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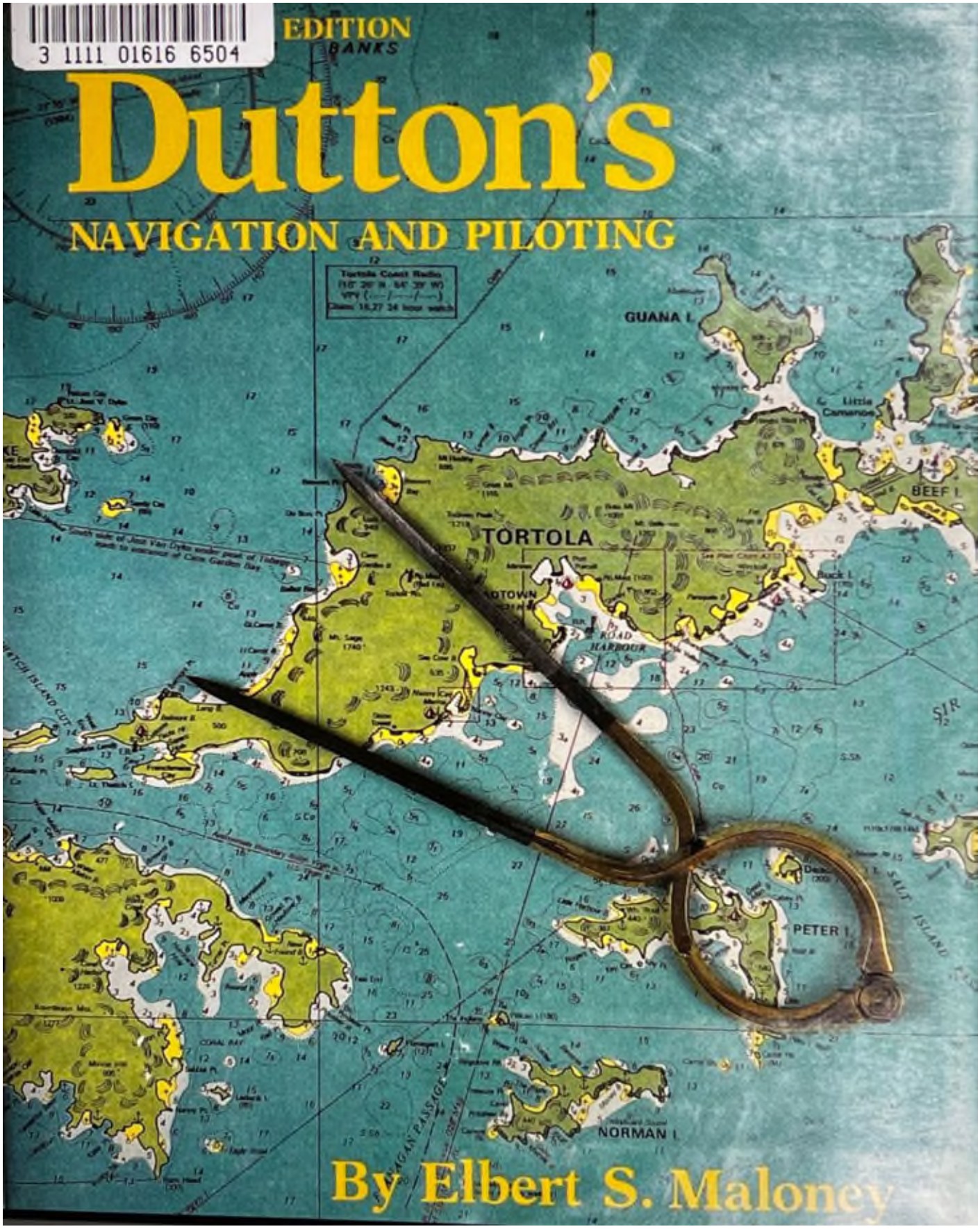
EDITION

Dutton's

NAVIGATION AND PILOTING



By Elbert S. Maloney

Dutton's Navigation & Piloting

FOURTEENTH EDITION

By Elbert S. Maloney

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Chapter 7

Instruments for Piloting

Introduction

701 As noted in chapter 1, navigation is both an art and a science, and this is reflected in the "tools of the trade." This chapter will describe some of the instruments and devices available to a navigator for determining the position of his vessel and guiding it safely and efficiently on its way.

Navigational instruments can be classified in various ways, any of which will result in some overlap. They will be considered here in groups according to their primary purpose—for measuring *direction, speed* and *distance, depth,* and *weather conditions;* for use in *plotting;* and for *miscellaneous* use. Earlier chapters have considered the compass and other "instruments" such as charts and publications. Sextants and chronometers will be covered later in the chapters relating to celestial navigation.

DIRECTION

Compasses

702 The two general types of compasses are: *magnetic compass,* which depends on the earth's magnetic field for its directive force; and *gyrocompass,* which depends upon the inherent stability in space of a rapidly spinning wheel plus mechanical or electrical torquing to keep its axis aligned with that of the earth. Marine compasses were discussed in chapter 3.

Gyrocompass Repeaters

703 A gyrocompass can transmit constant indications of true headings electrically to *gyrocompass repeaters* located at various positions throughout the ship. These repeaters resemble a magnetic compass in appearance, but unlike a magnetic compass they may be mounted in any position.

