAG

In practice, the drag, together with an added weight, is attached to the end of the hydrographic wire. It is desirable to have the meter wheel or block through which the wire runs as far out from the anchored ship as possible. At each desired depth the wire angle is determined, as is the angle between the ship's heading and the plane made by the wire and the vertical. We have prepared tables that give the required amount of wire to be let out so that the drag will be at the desired depth for a given angle. By successive adjustments, taking but a few seconds, each reading can be made at the exact desired depth.

The current speed is computed from the wire angle with the vertical, and the direction of the current is determined from the heading of the boat and the direction of the plane of the wire. Fig. 3 shows the procedure employed in measuring the wire angle.

The validity of these measurements depends primarily on three factors. First, the force on the drag must be large compared to the force of the current on the wire; secondly, the wire must remain nearly a straight line; and thirdly, the coefficient of drag must be constant over the range of flow studied. Actually, the technique would be usable if only the first factor held, for it is reasonable to assume that for any given depth the observed angle of the wire at the surface would remain a function of the current speed, even though the wire curved between the surface and the drag or if the drag coefficient changed with speed. In this case, however, the drag would have to be calibrated for each depth, and a constant proportionality factor between the current speed and the $\tan \theta$ would not exist.

CALIBRATION AND NUMERICAL RESULTS

One-half inch five-ply fir plywood was used to make the biplane (Fig. 2). The dimensions on the faces of the large working models were 2 x 3 feet. A thirty-pound weight was added to the bottom. In order to make simultaneous measurements along with the drag, we

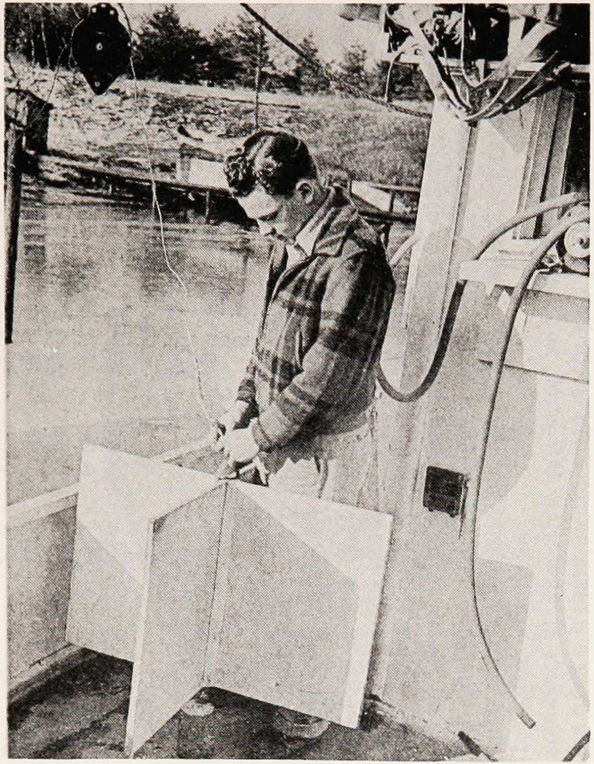

Figure 2. The current drag with weight, before lowering.

