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DEPARTMENT OF COMMERCE

U. S. COAST AND GEODETIC SURVEY

E. LESTER JONES, DIRECTOR

HYDROGRAPHY

PRECISE DEAD RECKONING IN OFFSHORE SOUNDINGS

By

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PRECISE DEAD RECKONING IN OFFSHORE SOUNDINGS.

INTRODUCTORY.

The earliest explorers of the seas recorded only that which the eye could see, and the many islands, reefs, and shoals marked "position doubtful" (P. D.) on our earliest charts attest the fact that locating an object out of sight of the mainland was an art in its infancy. As the study of the seas progressed we find many soundings "no bottom" added to the charts until finally science and invention made possible, and commerce and industry demanded, more exact information.

In the earlier surveys the soundings were long distances apart and their locations in most cases depended upon astronomical observations. A notable example of deep-sea hydrography, where the locations of the soundings depend upon astronomical observations, was the cable survey made by the U. S. Coast and Geodetic Survey steamer *Patterson* off the coasts of British Columbia and Alaska in 1903.

Weather conditions frequently interfere with astronomical observations and this method has to be supplemented by dead reckoning, adjusting the line for the several factors entering into it. This is the method being used in the Philippine Islands in surveying the deep waters of the Sulu Sea, where each end of the line is also determined by observations on known objects ashore.

A more precise method of dead reckoning for determining offshore positions was started in 1914, during a survey season off the coast of Georgia, and the following "Instructions for precise dead reckoning" and the observations in adjustments necessary in a survey of this kind are the result of the experience in this work by the several chiefs of party and represent the best present practice.

IMPORTANCE OF ACCURACY.

The accuracy, hence the value of precise dead reckoning hydrography, depends upon the precision with which the various elements entering into it are observed. . It is necessary for the helmsman to steer and the officer of the watch must con within a degree; currents must be observed often enough to give an accurate idea of the set and drift of the ship during the run; leeway must be applied, although it is by far the most uncertain of all the corrections; the log factor must be known to within two decimals; the standard compass should be kept as near magnetic as possible, and all deviations accurately known. Almost all these corrections are small in comparison with the lengths of the lines, and to meet the rigid requirements of the work they must be observed with more than average accuracy and precision.

It is customary to place six or seven buoys parallel with the general trend of the coast and a little outside the limit of visibility of the shore signals. The buoys are placed close enough inshore so that they can be picked up before the shore signals are lost. These buoys are located from anchorages of the ship while the ship is within sight of the shore signals. Cuts to the buoys are taken from each anchorage, and at least three good cuts to each buoy are desired. Local conditions and the degree of visibility of the buoys will determine both the most advantageous distance offshore and the most advantageous distance apart to place the buoys. In general, along a low sandy shore with signals at least 100 feet high, they can be placed 10 to 12 miles offshore and 2½ to 4 miles apart. With buoys so placed and located it is possible to carry the fixed position hydrography about 6 miles farther offshore than would be possible using shore signals alone. They also serve as known points to fix the inshore ends of the offshore lines.

THE COMPASS.

Keep the standard compass compensated and adjusted so that it is practically magnetic. This does away with any uncertainties in the deviations on the various headings and more accurate work obtains. The deviation of the steering compass should be kept as small as possible to aid the steersman.

Before starting any compensating, the azimuth circle should be tested on shore. Draw a circle slightly larger than the outside diameter of the azimuth circle on a piece of drawing paper or the back of an old chart. Two diameters of this circle are drawn at right angles to each other. Mount the paper on a planetable and carefully level the table. Set the azimuth circle on the paper with the line joining the mirror and the prism coinciding with one of the penciled diameters. See that the bubble on the circle is in the center. If not, adjust it. Turn the planetable toward the sun so that the sun's reflection from the mirror is directed through the prism and clamp the table. See that the pencil of light from the prism is reflected directly down on the penciled diameter. Now tilt the mirror slightly and see if the pencil of light follows along the penciled diameter. The azimuth of the sun will change very little in the time necessary to make this test. If the pencil of light is reflected directly down on the penciled diameter and stays there as the mirror is tilted, the azimuth circle mirror and prism are as near correct as any field test will show. Now test the direct vision vanes. First see if the line between them coincides with the penciled diameter at right angles to the one joining the mirror and the prism. By means of the tangent screw on the planetable repoint the mirror toward the sun, then rapidly shift the azimuth circle 90° in azimuth on the penciled circle. If your direct vision vanes point accurately toward the sun, you may assume they are at right angles to the line joining the mirror and the prism.