Azimuth Circle

704 The term *azimuth* is most often used for stating the direction of a celestial body, with *bearing* used for the direction of terrestrial objects. This division, however, is not rigid, and at times the terms are used interchangeably. Bearings and azimuths are expressed in degrees, using three digits, from 000° at north clockwise through 360°. True azimuth or bearing refers to direction with respect to true north, magnetic azimuth with respect to magnetic north, and compass azimuth with respect to north as indicated by the compass being used. A *relative* bearing or azimuth is reckoned from the ship's head, measuring clockwise with 000° being dead ahead.

An *azimuth circle* (see also *bearing circle* below) can be used for determining both *azimuths* of celestial bodies and bearings of terrestrial objects. It consists of a nonmagnetic ring formed to fit snugly over the top of a compass bowl (or onto the top of a gyrocompass repeater), about which it can be turned to any desired direction. Its inner lip is graduated from 0° to 360°, *counterclockwise,* for measuring relative bearings. An azimuth circle is shown in figure 704. On one diameter of this ring is mounted a pair of sighting vanes, consisting of a peep vane (A) at one end of the diameter and a vertical wire mounted in a suitable frame at the other end (B). To observe the bearing of a terrestrial object, the observer looks through the peep vane in the direction of the object, and by means of the finger lugs (C, C′) provided on the circle, he turns the

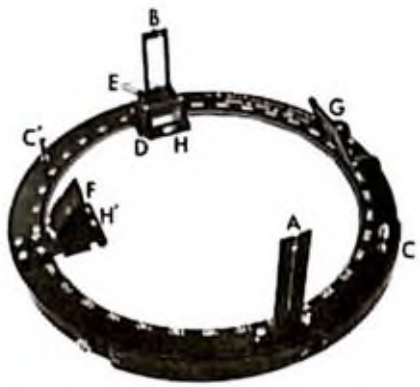

Figure 704. Azimuth circle to fit U.S. Navy standard 7½-inch compass.

latter until the observed object appears on the vertical wire of the opposite vane. At the base of the opposite vane is a mirror (D) marked with a centerline agreeing with the vertical wire of the vane. This mirror reflects the compass card into the observer's field of view so that he can see the observed object and the compass card at the same time. The compass bearing of the observed object is then read by the position of the vertical wire on the reflected compass card.

There is a reflector of dark glass (E) attached to the far vane (called *far* vane because it is *farther* from the eye, in observing, than the peep vane). The reflector is movable about a horizontal axis, enabling the observer to adjust it so that the reflected image of a celestial body can be brought to his eye, and a compass azimuth obtained as has been described for a terrestrial object.

At right angles to the line of sight of the pair of vanes just described, there is a second set of observing devices, designed especially for obtaining a compass azimuth of the sun. At one extremity of the diameter on which these appliances are mounted is a 45° reflecting prism encased in a metal housing (F). This housing is provided with a narrow slit in which light may be received from a concave mirror diametrically opposite (G), the slit being at the focus of the concave mirror. Light so received is reflected downwards by the prism and appears on the graduations of the compass card as a bright narrow band. To observe the compass bearing of the sun with this arrangement, the observer turns the azimuth circle until the sun's rays are reflected by the mirror across the card to the prism, when the bearing can be read on the compass card by means of the narrow band of light.

Two leveling bubbles (H, H') are provided, one under each far sight vane. The appropriate bubble is used to level the instrument in the vertical plane through the line of sight, and so eliminate a possible source of inaccuracy.

Relative bearings or azimuths can be obtained by reading the graduations of the azimuth circle against a mark on the bezel ring, colinear with the lubber's line of the compass. (See article 307.)

An azimuth circle without the prism-mirror appliance for sun observation is called a *bearing circle*. It serves the same purpose as an azimuth circle, except that azimuths of the sun are not as conveniently measured.

Telescopic Alidade

705 A *telescopic alidade* is similar to a bearing circle except that the alidade circle mounts a telescope instead of the sighting vanes. The telescope contains a reticle for greater precision in taking bearings. The image is magnified, making distant objects appear larger to the observer. A prism arrangement that reflects the bearing of the object from the compass card enables the observer to sight the object and its bearing simultaneously.

Pelorus

706 Since a clear view in all directions may be unobtainable from the compass, a *pelorus* (figure 706) or dumb compass may be mounted at convenient points, such as the wing of a bridge. It is less desirable than a gyrocompass repeater fitted with an azimuth or bearing circle, but it will meet the needs of small craft or vessels lacking more sophisticated equipment.

A pelorus consists essentially of a flat, nonmagnetic, metallic ring mounted in gimbals on a vertical stand. The inner edge of the ring is graduated in degrees from 0° at the ship's head clockwise through 360°. This ring snugly encloses a compass card called a *pelorus card*. The card, flush with the ring and the top of the bowl, is rotatable, so that any chosen degree of its graduation may be set to the lubber's line. A small set screw is provided for temporarily securing the card to the ring. Upon the card is mounted a pair of sighting vanes similar to those of a bearing circle. They may be revolved about the center of the card, *independently of the card itself*, and held in any desired position by a central clamp screw. On some models an electric light inside the stand illuminates the card from underneath for night work.