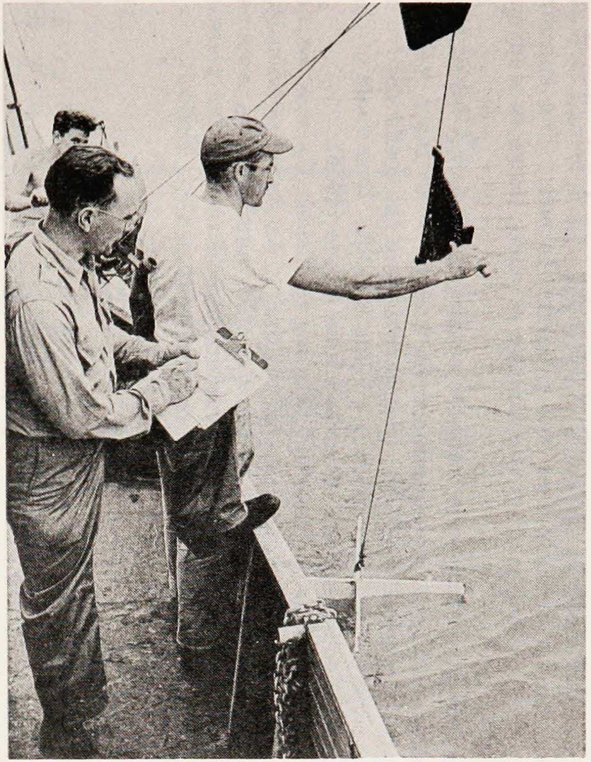

Figure 3. Reading the wire angle of the current drag. (In practice, the drag is just submerged for the surface reading.)

used a von Arx meter of the audible type, with a click being heard in earphones on deck each time the propeller turned. The current velocity was arrived at from the number of clicks heard in a given period of time.

Measurements were made from the surface to 50 feet. All of the data fitted well into the equation v (in knots) $= k\sqrt{\tan\theta}$, with k determined empirically as 1.04. Computations of the coefficient from (4) for this type of drag yielded a k value of 1.05. The value of C_D used in these computations was taken from Rouse (1946).

The velocity range within which the drag coefficient, C_D, is constant can be determined from the area of the drag. As stated previously, C_D is a function of form and of the Reynolds number. C_D remains constant for the body shape (a combination of rectangular plates) being used here for Reynolds numbers greater than 10^3. Hence

$$R_{\min} = 10^3 = \frac{DV}{v} = \frac{DV}{10^{-2}}\,, \tag{5}$$

or C_D is constant when

$$DV \geqslant 10\ \mathrm{cm^2/sec}\,. \tag{6}$$

From this it is seen that, even for drags with a minimum dimension of 10 cm, C_D is constant for flows as low as 1 cm/sec (less than .02 knot). Our smallest drag has a minimum dimension of one foot. With this drag C_D remains constant according to the above expression for all velocities greater than .007 knot, and hence it remains constant for all practical velocities.

In a tidal estuary such as the James River, where we first tried this technique, currents will vary over a tidal cycle from zero to nearly two knots at times. Experience showed that it was difficult to measure wire angles of less than 3° and of more than 45°. By use of the theoretical equations, the range of velocities covered by a given drag for angles between 3 and 45° can readily be determined. For our work, two sizes of drags were constructed, one with planes of 2 x 3 feet, another with planes of 1 x 1.5 feet. Each of these drags was used with either 15 or 30 pound weights.

TABLE I. DRAG CHARACTERISTICS

Drag	*Wt. in Water (lb.)*	*k* (knots)*	*Velocity Range (knots)*	*Accuracy in angle for 0.05 knot accuracy in current*		
				at 3°	*at 10°*	*at 20°*
Large—15 lb. wt.	8¼	0.64	.15–0.64	2°	3°	4°
Large—30 lb. wt.	22	1.05	.24–1.05	1°	2°	3°
Small—15 lb. wt.	12½	1.57	.36–1.57	1°	1½°	2°
Small—30 lb. wt.	26¾	2.30	.53–2.30	½°	1°	1½°

* Computed from (4) and expressed in knots.

