CHAPTER 8

Current Measurement

8.1 Introduction

The responsibility of a Hydrographic Service to provide current information, mainly as an aid to navigation, was mentioned in the Preface to this Manual. The responsibility for gathering the necessary current information lies mainly with the field hydrographer, and this aspect must be recognized as an integral part of any hydrographic survey. Current information that is obtained on a survey will be analysed, compared with previous information, interpreted, and eventually incorporated into the charts, *Tide and Current Tables, Sailing Directions*, or possibly tidal atlases. Since aiding safe and efficient navigation is the main goal of a hydrographic survey, current measurement will be called for mostly in narrow or shallow channels, harbour entrances, congested shipping lanes, or other areas where the margin for navigational error is small. Current information from deeper and less restricted offshore areas is also greatly appreciated by mariners, but its measurement may often require the assignment of dedicated current survey teams with specialized mooring equipment. Even in the offshore areas, however, bits of current information can be gathered during the course of a sounding survey, from analysis of the drift of the ships and launches.

Various aspects of currents and tidal streams have already been described in Part I of the Manual. Some of the terminology and characteristics associated with tidal streams were discussed in sections 1.5 and 1.11; harmonic analysis and prediction of tidal streams were dealt with in sections 3.7 and 3.8; and some of the causes and characteristics of non-tidal currents were treated in sections 4.2, 4.3, and 4.7 to 4.10. This chapter will deal with practical aspects of gathering current information as part of a hydrographic survey — preliminary investigation, methods of measurement, types of current meters, etc.

8.2 Preparatory investigation

The effort expended on current measurement can be more effectively directed when something of local conditions and navigational problems is understood. Before leaving for the field, the hydrographer should study the current information given for the survey area in the *Sailing Directions*, navigational charts, *Tide and Current Tables*, and current atlases, if they cover that area. The Regional Tidal Officer should be consulted for advice and for information that may not yet have been published, and also for copies of correspondence that may have been received complaining of errors or omissions in the publications, or requesting additional current information. When in the field, the opinions of experienced local mariners and fishermen should be sought. They should particularly be asked to comment on the information concerning currents in the area as shown in the Hydrographic charts and publications. On the basis of evidence gathered as above, and by first-hand reconnaissance, it must be decided if and where current observations are required to verify or supplement the existing information.

8.3 Location and depth of current measurement

Current measurements will normally be required only where appreciable velocities (0.2 knots or more) are encountered in shallow, narrow, or congested shipping routes, in harbour entrances, in berthing areas, etc. Where possible, the observations should be taken where the velocity is greatest, but if this is in the centre of heavy traffic, it may be necessary to move the observation site to one side of the channel. When this is the case, a few spot readings should be taken in the centre of the channel, to relate the current there to that at the site of the more complete observations. Indeed, it is always wise to take spot readings at various locations and at various times (e.g. at maximum flood and ebb) during the main observations: this can help to define the spatial variability of the currents with minimal effort. The exact position of each main observation site will, of course, be influenced by the availability of a suitable bottom for mooring current meters or anchoring a vessel, or of an existing platform such as a bridge footing or drilling barge.

Since the current information is intended mainly for the use of mariners, the depths of observation should span the depth of the deepest draught vessels frequenting the area; if only one depth is occupied, it should be about one-half the deepest draught; if two depths are occupied, they should be about one-third and two-thirds the deepest draught, etc. A moored current meter, however, may not be placed so near the surface that the subsurface float from which it is suspended could break the surface in any sea conditions or at any stage of the tide.

8.4 Time and duration of measurements

The length of record required to permit separation of the major tidal constituents by harmonic analysis is the same for currents as for water levels, a minimum of 29 days. This length of record should, therefore, be the target for current measurement in tidal waters. If, for some reason, 29 days of record cannot be obtained, an honest attempt should be made to get at least 15 days. The above is intended to encourage longer series of current observations, but is in no way intended to discourage short series when circumstances absolutely preclude the possibility of longer ones. Almost any carefully observed data are better than no data at all. In waters whose tide shows a large diurnal inequality, observations should be obtained over at least 25 hours, whereas if the tide shows only a small diurnal inequality, this may be relaxed to 13 hours, if necessary. Short series are more valuable if they can be observed when the range of the tide is large (usually at spring tide), since the tidal streams should then be large as well. Two short series taken one at spring tide and one at neap tide are much more informative than a single series of their combined length. In general, the more frequently the current is sampled, the more reliable is the data, because irregularities can more easily be smoothed out of the record. Frequent sampling is most important in short records, a sampling interval of 15 minutes being desirable, but one of 30 minutes being acceptable. The sampling interval might be extended to one hour if so doing permitted a longer record to be obtained through conservation of limited battery power or data storage space. As mentioned in section 8.3, spot readings taken at various locations and times during recording at the main sites are very valuable. While there can be no set sampling interval prescribed for these, they are most useful if taken near the times of maximum flood and ebb, in tidal waters. In fact, series of measurements of the time, rate, and direction of the current at maximum flood and ebb (or at the times of maximum and minimum ebb in the case of some tidal rivers) are very worthwhile even when it may not be feasible to observe a proper time series.