Taking True Bearings

True bearings are obtained as follows: set the pelorus to the ship's *true* course, by turning the card

Figure 706. A pelorus, used for taking relative bearings.

until its true-course graduation coincides with the lubber's line. Secure the card. Line up the sighting vanes approximately on the object to be observed. Direct the steersman to say "Mark! Mark! Mark!" when he is steady on his steering compass course, and when he does so, take the bearing exactly, and read the degree on the card as indicated by the sighting vanes.

As an alternative method of obtaining a true bearing, the navigator gives the steersman a warning "Stand by!" followed by a "Mark!" at the instant of the observation. If the steersman was on his course, the bearing was *true*. If not, it may be corrected by applying the number of degrees the steersman was off, being careful to apply the correction in the proper direction.

Magnetic Bearings

Magnetic or compass bearings are taken in exactly the same manner as true bearings, the pelorus card being set beforehand to the magnetic or compass course, respectively. By applying to such bearings the variation or the compass error, as appropriate, they can be converted to true bearings (article 312) for plotting on a chart.

Relative Bearings

The pelorus is used for taking relative bearings by setting the 0° graduation of the card to the lubber's line and observing the object. Relative bearings are converted to true bearings for plotting by adding the true heading of the ship to the bearings observed. In most modern installations on large ships, a gyro repeater is mounted in the pelorus stand in place of the pelorus card, so that gyro bearings can be obtained directly.

Hand-bearing Compass

707 On small craft, bearings are often taken with a *hand-bearing* compass. This is a small, portable compass that has sighting vanes or marks, may have a handle, and usually has some form of internal illumination for use at night. See figure 707. Its advantages stem from its ability to be carried to any place on deck from which a bearing can be taken on an object that might not be visible from the steering station due to the vessel's superstructure, sails, etc. Deviation may or may not exist at locations from which a hand-bearing compass is used; caution is advised. In the event of a failure (unlikely, but possible) of a boat's steering compass, a hand-bearing compass can be used quite adequately if consideration is given to the probability of different values of deviation.

SPEED AND DISTANCE

Types of Logs

708 A *log* is any device used to determine a vessel's *speed* or *distance traveled through the water*. Allowances or calculations must be made to determine speed and distance with respect to the bottom.

To determine a vessel's speed, the *chip log*, or *ship log*, was invented in the sixteenth century; it consisted of a piece of wood in the shape of a quadrant, weighted with lead at the center of the circular side. This log chip, as it was called, was secured to a bridle at each corner; the bridle, in turn, was secured to the log line. At one corner of the log chip, the bridle was held by a wooden peg so arranged that a sharp tug on the log line would pull out the peg, allowing the chip to be hauled back on board readily.

The log line was wound on a free-turning reel. To determine speed, the log chip was put overboard where it floated vertically due to its ballasting. A considerable length of log line was let out to get the log chip into undisturbed water astern where its resistance to forward motion kept it essentially stationary in the water; as the ship moved forward, the line was pulled off the reel. When the first knotted marker on the line passed off the reel, timing was started; at the end of a definite period, the line was seized and the number of knots in the line that

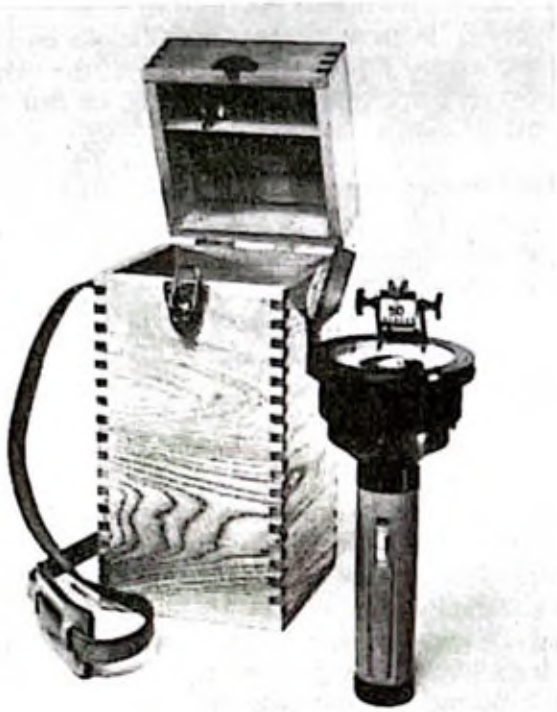

Figure 707. A hand-bearing compass.

had paid out were counted to determine the vessel's speed. From this arose the present use of the term *knot* to designate one nautical mile per hour.

The timing was originally done by reciting certain religious sentences, which, in theory, required an exact amount of time. Later, a sand glass was employed. This was usually a 30-second timer, and gave far more accurate results.

Modern Logs

Three types of modern logs are in general use on ships; some of these integrate values of speed to determine distance traveled as well as speed. These are: the pitot-static log, the impeller type, and the electromagnetic (EM) log. These logs all require the use of a *rodmeter* projecting through the bottom of the ship into the water. The rodmeter contains the sensing device used to determine speed. As the rodmeter can be damaged by striking submerged objects, it may be necessary to retract the unit in shallow water. A sea valve forms a support for the rodmeter and provides a means for closing the hull opening when the rodmeter is withdrawn or housed. The various logs have a remotely located *indicator-transmitter* housing the electrical or electromechanical parts. The signal received from the sensing device is converted into a readout of speed and distance traveled that can be transmitted by synchronous motors or electronically to display units throughout the ship.