If the azimuth circle, by this test, is found to be out of adjustment, unless a minor error which can readily be remedied on board, it should be returned to the office for overhauling and adjusting and another one requisitioned. Small errors in the direct-vision vanes can be corrected, but any displacement of the prism, caused by its being chipped or having been knocked out of adjustment, can hardly be corrected satisfactorily aboard ship. *Do not attempt to adjust compasses with an azimuth circle which is out of adjustment.*

The following is a simple method of compensating the standard compass: Prepare a table showing the rate of change of the sun's azimuth for every 10-minute interval during the time to be occupied in adjusting the compass. This table need be compiled for the nearest degree of latitude and degree of declination only. Set a watch to local apparent time. Have an officer to mark time and do the necessary computing, another officer to check his work, an officer to con the vessel, an observer to observe azimuths and handle the magnets.

Steady the ship as near magnetic north as possible and hold on this course with the steering compass. Observe an azimuth of the sun. Steady the ship bearing as near magnetic south as possible and observe another azimuth. By the use of the table of the rate of change, correct the azimuth observed while the ship was heading north to what that observation would have been had it been observed at the same time the azimuth on the south heading was observed. Take the mean of the azimuth observed on the south heading and the corrected azimuth of the north heading. This mean is what the sun should bear at the time the south azimuth was observed if the compass is to be free from all deviation except the A factor. A minute or two will have elapsed before this mean will have been determined. Have it corrected to a few minutes ahead by the rate of change table, the same way as the north azimuth was corrected, and at that time bring the sun to bear on this corrrected mean by raising or lowering the athwartship magnets. This should be checked and further adjustments made until the sun bears the same whether observed on a north heading or a south heading. When it does this all deviation is removed on these two headings, except for the A factor.

Next do the same work with the ship steadied on east and west, using the fore and aft magnets to bring the needle into proper place.

Then do the same work with the ship steadied on northeast and southeast, moving the soft iron spheres at the side of the binnacle in or out as necessary. Note that the quadrantal adjustment is made on adjacent cardinal points and the semicircular adjustments made on opposite points.

After the standard compass is adjusted, the ship should be swung for residual errors and a comparison made with the quarterdeck and steering compasses. The quarterdeck and steering compasses can be adjusted in the same way as the standard compass.

The Manual of the Compass, published by the Hydrographic Office of the Navy, is recommended for study.

THE LOG FACTOR.

This is by far the most important element entering into precise dead-reckoning work. An error in the log factor will not show on the closures of the lines. If a ship runs from A to B, an actual distance of 30 miles, and the log gives a distance of 40 miles, the log on the return run from B to A would show a total distance of 80 miles, there would apparently be no closure adjustment necessary, and the point B would be plotted 10 miles too far distant from A.

To determine the log factor is easy, although it requires careful attention. Select a course 3 or 4 miles long in water of suitable depth for anchoring a launch or small boat at each end of the course. By observing the direction of the current before the runs are started it is possible to place the second launch so that the course of the ship will be fair with the current. From each of the small boats observe currents at 10-minute intervals while the ship is making the runs between them. The distance run by the ship "over the ground" is determined by three point fixes taken at the beginning and ending of each run. The distance "through the water," which is the quantity desired, is found by adding (or subtracting) the amount of the current to (or from) the distance "over the ground" (according as to whether the ship was steaming against the current or with it).

Make enough runs at both sounding and full speeds to insure a factor correct to a couple of hundredths.

CURRENTS.

Currents should be observed at the start and finish of each line and at intervals of about two hours while on the line. If the currents are changing rapidly it is necessary to observe at more frequent intervals. The usual current pole and line (see par. 533, General Instructions for Field Work) are used. The observations should be made from the stern; a pelorus mounted there will facilitate the observations. The current line should be handled by an officer, the quartermaster or a seaman being used to read the ship's head by compass at each mark of the officer.