In non-tidal waters, the continuity of current observations is less important than in tidal waters. What is more important is to obtain measurements over the range of conditions that influence the current, these being mainly river discharge, runoff, and wind. Long continuous periods of record are certainly satisfactory if they span a sufficient range of conditions, but it is frequently more convenient to schedule several shorter periods to coincide with such events as the spring freshet, the dry season, the stormy season, etc. The sampling interval for observations in non-tidal waters may, in general, be longer than that recommended for tidal waters, one hour being a reasonable value unless seiche activity is thought to contribute significantly to the current (see section 4.6). The seiche contribution may be studied from a record of duration equal to several seiche periods, observed with a sampling interval about one-tenth of the seich period: seiches are not, of course, always present, and care should be taken that seiche activity is included in the record if it is to be studied.

8.5 Observation methods — general

Current observations may be categorized as "direct" or "indirect" on the basis of whether the velocities are measured as such or are deduced from their relation to other measured parameters. Five examples of indirect current observation are described below — the continuity, the hydraulic, the long wave, the electromagnetic, and the geostrophic methods. Of these, only the first three are likely to find even limited application on hydrographic surveys, but they may all contribute to the information in Hydrographic publications through the courtesy of other investigators. Direct current measurement is sub-classified as either "Eulerian" or "Lagrangian." Eulerian measurements are taken at a fixed location over a period of time; Lagrangian measurements are taken by tracking the path of an object that drifts with the water over a period of time. Results from the two methods could be comparable only if the drifter remained within the same current regime throughout its path, which would usually require the path to be very short. In general, it is easier to interpret Eulerian than Lagrangian measurements. The methods described below that involve drifters of one sort or another may be considered to be Eulerian, because it is envisaged that the drifters would be recovered and re-set, to traverse the same small region repeatedly during the series of observations.

8.6 Self-contained moored current meters

These instruments consist of sensors to detect current rate and direction, data recorder (usually magnetic tape), clock, power supply, and a watertight pressure case to house the vulnerable components. In some instruments, additional sensors may be supplied for such things as pressure, temperature, and electrical conductivity (from which salinity is determined): while these other parameters may not be of direct concern to a hydrographer, they may be observed with no extra effort by using an instrument that is so equipped. To date, direction sensors still rely on the magnetic compass, gyro-compasses not yet having been successfully engineered into small current meters. This is a serious drawback only in the far North, where the horizontal component of the earth's magnetic field is weak near the magnetic pole. The rate sensor is usually either a propeller mounted on a horizontal shaft, or a drum-shaped Savonius rotor mounted on a vertical shaft. Some instruments have a tail fin and are suspended so that the whole body of the meter turns to face the current, in the manner of a weather vane; others, particularly among those using Savonius rotors, have a direction vane that rotates independently of the instrument case. The common recording procedure is to store a pair of rate and direction readings at a fixed sampling interval, typically about 15 minutes. More sophisticated instruments may be programmed to accumulate the vector average of readings taken every few seconds over a fixed interval, and to store only the average rate and direction after each recording interval. In this way, data storage is conserved, but wave "noise" is filtered out of the record by high frequency sampling. Solid-state sensors are available on some models to replace the propeller or rotor. There are two acoustic types, one of which detects the change in travel time of a sound pulse between two probes, and the other of which detects the Doppler shift in frequency of a sound pulse reflected from particles in the moving water. There is also the EMF (electro-magnetic force) type sensor, which senses the voltage generated as the moving water (a conductor) cuts the lines of force of a magnetic field in the sensor.

Figure 60 shows a typical configuration in which to moor a string of current meters in moderately shallow coastal waters. The subsurface float must be deep enough not to break the surface at any wave or tide condition; the cable supporting the meters is non-rotating stainless steel wire, with a swivel above the anchor, below the float, and above and below each meter; the ground line and the line to the surface marker are buoyant polypropylene rope; and the anchor release is triggered by a coded acoustic signal. The ground line should be a least as long as twice the water depth, and be laid out in a known direction. Normal recovery procedure is to trigger the release, pick up the subsurface float, and retrieve the meters and the rest of the mooring in order. If the release should fail, the mooring may be recovered in reverse order, starting with the surface marker buoy. If the surface buoy is lost, or was not considered necessary when the mooring was placed, the string may be recovered by grappling for the ground line normal to its length. In very shallow water, a single instrument might be mounted on a tripod or frame and weighted to the bottom. Further details and alternative suggestions for mooring current meters may be obtained from the Regional Tidal or Current Officer or from oceanographic field personnel.

8.7 Over-the-side current meters

These instruments are basically the same as those described above, but the internal recorder is usually replaced by a visual display and/or recorder on deck, to which the information is fed through electrical conductors in the suspension cable. With the vessel at anchor, the meter is lowered by winch and readings taken at selected depths. The procedure should be repeated at intervals of about 30 minutes for as long a series as is feasible. If the system has an automatic recorder, or if personnel are available to monitor the visual display continuously, the meter should be left to record at a selected control depth rather than being brought inboard between lowerings. A pressure indicator that can be set to zero at the surface is a desirable feature in over-the-side current meters, to provide an automatic record