The dead-reckoning analyzer (article 724), the modern gyrocompass, and various navigational computers require an automatic input of speed that is also transmitted from the indicator-transmitter unit of the log.

Speed can also be measured using the *Doppler principle* (see chapter 37); this gives speed (and distance) with respect to the bottom rather than through the water.

Pitot-static Log

709 The rodmeter assembly of a *pitot-static* log detects both dynamic and static pressure. As a ship moves through the water, the forward side of the rodmeter is exposed to *dynamic* pressure that is proportional to the speed of the ship. Dynamic pressure is defined as the pressure on a surface resulting from a fluid in motion against that surface; it includes static pressure as well as that from the flow of the fluid. The pressure of still water is called *static* pressure. A *pitot tube* is a device by which the difference in dynamic and static pressures may be detected. Obviously, the difference of the two pressures will vary with the speed of the ship. The device consists of two tubes, one inside the other. One tube opens forward and is subjected to dynamic pressure when the ship is in motion; the other

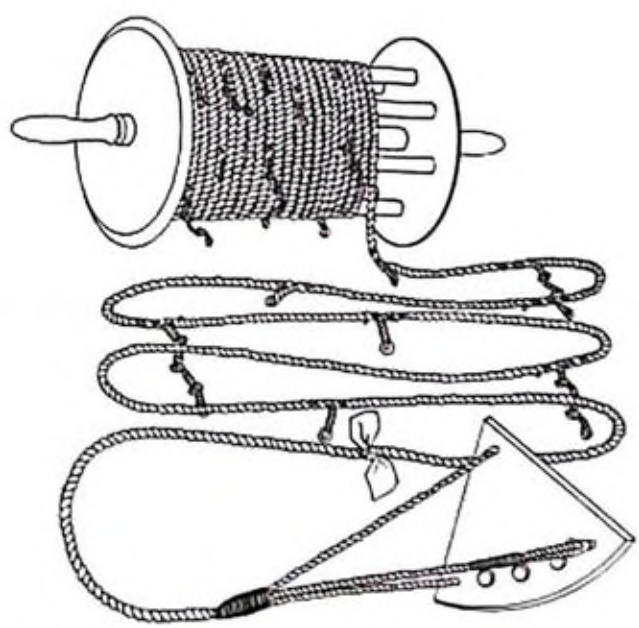

Figure 708. A chip log, or ship log, for measuring a vessel's speed (now obsolete).

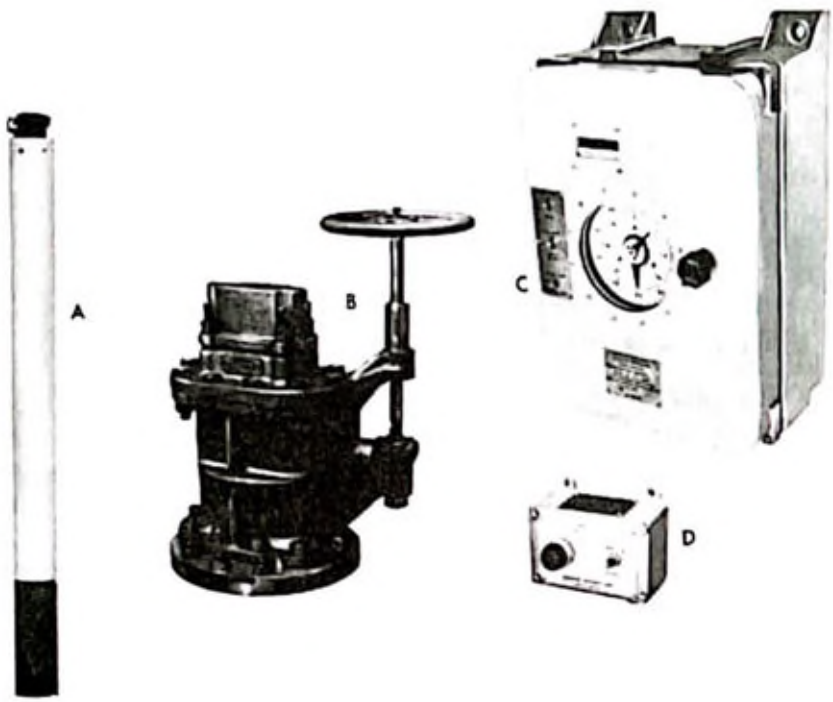

Figure 711a. Underwater log equipment; electromagnetic type, 0–40 knots.

opens athwartship and is exposed only to static pressure.

The control unit for converting the pressure indications into speed units consists of a sensitive bellows arrangement connected to the dynamic and static orifices of the rodmeter. Suitable mechanical and electrical linkage converts the movement of the bellows into rotary motion for transmission to the speed and distance indicators by self-synchronous motors.

Two types differing slightly in construction but using the pitot-static principle are in general use. They are commonly known as the Pitometer Log and the Bendix Underwater Log.