The office recommends the following markings for a current line, and all lines should conform thereto:

Zero	Red bunting.
One-tenth of a knot	Single string with 1 knot.
Two-tenths of a knot	Single string with 2 knots.
Three-tenths of a knot	Single string with 3 knots.
Four-tenths of a knot	Single string with 4 knots.
Five-tenths of a knot	Single string extending both sides of current line.
Six-tenths of a knot	Double string with 1 knot.
Seven-tenths of a knot	Double string with 2 knots.
Eight-tenths of a knot	Double string with 3 knots.
Nine-tenths of a knot	Double string with 4 knots.
One knot	Heavy laid cord with one knot.

The length of the stray line (from the pole to the first mark) should be about 100 feet. The length between knots (nautical miles) should be 101 feet 4 inches and the length between the small marks 10 feet 1.6 inches. For further discussion, see Currents, General Instructions for Field Work.

APPLYING THE CURRENT CORRECTION.

The current is constantly changing both in hourly velocity and in direction. The expression "average current" is used hereafter to indicate that quantity that would have been obtained were enough observations made to determine each change in direction and each change in hourly velocity and the mean of these observations determined.

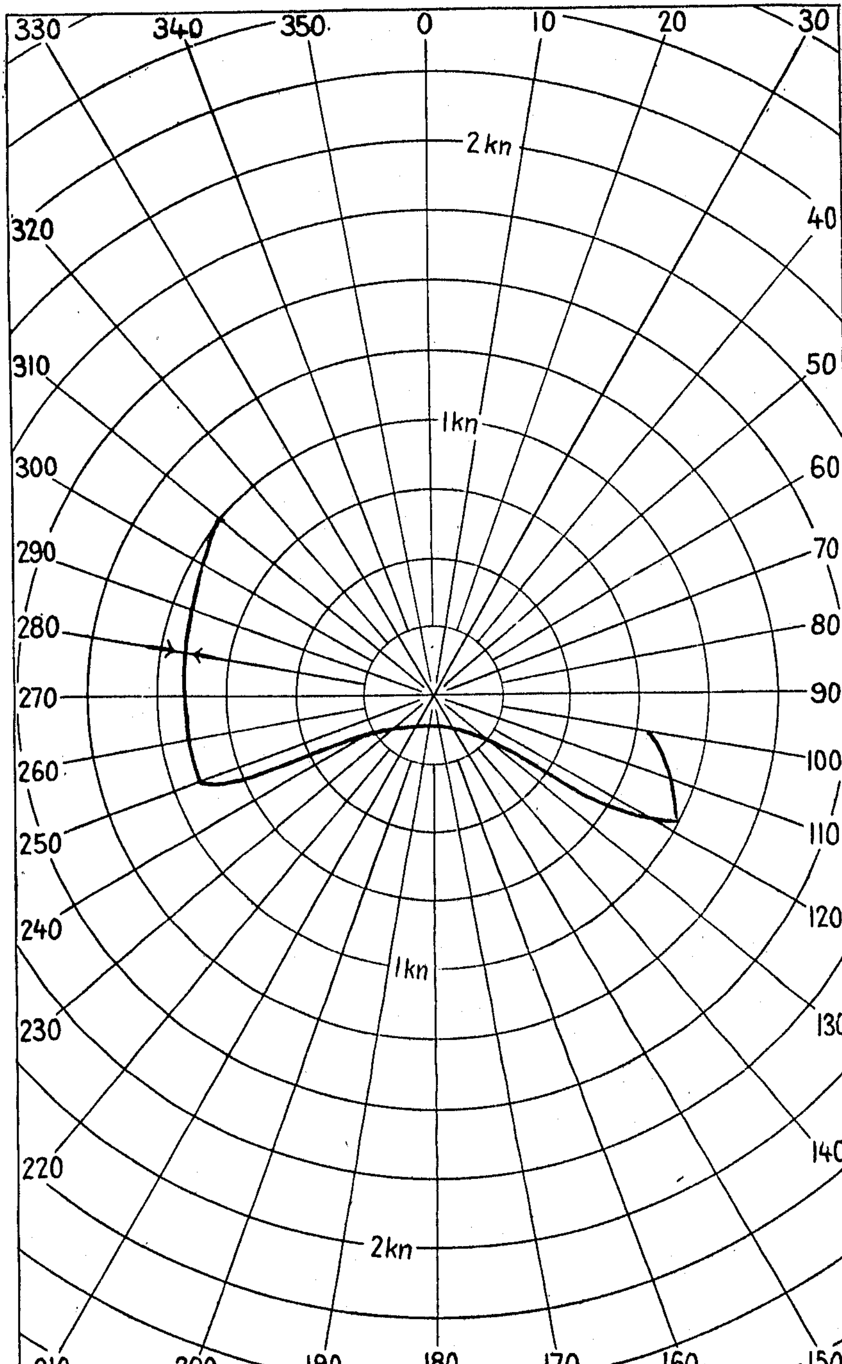

Fig. 1.—Current graph.

An average velocity and an average direction of the current for the run of the ship are approximated from the observations taken at the beginning and ending of each two-hour run. The use of polar coordinate paper facilitates the finding of this average. From the lack of information to the contrary it is assumed that the ship has been set from its course the total amount of the current correction. The correction is the product of the time of the run—in hours and decimals—and the average hourly velocity. It is laid off in the direction in which the current has been setting, from the position of the ship as determined by the course and log distance.

When there has been a change of course between the current observations, estimate the value of the current at the time of the change and apply the average between this estimated current and the current obtained at the beginning of the run to the first part of the line, and the average between this estimated current and the current obtained at the end of the run to the latter part of the line.

When the current has made a radical change of direction in the two-hour run, the graph in the majority of cases passes through or near the origin. See example of currents as illustrated. It is necessary to study the currents in any locality thoroughly before you can approximate the changes. For this reason currents should be observed at regular intervals while the ship is at anchor on the working grounds.