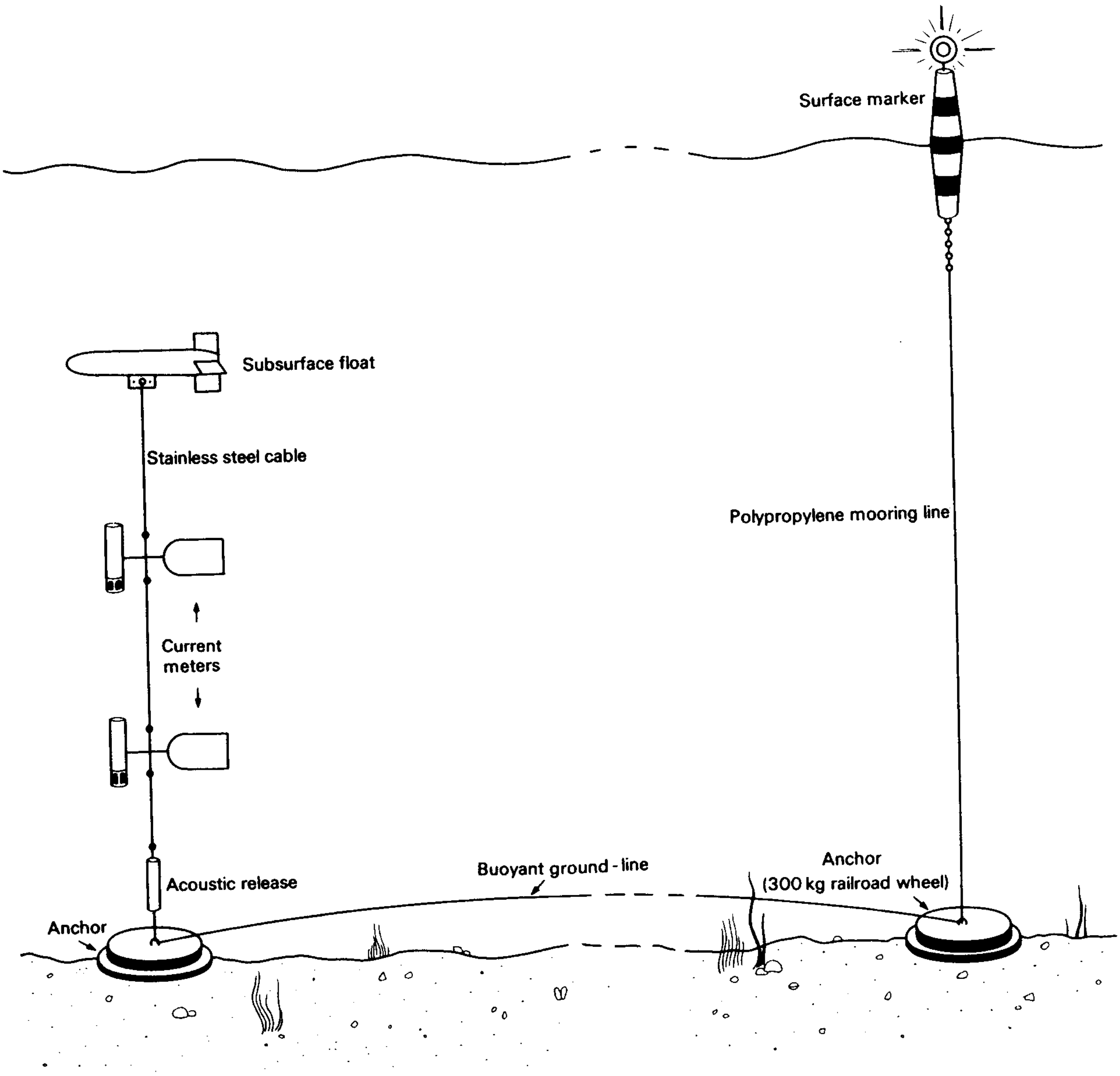

FIG. 60. Typical current meter mooring configuration for coastal waters.

of the various pressures (hence depths) at which readings were taken. If this is not provided, the depth must be determined from the length of cable out and its angle from the vertical.

One of the self-contained meters described in section 8.6 may be used for over-the-side operation instead of for mooring, if so desired. It must then, however, have a pressure sensor as well as rate and direction sensors and a clock. A record, independent of that in the meter, should be kept of the times at which the instrument was recording at particular depths. This, coupled with the pressure record, provides additional time checks on the record; or, if the pressure sensor fails, helps to identify the depths of the readings. Since the record is not usually accessible during operation, the initial estimate of the depth of the self-contained meter is determined from the length of wire out and its angle from the vertical. Some meters may be monitored acoustically by hydrophone during operation, but the added equipment, including a decoder, perhaps unduly complicates the procedure. Again, between lowerings to selected depths, the instrument should be left to record at a chosen control depth.

A current meter suspended from a movable platform records the movement of the water relative to the platform, so it is necessary to remove the platform motion from the record or, at least, to identify parts of the record that should be ignored because of excessive platform motion. To achieve this when the platform is a vessel positioned by a single anchor, a record should be kept of the direction of the ship's head and the scope of the anchor.

8.8 Suspended current cross

This is a piece of equipment that can be simply constructed to measure currents from a reasonably stationary platform. Its design and use are illustrated in Fig. 61. A rigid cross, about half a metre in each of its three dimensions, is weighted at the bottom and suspended from the top by a thin wire. The drag force (*D*) of the water on the cross swings it in the direction of the current until the suspension wire is hanging at an angle θ off the vertical. At this point, the horizontal component of the tension in the wire must balance the drag force on the cross, and the vertical component must balance the weight minus the buoyancy of the weighted cross (i.e. the weight in water, *W*), so

$$(8.8.1) \quad \tan\theta = \frac{D}{W}$$

The drag force of a moving fluid on a bluff object (not streamlined) is

$$(8.8.2) \quad D = \tfrac{1}{2}C \rho A v^2$$

where A is the cross-sectional area of the object normal to the flow, v is the speed of the fluid relative to the object, ρ is the density of the fluid, and C is the drag coefficient, a dimensionless constant approximately equal to unity. The procedure for measuring current is as follows:

(1) lower the current cross over a fixed pulley to the desired depth of water (allow for wire angle),