Impeller-type Log

710 An *impeller-type* log uses a propeller to produce an electrical signal by which the speed and distance traveled are indicated at one or more remote locations. Typically, a rodmeter head is projected about two feet out from the vessel's hull through a sea valve. The head assembly contains an 8-pole, two-phase, propeller-driven frequency generator. The impeller is driven by the water as the impeller moves through it. The frequency generated is directly proportional to ship's speed.

The output of the generator is amplified and passed to a master transmitter indicator where the number of alternations, reduced by gears, shows the mileage on a dial. The frequency of the alternating current, being proportional to the speed of the ship, is transmitted to the display mechanism that indicates the speed of the ship.

Electromagnetic Log

711 The *electromagnetic* (EM) log is generally calibrated for speeds from 0 to 40 knots. Components are shown in figure 711a. The rodmeter (A), which can be fixed to the hull, is generally retractable through a sea valve (B), as described in article 708. It is an induction device which produces a signal voltage that varies with the speed of the ship through the water. Any conductor will produce an electromagnetic field or voltage when it is moved across a magnetic field, or when a magnetic field is moved with respect to the conductor. It is this relative movement of the conductor and the magnetic field producing a measurable induced signal voltage that is used in the EM log. Figure 711b shows a cutaway view of the sensing unit in the rodmeter. The magnetic field, produced by a coil in the sensing unit, is set up in the water in which the ship is floating. Two Monel buttons, one on each side of the rodmeter, pick up the induced voltage as the ship moves through the water. A complete discussion of the principle involved and instructions for adjustment and repair are included in the manual supplied with each instrument.

The *indicator-transmitter*—labeled (C) in figure 711a—contains all the electrical and electromechanical parts of the log except the components in the rodmeter and remote-control unit. It indicates

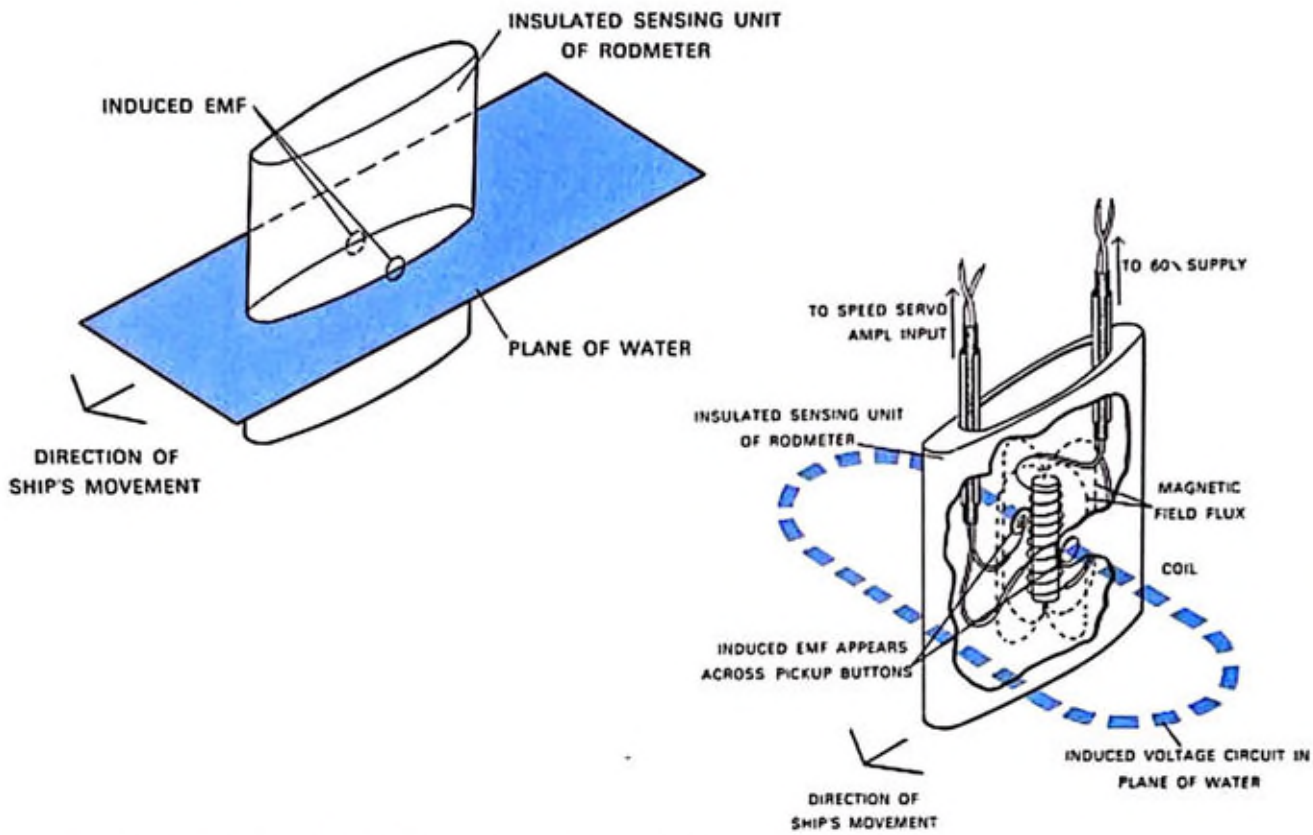

Figure 711b. Functional schematic of a rodmeter sensing unit.

the ship's speed on a dial, and operates synchro-transmitters to generate corresponding synchro-signals for transmission to receivers located elsewhere in the ship. It also registers the number of miles the ship has steamed. Provision is made in the indicator-transmitter for calibrating the log.