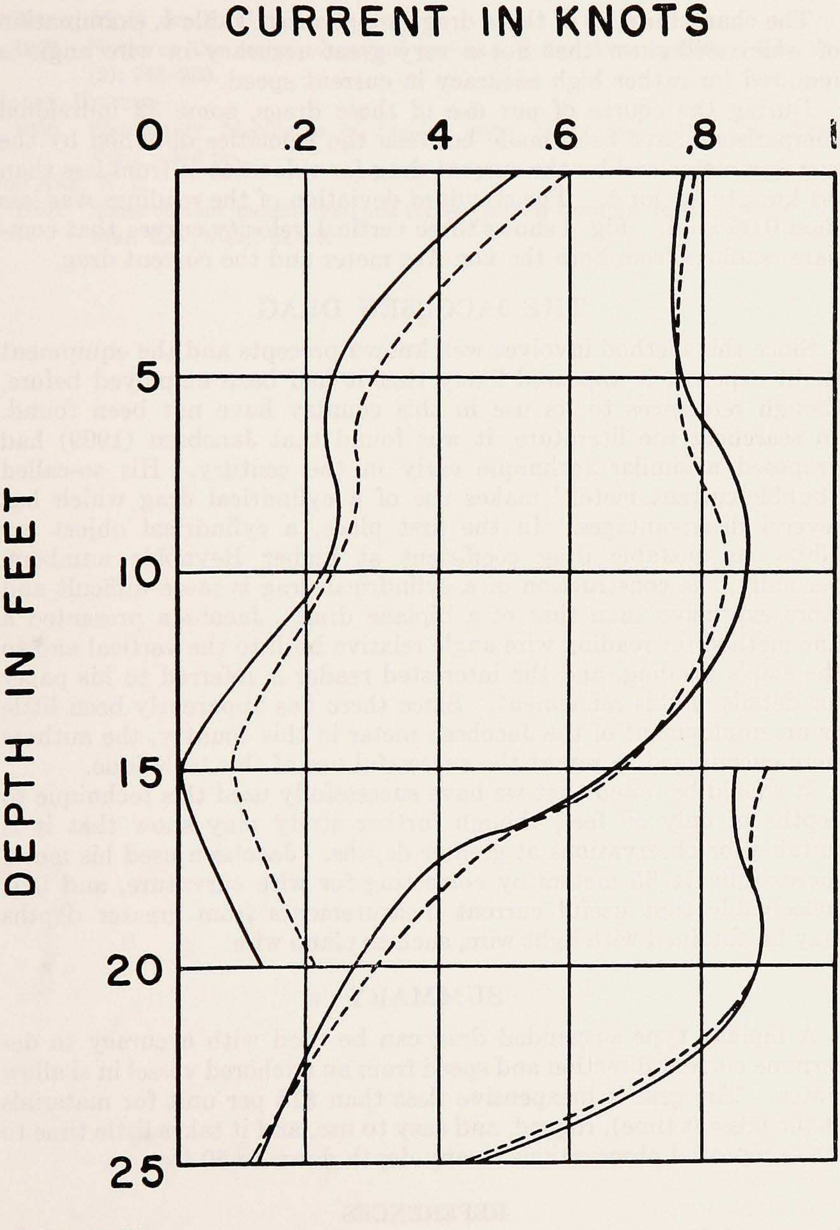

Figure 4. Comparison of velocity profile made by confined submerged drag (solid line) and the von Arx current meter (broken line).

The characteristics of these drags are given in Table I, examination of which will show that not a very great accuracy in wire angle is required for rather high accuracy in current speed.

During the course of our use of these drags, some 32 individual comparisons have been made between the velocities obtained by the von Arx meter and by the current drag for velocities of from less than 0.1 knot to 1.0 knot. The standard deviation of the readings was less than 0.06 knot. Fig. 4 shows three vertical velocity curves that compare readings from both the von Arx meter and the current drag.

THE JACOBSEN DRAG

Since this method involves well known precepts and the equipment slight expense, it appeared likely that it had been employed before, though references to its use in this country have not been found. In searching the literature, it was found that Jacobsen (1909) had proposed a similar technique early in the century. His so-called "bubble-current meter" makes use of a cylindrical drag which has several disadvantages. In the first place, a cylindrical object exhibits an unstable drag coefficient at higher Reynolds numbers. Secondly, the construction of a cylindrical drag is more difficult and more expensive than that of a biplane drag. Jacobsen presented a fine method for reading wire angle relative both to the vertical and to the ship's heading, and the interested reader is referred to his paper for details of this refinement. Since there has apparently been little or no employment of the Jacobsen meter in this country, the authors were encouraged to report the successful use of this technique.

It should be noted that we have successfully used this technique to depths of only 50 feet, though further study may show that it is suitable for observations at greater depths. Jacobsen used his meter successfully to 35 meters by correcting for wire curvature, and it is conceivable that useful current measurements from greater depths may be obtained with light wire, such as piano wire.

SUMMARY

A biplane type suspended drag can be used with accuracy to determine current direction and speed from an anchored vessel in shallow water. The gear is inexpensive (less than $15 per unit for materials at the present time), rugged, and easy to use, and it takes little time to make repeated observations at any depth down to 50 feet.

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