(2) measure the angle (θ) between the downward vertical and the wire (wire angle indicators are available for this purpose),

(3) estimate the azimuth toward which the suspension wire is heading in the horizontal plane, to get current direction,

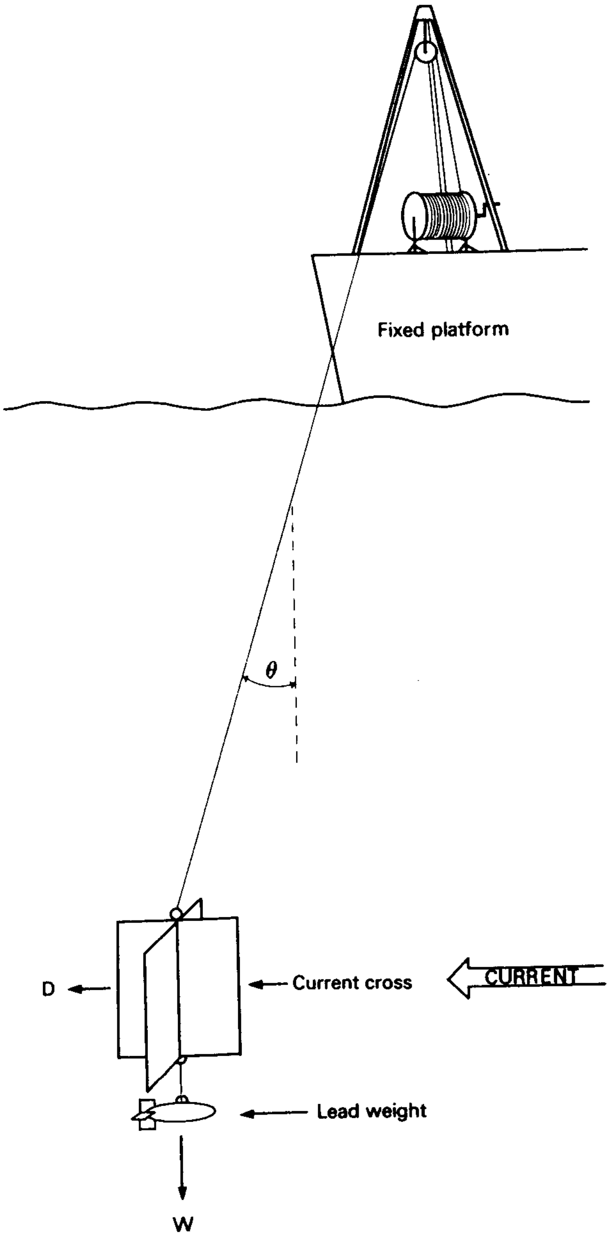

Fig. 61. Current measurement by suspended current cross.

(4) record the time and date, the inclination angle, and the azimuth of the suspension wire,

(5) assure that the weight of the loaded cross in water and the cross-sectional area of the cross plus weights are recorded for each measurement, because different combinations may be required to give reasonable inclinations at different speeds,

(6) to confirm the validity of the measurements, at least some observed sets of θ, W and A should be converted to current speed: if the apparatus was supplied with calibration tables, this may be done by table look-up; if it is an *ad hoc* piece of equipment assembled in the field, speeds may be calculated from the formula

$$(8.8.3)\quad v = [0.019(\frac{W}{A})\tan\theta]^{1/2}\,\mathrm{m\ s^{-1}}$$

where W is the weight in water in kg, and A is the area in m^2.

The constant (0.019) in 8.8.3 was derived by substitution of 8.8.2 into 8.8.1, with $C = 1.0$, $\rho = 1020$ kg m^{-3}, $g = 9.8$ m s^{-2}. Multiplication of W by the acceleration of gravity, g, in 8.8.1 was necessary to convert weight units (kg weight) to fundamental force units (kg m s^{-2}).

A current cross may be employed down to depths of 15 m if the suspension wire is thin enough (about 2 mm) to keep the drag on the wire small relative to that on the cross. If a cross is constructed in the field to meet an unexpected requirement, it should be retained for later calibration, because the expression in 8.8.3 is only approximate, and because an error could be made in determining W/A. The area and/or the weight of the cross must be chosen so that a reasonable inclination angle (θ) is obtained in the current speeds anticipated. If the angle is too small, it cannot be read accurately; and if it is too large, the cross may plane on its side. The maximum inclination that should be encountered during operation is about 40°. To assist in the design of a current cross for a particular application, Table 8 gives the current speeds that would produce the maximum deflection of 40° for various values of W/A, according to expression 8.8.3. If it is wished to work in knots, a sufficiently accurate conversion is 1 m s^{-1} = 2 knots.

TABLE 8. Current speeds associated with 40° deflection angle, for current crosses with various weight/area ratios.

W/A (kg wt.)/(m^2)	v (m s^{-1})	W/A (kg wt.)/(m^2)	v (m s^{-1})
1	0.1	100	1.3
5	0.3	140	1.5
10	0.4	200	1.8
20	0.6	300	2.2
40	0.8	500	2.8
60	1.0	1 000	4.0

While a wooden cross is usually employed in this application, other material and forms may be used as well. If a large value of W/A is required, it may be convenient to use a concrete cube. For solid cubes, W/A is proportional to the length of the side, and for a concrete cube of 30-cm side, $W/A = 500$ (kg wt.)/(m^2). In theory, a sphere is the best shape to use, because it presents the same cross-sectional area to the current regardless of its attitude. A cross, however, is easy to assemble and transport and it serves well.