The *remote-control unit*—labeled (D) in figure 711a—is used to set speed into the indicator-transmitter when the equipment is being operated as a dummy log. (See article 712.)

In addition to the ship's forward motion, pitching and rolling will produce output signals from the rodmeter, which could lead to an indicated speed that is too high. Provision is made in the indicator-transmitter so that these undesirable signals can be rejected.

Continuing progress in solid-state electronics is being reflected in advances in the design of ships' logs, and a Doppler log is under development for naval vessels.

RPM Counters

712 An *engine revolution counter* provides a convenient means of determining speed and distance; these are widely used, especially on merchant ships. One of these instruments is in the engine room for each shaft; repeating indicators may be installed on the bridge. They automatically count the revolutions of the propellers and show the total count continuously on their dials. By means of a master counter connected to the individual counters, the average revolutions made by all propellers can be obtained. The output from these devices may be either a total number of revolutions or the rate in revolutions per minute (RPM), or both. The records of the acceptance trials of a ship furnish data as to the revolutions required for a mile, as well as RPM for various speeds. Such data can be derived, or verified, from later runs by the vessel over a measured mile, a number of which are available for this purpose. (A measured mile is not necessary; trials can be run over any known distance, with only slightly more complicated calculations required.) This information is used to construct a curve with RPM as ordinates and corresponding speed in knots as abscissas. From the curve, a *revolution table* is prepared for use on the bridge while underway. It gives the RPM required for each knot

Figure 713. Speedometer/log for small craft, impeller type.

of speed. In making use of engine revolutions as speed indicators, the draft of the ship, the condition of its bottom as to cleanliness, and the state of the sea must be considered.

When a vessel's regular log is not operating, speed information, based on shaft RPM, can be set by hand into a *dummy log*. This is necessary to supply speed data to the gyrocompass, a dead reckoning tracer (DRT) (article 724), and various computers that may be in use.

Small-craft Logs and Speedometers

713 On small craft, the term *speedometer* is commonly used to designate devices that measure only speed. The term *log* is applied to instruments that measure speed or distance, or both. Simplified versions of all three types discussed for larger vessels are used on commercial and recreational boats.

On smaller, faster boats, the common type of speedometer is a simple form of *pitot-static log*, with the indicating meter coupled directly to the sensing head by a length of tubing. The principal fault of this type is its lack of sensitivity at low speeds. On larger and slower boats, the *impeller type* is used in a "miniaturized" version. A small propeller-shaped or millwheel-design rotor projects from the hull a few inches; it may be fixed, or retractable for cleaning (problems of fouling with grass and weeds are not unknown). Indications of speed may be transmitted from the sensor to the indicator either mechanically or electrically.

A few models of the *electromagnetic* type have appeared for boats; the sensing elements are flush with the hull or even entirely internal. Although more expensive than the impeller type, this design avoids the problem of fouling with weeds or marine growth that will adversely affect an impeller that cannot be withdrawn into the hull when not in use.

The indicator unit of impeller-type and electromagnetic logs may include additional circuitry for sensing small speed changes—useful in trimming sails—and/or for *integrating* speed measurements with respect to time in order to provide an output of distance traveled.

Many boats depend upon a *tachometer* giving engine RPM for a determination of speed. An RPM vs. speed table is prepared on a measured mile or other course of known length, and a graph is plotted as described for ships in article 712.

A few small craft, chiefly ocean-cruising sailboats, still use the traditional *taffrail log*. This consists of a rotor streamed at the end of a braided log line sufficiently far astern to be clear of the wake effect. The log line is connected to an indicating device, usually reading nautical miles and tenths on two separate dials. In sailing ships, this indicator was frequently attached to the taffrail, the hand rail at the after end of the ship, hence the name.

Good taffrail logs are quite reliable if kept clean of weeds and other floating debris, although all logs tend to over-read slightly when moving through a head sea, and to under-read with a following sea.

Stadimeters

714 A *stadimeter* is an instrument for measuring the distance of objects of known heights, between 50 and 200 feet, covering ranges from 200 to 10,000 yards. Other ranges can be measured by using a scale factor for the graduations. The two general types in use, the Fisk and the Brandon sextant type, are illustrated in figure 714.

The Fisk type stadimeter consists of a rectangular metal frame upon which is pivoted an index arm graduated in feet. The arm bears an index mirror directly above the pivot. By moving the arm this mirror is rotated through a small arc, providing the necessary adjustment between the direct and reflected images as viewed through the sighting telescope. The stadimeter measures the angle subtended by the object of known height and converts it into range, which is read directly from a micrometer drum attached to a pointer that moves the index arm. The instrument is initially set for the known height of the object by moving the carriage holding the drum and pointer along the index arm. The drum is then turned until the top of the