On page 7 is reproduced a graph on polar coordinate paper with currents as actually observed for one day. At the first anchorage the current was running 0.8 knot, 100° true. At the next current anchorage the current was running 1 knot, 118° true. From the graph we deduce the average current was 0.9 knot, 110° true, for the run. As the ship was under way exactly two hours, the current correction amounts to 1.8 knots, 110° true. The ship then ran to another current anchorage and found a current 0.9 knot, 250°. A study of the currents made when the ship was at anchor showed a slack between radical changes like this: The graph was constructed as shown in the illustration and an average current of 0.3 knot per hour, 190° true, applied. The ship proceeded on the line and at the end of one hour made a change of course amounting to 90°. The ship anchored again for current observations after an hour's run on this new course. The current found here was 1 knot, 310° true. From the graph we assume that at the time of the change of course the current was setting 0.9 knot, 280° true. The average current for the first part of the run was 0.9 knot per hour, 265° true, and for the latter part of the run 0.94 knot per hour, 295° true.

LEEWAY.

Leeway, as used in this publication, is the distance the vessel is actually pushed over the water surface in the true direction in which the wind is blowing.

The allowance for leeway is the most uncertain of all the corrections. It is practically impossible to make direct observations, and this correction should be approximated for each ship according to the best information. Experiments made on the U. S. Coast and Geodetic Survey ship *Bache* showed about 0.2 mile leeway with a

15 mile breeze. This amount increases rapidly with the velocity of the wind. An anemometer, with recording device for continuous record, should be installed in the most advantageous position. This record will show the velocity of the wind when the ship is at anchor and will show the resultant of the wind movement and the breeze created by the ship's moving through the air when the ship is under way.

The direction of the wind can be observed when the ship is at anchor. The true and not the magnetic direction of the wind should be recorded.

The table of wind components shown below is simply a resolution of forces. With the ship steering north at 8½ miles an hour and a breeze blowing from the northeast at 8 miles an hour, the anemometer would show a velocity of 15 miles an hour and to an observer on the bridge the wind would apparently be coming from the north-northeast.

To use the table: Enter with the top argument as shown by the anemometer record and enter with the side argument the difference between the true course steered and the true direction of the wind. (The true direction of the wind is observed when the ship is at anchor.) The true velocity of the wind will be found opposite.

Wind components.