8.9 Drift poles — general

A drift pole is a long buoyant spar of uniform cross-section, weighted at its lower end so that it floats vertically in the water column, with only a small portion of its upper end above the surface. A small flag, radar reflector, light, or even a radio transponder may be fastened to the upper end to help locate it. The area exposed to the wind, however, must be kept small in relation to that exposed to the current, to prevent the wind from unduly affecting the drift of the pole. For hydrographic studies, the length of the pole under the water should approximate the deepest draught of vessels regularly operating in the area, so that it will experience an average current similar to that experienced by a ship. Drift poles may be assembled to the desired length from prefabricated sections, or may be made up from local lumber for temporary use. In some areas it may be difficult to acquire and to manipulate drift poles as long as the draught of the largest vessels. How long a pole can be accommodated will depend a great deal on the survey vessels, equipment, and manpower, but a 10-m pole would probably be the maximum for any operation.

8.10 Drift poles — tethered

This procedure is designed for use from an anchored vessel. A drift pole is tethered to the stern of the vessel (anchored at the bow and riding the current) at the end of a measured line. The line should be made of buoyant polypropylene rope, about 100 m long, and marked off in 10-m sections. Starting with the line coiled on deck, the drift pole is released and allowed to drift away from the stern of the vessel as the line is payed out fast enough to provide slack, but slowly enough to prevent fouling. The time taken for the pole to drift the full length of the line (or a measured fraction of it, if the current is slow) is recorded, along with the relative bearing of the pole at the end of its run and the direction of the ship's head. From this, the current speed and direction may be calculated, if it is assumed that the vessel has not moved during the exercise. The ship movement should be monitored as well as is possible, so the observations may be adjusted accordingly. The procedure should not be undertaken when the tide is turning and the vessel is coming about on its anchor, but the time of turn should be recorded as such. The drift pole releases may be repeated at 30-minute intervals to provide a meaningful series of current measurements.

8.11 Drift poles — free-floating

This procedure is useful when it is wished to study current patterns over a fairly extensive area. It requires several drift poles, at least one launch capable of placing and recovering the poles, and a fairly accurate method of position fixing (visual or electronic). Drift poles are released one at a time in representative sections of the region, and their positions, along with the times, are recorded as soon as they are floating free from the launch. As the poles continue to drift freely, their positions are fixed about every half hour, or more frequently if the region is small and/or the currents are strong. A drift pole should be picked up and repositioned if:

(a) it is in danger of going aground,
(b) it is about to leave the region of interest,
(c) the distribution of the poles no longer provides representative coverage of the region, or
(d) two poles are too close together to provide independent information.

Any one of a variety of methods may be used to fix the drift pole positions: if a launch has the capability of fixing its own position, it may come gently alongside the pole and take a fix; if the launch also has radar, it may fix the position of a drift pole from a fair distance, possibly fixing several poles from the same location; a centrally stationed vessel with proper radar may be able to monitor all the poles, using a launch only to recover and reset them; positions may be determined by theodolite observations from shore; or the poles may carry radar transponders or radio beacons and interact with an electronic positioning system. The number of drift poles that can be monitored at one time will depend on the size of the region, the speed of the current, the number and speed of the launches, the quality of the radar or other positioning system, etc. In a simple region, such as a short and narrow channel, one or two drift poles frequently positioned and frequently reset may provide better coverage than a larger number of poles less frequently positioned and reset.

8.12 Current drogues

Current drogues are deployed and monitored in the same manner as drift poles, but are designed to drift with the current at specific depths, instead of with the average current over an interval of depth. They consist of a surface marker with floatation, from which is suspended an object with a large surface area to intercept the current at the desired depth. They must be designed so that the area exposed to the wind and to the current at other depths is small compared to the area of the drogue at the selected depth. Square crosses, similar to those discussed in section 8.8, may be constructed from plywood or sheet metal and weighted at the bottom to serve as drogues. A drogue that has a large effective surface area, but is not bulky to transport, is the "parachute drogue," which is in appearance just what its name suggests, except that the chute is deployed horizontally instead of vertically. Care must be taken in launching a parachute drogue to assure that the shrouds do not get tangled or fouled. There is a common misconception that the chute must be fully open at all times to operate properly. The chute, however, opens only to oppose the water movement past it, i.e. to oppose being dragged by the surface float and marker. If the drogue is moving freely with the current at that depth, the chute may properly appear collapsed, as long as it is free to open if needed. Figure 62 illustrates current drogues of the square cross and the parchute type, and also a drift pole, for comparison.

8.13 Continuity method

It follows from the continuity principle, which is basically the principle of the conservation of mass, that the rate at which the total mass of liquid inside a container increases must equal the net rate of transport through the entrance to the container. Neglecting the small changes in density that may occur, we may equally well say that the rate at which the