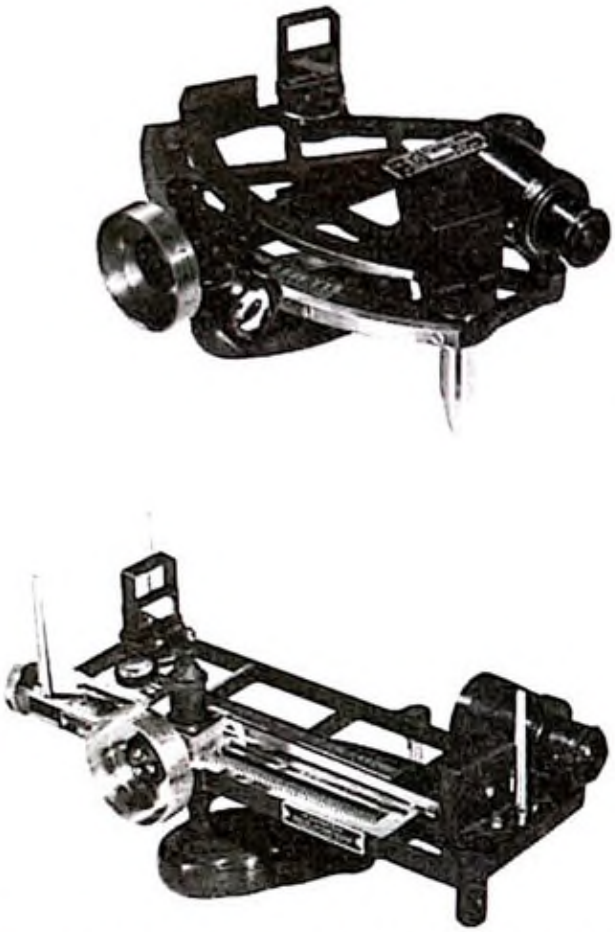

Figure 714. Stadimeters; Brandon sextant type (upper), and Fisk type (lower).

reflected image is brought into coincidence with the bottom of the direct image, and the range read.

The Brandon sextant-type stadimeter uses the same principle as the Fisk type, but the construction is different. The frame, similar in appearance to a sextant frame, has mounted upon it two pivoted arms, the index arm and radius arm. The radius arm is first positioned using the scale for the known height of the distant object sighted upon. Rotation of the micrometer drum moves the index arm, accomplishing the rotation of the index mirror necessary for the desired coincidence of images.

The adjustment of a stadimeter is similar to that of a sextant as described in chapter 24.

Distances of objects can also be ascertained by determining the angle subtended by an object of known height, as measured by a sextant. The angle so measured can be converted to distance by means of trigonometry or Table 9 in *Bowditch*.

DEPTH

Hand Lead and Deep-sea Lead

715 The *lead* (pronounced led), or *lead line*, for determining the depth of water consists essentially of a lead weight attached to one end of a suitably marked line. It is undoubtedly one of the oldest of piloting instruments.

Since the days of man's first ventures onto the waters, a mariner's major concern has been the depth of the water, the prevention of grounding. The first man who ran his dugout onto a shoal soon learned that he needed some way to find the depth of the water. Probably his first tool was a marked pole—a *sounding pole*—but the sounding line soon followed. From these developed the *deep-sea lead*, which could be used for greater depths. The base of the lead was concave, so that the hollow could be *armed* with tallow or salt-water soap, thus yielding both a sounding and a sample of bottom sediment to assist in determining position. From the *Historia* of the Greek historian, Herodotus, one learns that this technique was in use in and around the mouth of the Nile in the fourth century B.C.: "When one gets 11 fathoms and ooze on the lead, he is one day's journey from Alexandria." Even so long ago the nature of the bottom was of navigational significance.

Such soundings could be obtained only in the vicinity of the continental shelf, and only at comparatively long intervals, due to the time consumed in recovering by hand a lead of fifty or more pounds and a hundred or more fathoms of line. Later, greater depths could be measured with a *sounding machine* that used fine steel wire and mechanical methods for retrieving the weight and devices at its end. Due to currents and the forward motion of the ship, the sounding wire was normally not vertical, and so its length did not give a true indication of depth. *Sounding bottles* attached to the wire measured pressure at the bottom that could be translated to a measurement of depth. The sounding machine allowed accurate measurements of considerable depths, but only a very few measurements could be taken in an hour of continuous effort.

Modern technology has now eliminated the difficulties described above, but a lead line can still be a very valuable backup "tool" for a navigator, particularly when proceeding slowly in "thick" (foggy) weather and shallow waters. Of the various types of lead lines used for taking soundings, the two most common are the *hand lead*, weighing from 7 to 14

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pounds, with a line marked to about 25 fathoms; and the *deep-sea lead*, weighing from 30 to 100 pounds, the line being 100 fathoms or more in length.

Lines are generally marked as follows:	*Metric Equivalent*
2 fathoms from the lead, with 2 strips of leather	3.66 meters
3 fathoms from the lead, with 3 strips of leather	5.49
5 fathoms from the lead, with a white rag	9.14
7 fathoms from the lead, with a red rag	12.80
10 fathoms from the lead, with leather having a hole in it	18.29
13 fathoms from the lead, same as at 3 fathoms	23.77
15 fathoms from the lead, same as at 5 fathoms	27.43
17 fathoms from the lead, same as at 7 fathoms	31.09
20 fathoms from the lead, a line with 2 knots	36.58
25 fathoms from the lead, a line with 1 knot	45.72
30 fathoms from the lead, a line with 3 knots	54.86
35 fathoms from the lead, a line with 1 knot	64.01
40 fathoms from the lead, a line with 4 knots	73.15

Fathoms that correspond with the marked depths are termed *marks* and intermediate fathoms are called *deeps*. The only fractions of a fathom used are a half and a quarter. A practice sometimes followed is to mark a hand lead line at the critical depths of the vessel using it.