Speed of vessel.	5 knots.			8½ knots.		
Anemometer record. / Actual degrees off bow.	10 mph.	15 mph.	20 mph.	10 mph.	15 mph.	20 mph.
00	5.00	10.00	15.00	1.50	6.50	11.50
10	5.08	10.07	15.08	1.64	6.63	11.66
20	5.17	10.21	15.28	1.78	6.77	11.89
30	5.42	10.44	15.57	1.92	7.13	12.23
40	5.66	10.87	15.90	2.06	7.56	12.78
50	6.07	11.33	16.39	2.20	8.17	13.49
60	6.54	11.85	17.03	2.74	8.87	14.43
70	7.12	12.48	17.74	3.27	9.91	15.47
80	7.84	13.25	18.54	4.15	11.04	16.69
90	8.65	14.12	19.35	5.27	12.40	18.10
100	9.58	14.99	20.19	6.30	13.93	19.63
110	10.54	15.90	21.10	9.00	15.64	21.15
120	11.49	16.82	22.08	10.98	17.25	22.81
130	12.40	17.71	22.85	12.97	18.92	24.24
140	13.30	18.47	23.54	14.84	20.43	25.13
150	13.96	19.08	24.11	16.35	21.65	26.83
160	14.51	19.57	24.60	17.44	22.57	27.67
170	14.84	19.84	24.91	18.18	23.22	28.19
180	15.00	20.00	25.00	18.50	23.50	28.50

APPLYING THE LEEWAY CORRECTION.

The difference between the current correction and the leeway correction should be clearly understood. The correction for leeway gives the true position of the vessel in relation to the water surface. If there is a current this water surface is a moving surface and the current correction is necessary to obtain the true position of the vessel in relation to the "ground"—its geographic position. In making leeway a ship is being actually pushed over the water surface