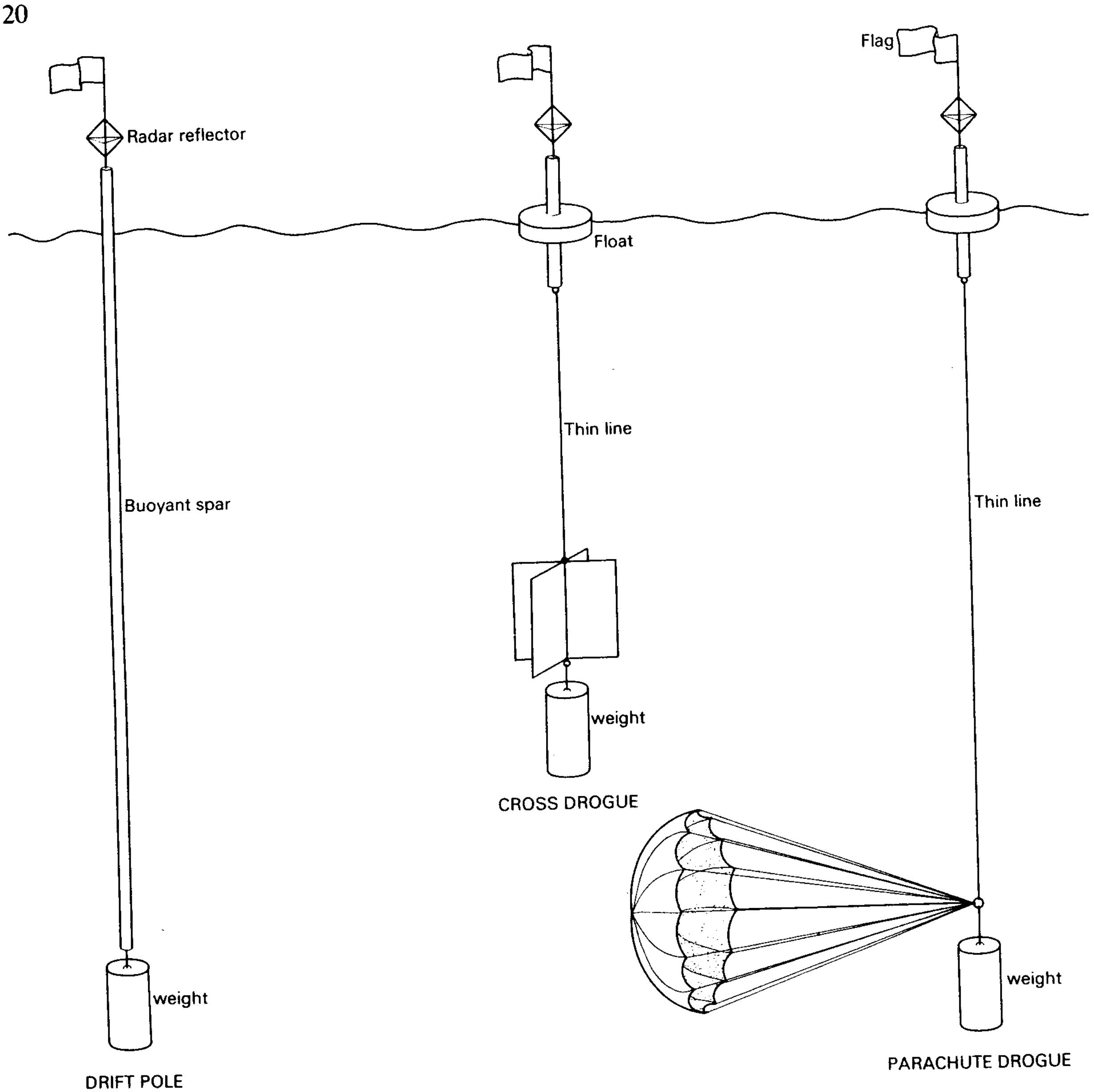

FIG. 62. Drift pole, standard current drogue and parachute drogue.

volume of water inside an embayment increases must equal the net inward volume transport through its entrances. The simplest application of this principle to current determination is to estimate the average tidal streams flowing through the single entrance to an embayment. It is required to know the surface area of the embayment (A), the cross-sectional area of the entrance (a), and the harmonic constants for the main tidal constituents in the mean vertical tide over the surface of the embayment. Suppose H and g are the average amplitude and phaselag of a constituent of the vertical tide in the embayment. Let $h(t)$ be the contribution of the constituent to the tidal height in the embayment at time t, and $V(t)$ be its contribution to the volume of water in the embayment. Assuming that the surface area is roughly the same at all stages of the tide,

$$(8.13.1) V(t) = Ah(t) = AH \cos (\omega t - g)$$

where ω is the angular frequency of the constituent. Differentiation of 8.13.1 with respect to time, and use of some simple trigonometric relations, gives the rate of change of $V(t)$as

$$(8.13.2)\ \frac{d}{dt}V(t) = -\omega AH \sin(\omega t-g) = \omega AH \cos(\omega t-g+90^\circ)$$

By continuity, the rate of change of volume must equal the rate at which water is being transported in through the entrance, and this, divided by the cross-sectional area of the entrance, is the mean tidal stream speed through the entrance, $u(t)$, whence, from 8.13.2, divided by a,

$$(8.13.3)\ u(t) = \frac{\omega AH}{a} \cos(\omega t-g+90^\circ)$$

The amplitude and phaselag of the tidal stream constituent are thus $\omega H(A/a)$ and $(g-90^\circ)$ in the appropriate units. Consider the following numerical example, using the tidal constituent M_2, for which $\omega = 0.00014$ radians per second. Let $A = 20\ \text{km}^2$, $a = 0.007\ \text{km}^2$, $H = 1.0$ m, and $g = 025^\circ$. By 8.13.3, the amplitude of the average M_2 tidal stream in the entrance is $0.00014(1.0)(20/0.007) = 0.4\ \text{m s}^{-1}$, and its phaselag is $025^\circ-90^\circ = -065^\circ$, or, adding 360° to conform to the convention that phaselags are positive angles, 295°.

The field hydrographer would not be expected to perform the continuity calculations necessary to convert water level observations into current information, but could be expected to provide sufficient water level data from inside an embayment to support the calculations. Observations from one gauge site are sufficient for many small embayments, but observations from several gauge sites may be required to represent the average tidal surface of a long and shallow inlet. The usefulness of the method has been demonstrated by the calculation of tidal stream constants for various cross-sections of the St. Lawrence estuary and river between Pte. des Monts and Lake St. Peter. A steady river discharge through the system is not reflected in the water levels, and its effect on the current at the outlet must be added as a constant current, with speed equal to the volume discharge rate divided by the cross-sectional area of the outlet.

8.14 Hydraulic method

The cross-sections of some narrow and shallow passages are too small to accommodate the large volume transports of water associated with the propagation of very long waves (tides, seiches, etc.). The result is that the water level rises or falls at one end of the passage, creating a hydraulic head between the two ends. The flow in the passage is said to be "hydraulic" if water enters the passage at very nearly zero velocity and is accelerated down the pressure gradient created by the hydraulic head. Neglecting frictional losses, the law of the conservation of energy tells us that the gain in kinetic energy per unit mass ($v^2/2$) along a streamline must equal the loss in potential energy (gh), where v is the current speed, g is the acceleration of gravity, and h is the hydraulic head. Thus, we might expect to find the relation

$$(8.14.1)\ v^2 = 2gh$$

In practice, however the gauges at the ends of a passage might not be far enough apart to detect the full hydraulic head, and their zeros might not be set to exactly the same datum. The practical form of 8.14.1 is, therefore

$$(8.14.2)\ v^2 = ah + b$$

where a and b are constants to be determined by calibration against direct current measurements. The constant b may also include allowance for the initial kinetic energy possessed by water entering the system at a non-zero velocity.

Self-contained pressure gauges of the type described in section 6.7 are convenient to place at each end of the passage to measure the fluctuating hydraulic head, since they detect the sum of hydrostatic and atmospheric pressure, and it is to this combined pressure gradient that the water responds. These gauges can be left to operate unattended for several months, but during part of the period direct current measurements should be taken in the passage to permit determination of appropriate values for the constants a and b. Whether or not the method is applicable in a particular passage is revealed by how well the results of the calibration conform to equation 8.14.2, with a and b constant. It may be reasonable to permit choice of two sets of constants, one for flow in one direction and one for flow in the other, but if the results cannot even then be fitted satisfactorily to expression 8.14.2, it must be assumed that the flow is not sufficiently hydraulic for the method to apply.

8.15 Long wave method

The relation between the particle motion and the wave form was discussed for long waves in section 1.5, both for standing and progressive waves. If water level measurements in a region are available from enough locations, it may be possible to identify the propagation characteristics of long waves (e.g. tides and seiches), and so to deduce a great deal about the streams associated with them. This is another reason why water level measurements during a hydrographic survey should not be limited to the absolute minimum needed for sounding reduction.

8.16 Electromagnetic method

This method works on the same principle as the electric dynamo: if an electrical conductor is moved through a magnetic field, a voltage is developed along the conductor in proportion to the rate at which the conductor cuts through lines of magnetic force. Although pure water is a very poor conductor of electricity, most naturally occurring water (especially seawater) is a reasonably good conductor, because of the dissolved salts in it. The vertical component of the earth's magnetic field therefore causes an electric voltage to be generated in water that flows through it, and the voltage is proportional to the speed of flow as well as to the strength of the magnetic field. In theory, therefore, the flow through a channel may be measured by placing the probes of a sensitive voltmeter in the water, one at each side of the channel, to detect the voltage generated by the flow. The voltage that is measured can be shown to be proportional to the total transport through the channel, rather than to the flow at a particular depth. This is because higher voltages generated at depths where the flow is greater are partially short-circuited by the water at depths where the flow (and hence the voltage) is less, so that an average voltage is detected. A further complication arises from the fact that the material on the bed of the channel, and beneath it, is not a perfect insulator, so that part of the signal is also short-circuited by this path. Because the conductivity of the material in and below the bed is never well enough known to permit calculation of its effect on the measurements, direct observations of the flow must be made during part of the installation period, to permit calibration of the system.

There are many practical difficulties to face in implementing such a measuring system. An insulated electrical cable must be led from the voltage recorder to the electrode at the far side of the channel; this is usually done by laying it along the bottom, unless there is a bridge along which it can be strung. The electrodes at the two sides of the channel must be carefully matched, since the voltage generated by their "battery effect" may otherwise be as great as the signal being measured. In channels through which the flow is small, it is difficult to separate the signal from extraneous "noise" generated in the system. In channels through which the flow is large enough to generate a strong signal, it is often difficult to lay and maintain the electrical cable intact to the far side. This is not a method of current measurement that is recommended for routine use on hydrographic surveys.

8.17 Geostrophic method

The Coriolis force, that results from the earth's rotation and deflects currents to the right in the Northern Hemisphere, was discussed in section 1.8. The forces acting on a current that experiences no acceleration must be in balance; the balance in the direction of flow being between the pressure gradient and the frictional forces, and the balance in the direction normal to the flow being between the pressure gradient and the Coriolis forces. If, in addition to zero acceleration, the assumption is made that friction is negligible, there would be nothing to balance a component of the pressure gradient in the direction of flow. The current would then have to flow in a direction normal to the pressure gradient, and at a speed just sufficient to produce a Coriolis force equal and opposite to the horizontal pressure gradient force. Such a current is said to be in "geostrophic" equilibrium. The hypothetical current whose Coriolis force just balances the horizontal pressure gradient force is called the "geostrophic current," and if the pressure field in the ocean is known, the rate and direction of the geostrophic current may easily be calculated. The geostrophic current will, however, resemble the actual current only insofar as the assumptions of zero acceleration and zero friction are true, and as the horizontal pressure gradient is accurately determined.