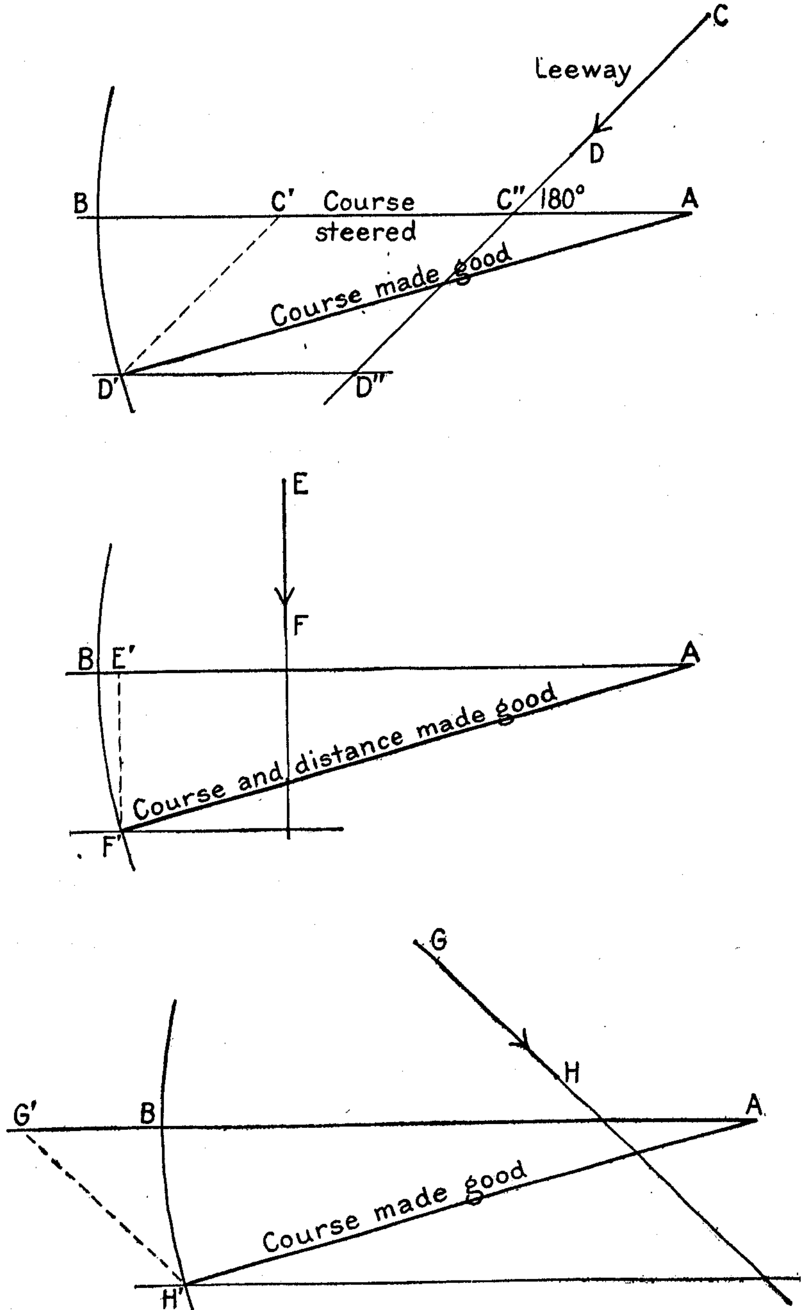

FIG. 2.—Leeway adjustment.

and is dragging the log after it, hence the log distance is the resultant of the distance the ship would have steamed in calm weather and the distance the ship has been pushed over the water surface by the wind. The log distance plotted along a line which differs from the ship's course by an amount equal to the displacement of the ship due to the velocity and direction of the wind, gives the course and position of the ship on the water surface as corrected for leeway. Unlike the wind, the current does not affect the speed or direction of the vessel on the water surface and is therefore not registered on the log. It does, however, affect the distance and direction traversed "over the ground," and the position of the ship after being corrected for its displacement on the water surface must be corrected for the displacement of the water surface itself. (See currents, p. 6.)

Referring to figure 2, the ship's course is 180° true. At the end of two hours the log shows the ship has gone through the water the distance *AB*. With *A* as a center and radius *AB* strike a small arc. Say the wind has been blowing on the starboard side, 135° true from the bow—i. e., a northwest wind—with velocity enough to cause the ship to make the distance *CD* leeway. The point *D'* in the figure is the position of the ship after the leeway has been applied, and *C'D'* is equal to and parallel with *CD*, the leeway. An easy way to locate the point *D'* on the arc is to extend the line *CD* and make *C'' D''* equal to *CD*. Construct a line through *D''* parallel to the course steered, the intersection of this line with the arc will be the point *D'*. The actual course of the ship has been *AD'*, and this is the distance shown by the log. *H'* and *F'* are the positions on the arc with the wind 45° and 90° from the bow and leeway corrections of *GH* and *EF*, respectively.

The figures show the wind blowing on the starboard side only. With the wind on the port side the correction is handled in a similar manner.

TRANSFER AND LOG LOSS.

When sounding with the sounding machine, stopping and backing until the ship is dead in the water, there are two further corrections to make. A single-screw ship in backing will throw her stern to port except when a stiff breeze is blowing on the starboard side. The ship's head will fall off anywhere from 40° to 90°, and to get back on course after sounding requires a full left rudder. In getting back on the course the ship follows a half-moon course, and in doing this works a little to the right of the course. This working to the side is called "Transfer." Also, when stopping and backing and then going ahead full speed, the log loses some small amount. This amount has to be determined by experiment. Applying this log loss makes the distance between anchorages slightly longer than the distance as shown by the difference of the log readings. Experiments made on the U. S. Coast and Geodetic Survey ship *Bache* showed a transfer of about 0.05 nautical mile and a log loss of about 0.04 nautical mile at each sounding, with the ship's head falling off about 50°. Determine the transfer and apply it rather than try to keep the ship on course by throwing the rudder full left just before stopping and backing.

Figure 3 illustrates the application of transfer.

THE RUNNING OF THE LINES.

The lines which you desire to follow are laid down on the boat sheet as in sextant fixed hydrography. The position at the start of each line is known either by a 3-point fix or by a distance and bearing from a buoy. From the starting point lay off the estimated leeway correction, also the estimated current correction for the next two-hour run in the direction in which the current is running, also lay off the amount of transfer if using the sounding machine. Note that all these corrections are applied to the starting point in exactly the same direction in which they will occur. Set the distance the ship is expected to run until the next current anchorage on a pair of dividers. Place one point of the dividers on the point obtained after all corrections have been applied to the starting point and strike an arc crossing the line you are trying to follow. With parallel rulers determine the true course between these points. The compass course will be the true course corrected for deviation and variation. This is the compass course to be steered to the next anchorage.