The horizontal pressure gradient in the ocean depends upon the horizontal atmospheric pressure gradient, the slope of the sea surface, and the distribution of water density within the body of the ocean. Oceanographers can calculate the density distribution from measurements of the water temperature and salinity, and so determine how the horizontal pressure gradient changes with depth. To convert these relative values to absolute values of the pressure gradient requires a knowledge of the actual pressure gradient for at least one depth. Since it is rarely possible to know the slope of the sea surface, the assumption is usually made that the horizontal pressure gradient is zero at some large depth (e.g. 2 000 m). This depth is called the "depth of no motion," because the horizontal pressure gradient can be zero only if the Coriolis force, and therefore the current, is also zero. The relative geostrophic currents calculated from the density distribution may then be referred to zero at the depth of no motion, to obtain estimates of the absolute values of geostrophic current. In the open ocean, where friction and accelerations are small, the geostrophic currents resemble the actual currents reasonably well, and much has been learned about ocean circulation by this method.

In coastal waters, where friction and acceleration may not properly be neglected, great care must be taken if geostrophic currents are to be interpreted in terms of actual currents. If the current is known to have a fairly uniform direction of flow, we may consider only the balance of forces normal to the flow, and so avoid friction, which acts parallel to the flow. Also, if observations are taken over a long enough period, the effects of acceleration must average to near zero. Therefore, if the density distribution is determined as an average over a period sufficiently long to remove acceleration effects, and if only the component of the horizontal pressure gradient perpendicular to the main flow is used, the profile of the geostrophic currents so calculated should resemble reasonably well the profile of the actual average current over the same period. Selection of a reference for a geostrophic current profile in coastal water is difficult, since a depth of no motion cannot be assumed reasonably to exist in shallow water. This difficulty may be partly overcome by adjusting the current profile to satisfy the estimated transports of water and salt through the channel, or by measuring the average current directly at a particular depth, and fitting the profile to that value at that depth.

This discussion of geostrophic currents is given here not with the expectation that field hydrographers would be required to execute the associated observations or calculations, but with the realization that a great deal of the existing body of ocean current information has come from this source, so that the method should be understood and appreciated.

8.18 Current surveys — general remarks

Shipping and marine interests should be notified in a *Notice to Mariners* of any planned current survey that might in any way interfere with their operations. The information should appear in a *Notice* about a month before the commencement of the survey, early enough to be acted upon, but not so early as to be forgotten. It should tell the purpose of the survey, the general area and time period involved, the nature of the operation (e.g. current meter moorings, anchored vessels, tracking of drift poles, etc.), and should describe the appearance of any surface markers and surface drifters that are to be used. The locations of moorings and anchor stations that are planned should be given as closely as possible. An attempt should also be made to have the same basic information broadcast on the marine radio during the survey, particularly if the operation is in or near shipping lanes or fishing grounds. Another effective outlet for the information is sometimes the fishing and marine broadcast over the local commercial radio station. Such notices not only reduce the risk of lost or damaged equipment and of lost data, but they foster better public relations, by satisfying natural local curiosity. The issuing of notices, however, does not relieve the surveyor of the need to choose mooring locations and conduct operations in a manner that will cause the least disruption of other interests, while still providing the desired data. From the standpoint of equipment safety, the mooring of current meters in an area frequented by fishing draggers is particularly hazardous.

The convention for quoting the direction of currents is the exact opposite of that for winds: the current direction is the direction toward which it is flowing, whereas the wind direction is that from which it is blowing. The compasses in current meters are designed to record in agreement with this convention, and all manual records must accord with it as well.

As it is for water level observations, accurate time keeping is also important for current observations, particularly in tidal waters, where it is wished to relate the phases of the tidal streams to those of the constituents in the equilibrium tide. In the mooring and recovery logs, the time of every event that could be reflected in the current record should be recorded and described; e.g. rotor spinning in the wind, meter in water, anchor on bottom, anchor release tripped, etc. This information provides supplementary time checks on the records, which can frequently resolve uncertainties caused by an error in either the initial or final time check. In all records involving time, the zone time being used must be clearly indicated on every sheet by the appropriate abbreviation (GMT, AST, PDST, etc.).

It may be that the same current meter is to be moored more than once during the season, or even during a single survey. Even though the data storage capacity of the meter may be large enough to accommodate the combined records from several moorings, the data record should always be removed, and replaced by fresh magnetic tape (or film, etc.), before the meter is moored again. Keeping separate records for each installation reduces the possibility of confusion later on, but the main reason for removing the record before resetting is to protect if from loss or damage. The time, effort, and expense invested in a successful mooring are worth a great deal more than the material on which the data are recorded, and there is no economy in risking the data simply to conserve magnetic tape. There is, of course, no objection to cutting off the used portion and continuing with the unused portion of a tape or film, if this can be done with no risk to the record and if sufficient storage space remains on the unused portion. Magnetic tape records should be stored in ferrous metal containers and kept out of strong magnetic fields and excessive heat until the data has been extracted from them. All current records and supporting documentation should be submitted to the Regional Tidal Officer at the end of the season, or earlier if an opportunity is afforded. Where possible, copies should be made of records and documents, and stored separately from the originals.