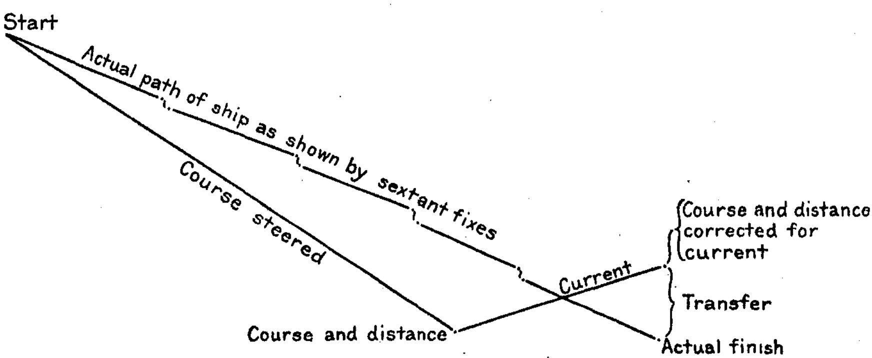

FIG. 3.—Transfer correction.

At the next current anchorage lay off the course and corrected log distance from the true starting point, apply the actual leeway correction, next the average current correction as obtained from the two current observations, one at the beginning and the other at the end of the run, and finally the transfer. This gives the plotted position of the ship.

The line proceeds by these two-hour runs until it can be finished by a 3-point fix or tied up to a buoy. The error of closure between the final plotted position and the true final position is distributed among the various runs according to the time spent on each.

In figure 4 is given an example of the work at each current anchorage, both in determining the new compass course and in plotting the line already run.

METHOD OF NUMBERING POSITIONS.

In numbering the positions on the line, two numbers should be given to each anchorage, one representing the end of the run and the other representing the beginning of the next run when the ship has steadied on the new course; two numbers are assigned to each change of course, one when the log is read just as the order to shift

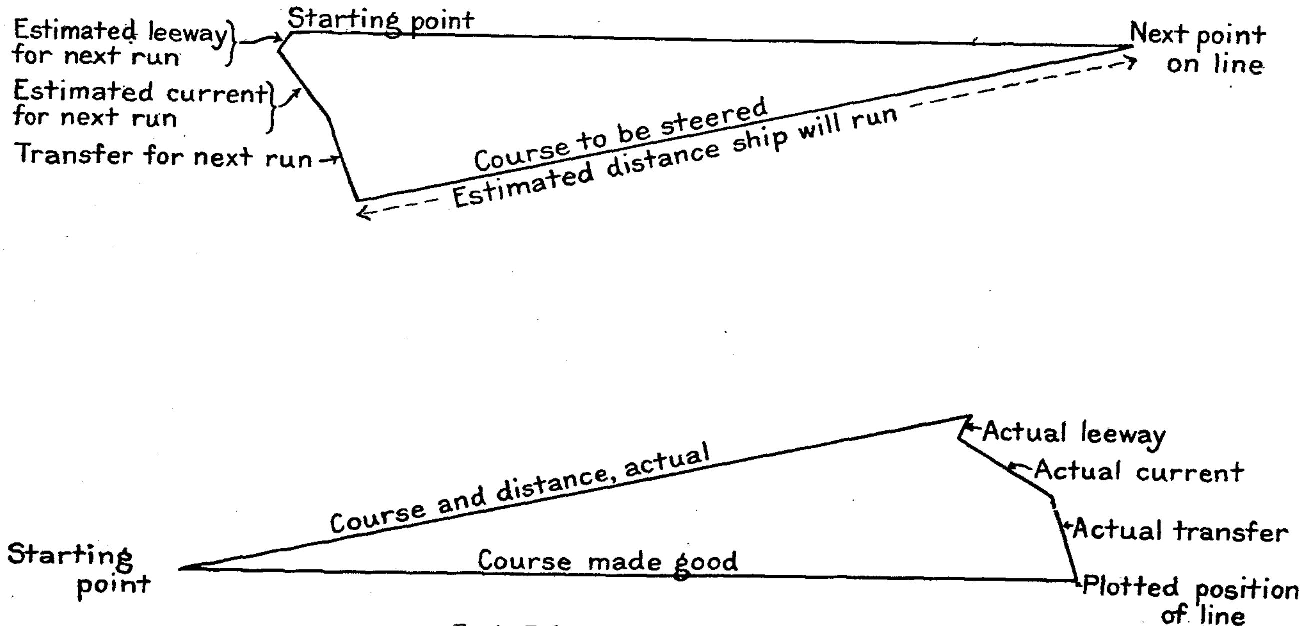

FIG. 4.—Estimated and final course corrections.

the rudder is given and the other as the log is read when the ship has steadied on the new course. A safe rule is to give a position number to each log reading except the 15-minute log readings between current anchorages which are made for aiding in plotting the soundings and for checking the speed of the ship. An example of numbering the line is given in figure. 5.

PLOTTING THE SOUNDINGS.

After the line has been plotted and adjusted, the distance between two adjacent current anchorages is measured with beam compass to any convenient scale. The distance as recorded by the log is compared with this to determine the correction for overrun or underrun, and the various distances given by the 15-minute log readings plotted after being reduced for their proportional share of this correction. When using the machine the log is read at each sounding and these readings are plotted in exactly the same manner.

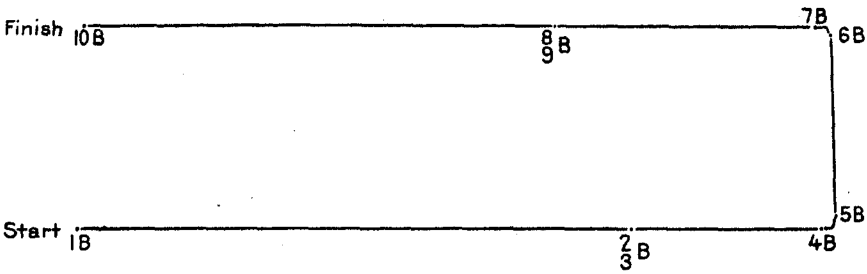

FIG. 5.—Numbering of positions.

GENERAL REMARKS.

Hand lead should should be used up to 15 fathoms, trolley rig between 15 and about 25 fathoms, and the sounding machine beyond 25 fathoms.

In sounding with the sounding machine the ship should be run about 6 minutes on course full speed, then stopped, and backed until all headway is killed.

In sounding with the trolley gear soundings should be taken as fast as the leadsman can handle them, keeping the soundings evenly spaced as to time to facilitate plotting.

When sounding, the log should be read and recorded every 15 minutes. This is to check the speed of the ship, which should be about 5 miles an hour, and to aid in plotting the soundings. If the ship is equipped with a revolution counter this should be read and recorded every time the log is read for a check.

In the absence of detail instructions from the office, bottom specimens should be obtained every 15 minutes when sounding with trolley rig or hand lead and at every sounding when using the sounding machine. Surface and bottom temperatures should be taken at every anchorage.

In addition to the sounding record, a dead-reckoning log is kept by the officer in charge of the watch. This dead-reckoning log should be sent with the smooth sheet to the office. A sample page from this log is shown in Form 612.

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
FORM 612

PRECISE DEAD RECKONING

LOG FACTORS
Log No.-------

Full speed ------------------

Sounding speed -------------

Full and stop ---------------

(Log dist. x log factor=True dist.)

-- (*Locality*)   ------------------ (*Date*)   ------Day

U. S. C. and G. Survey Ship-----------------, ---------------, Commanding

Hydrographic Sheet No.----------

Pos.	Time	Elapsed Time	DISTANCE					COURSE				CURRENT			LEEWAY			TRANSFER	REMARKS
			Log Reading	Log Dist.	True Dist.	Log Loss	Total Run	P. S. C.	Dev.	Var'n	True	Set	Drift	Corr'n	Dir'n of Wind	Vel.	Corr'n	Dir'n / Am't	