Lead lines should be measured frequently while wet and the correctness of the markings verified. The distance from the leadman's hand to the water's surface should be known in order that proper allowance may be made in taking soundings at night.

Small vessels often use a lead line with a weight of 2 to 5 pounds on a line of 20 to 30 feet. The line is normally marked with plastic tags giving the depth directly in feet or meters. Boatmen may find a sounding pole useful in some circumstances, particularly if it is marked with the craft's draft and at whole feet above that depth.

Electronic Depth Sounders

716 A sound pulse generated in the water will echo from the bottom and can be received by a microphone. Since the speed of sound in water is known fairly closely, the depth can be determined by measuring the time interval between the generation of the sound and the return of the echo, according to the equation: depth = speed × ½ time interval between sound pulse and echo.

The speed of sound waves in water varies with the salinity of the water, its temperature, and the pressure (depth). The variation is not great, and most echo-sounding equipment of American manufacture is calibrated for a speed of 4,800 feet per second (1,463 m/s). At sea, the actual speed of travel of sound waves is nearly always slightly greater than this calibration speed, and any error introduced lies on the side of safety, except where the water is fresh or extremely cold. (If the equipment used in surveying the depths used the same calibration speed, there would be no error.) This assumed speed being equivalent to 800 fathoms per minute, an elapsed time of one second would indicate a depth of 400 fathoms.

Devices for measuring depth in this manner are variously known as *echo sounders* or *electronic depth sounders*. (The term "Fathometer" is often used, but this is properly applied only to the equipment of one manufacturer whose trademark it is.) The essential components of an electronic depth sounder are a *transmitter*, a *transducer*, a *receiver*, and a *display* (indicator or recorder). The transmitter and receiver are normally combined into a single unit; there may be both an indicator and a recorder.

Transmitter-receiver

The transmitter generates a pulse of electrical energy at either a *sonic* (audible) frequency in the range of 20 to 20,000 hertz or at an *ultrasonic* frequency, usually 150–200 kHz; the trend is now toward the higher frequencies, as these permit smaller transducers and sharper beams. The receiver amplifies the very weak returned echo and converts it to a form suitable for visual display.

Transducer

An electrical cable carries the electrical pulse from the transmitter to the transducer mounted on the vessel's hull where it is converted to sound (pressure) waves and sent directly downward in the shape of a cone. The returning echo is picked up by

Figure 716. Electronic depth sounder, commercial type.

the same transducer, converted to electrical energy, and sent back to the receiver by the same cable. (In a few instances, a separate receiving transducer and cable are used.)

On most large ships, the echo-sounding equipment generates a cone of 30° to 60° apex angle. The area of the bottom covered by such a cone is a function of depth; in deep water this can be quite large. The trend in the development of newer echo-sounding equipment is toward narrower beams, obtained by using higher frequencies (generally around 200 kHz), or larger transducers, or both. Higher frequencies, however, have the disadvantage of greater attenuation and lesser depth range; practical installation considerations place a restraint on transducer size. For survey work, complex arrays of multiple transducers may be used; transducers may be stabilized to counter ship's rolling and pitching motions that could result in erroneous data.

Depth sounders for smaller vessels commonly use either 50 or 200 kHz. Deeper depth penetration is achieved by the lower frequency pulses that employ transducers with sound cones of 40° to 60°. The higher frequency pulses are sent and received with transducers having sound cones of 8° to 12° that provide much sharper definition. Some more expensive models operate on either frequency as selected by a front-panel switch; these use a specially designed dual-frequency transducer that has a sound cone to match the frequency being used.

Display

Electronic depth sounder displays vary greatly in detail, but all operate on the same principle of indicating the elapsed time for a pulse to go to the bottom and return. Display types include rotary flashing light, digital readout, electrical meter, and bottom profile, which may be recorded on a moving paper chart or shown on a TV-like screen. Some models have the capability of operating on more than one range or displaying depth measurements in a choice of units—feet, fathoms, or meters; *it is essential that the navigator be certain what range and unit of measurement is being used.*

The flashing-light type has an arm that is mounted on the end of a shaft of a constant-speed motor. A flash occurs when the pulse is sent out—zero depth—and again when the echo returns. A scale is mounted over or just outside the end of the arm and calibrated in units of depth. One revolution of the arm corresponds to the range of the sounder, and the fraction of a revolution when the light flashes for the echo is proportional to the depth. A recent development is a liquid-crystal display (LCD) that has the appearance of a rotating flashing light, but no moving parts.

Digital-readout models use electronic circuitry to provide a direct display of depth. Meter type units use a similar technique, but have now been largely displaced by the more easily read digital displays. Two or more ranges are available in some models.

Depth recorders provide a permanent indication, usually by means of a hot stylus and sensitized paper that moves across the face of the device. Some recorders also show instantaneous depth in a flashing-light or digital display. Many models include the "white (or gray) line" feature that electronically emphasizes the bottom contour and makes possible the detection of fish just above the bottom.

A more recent development is the echo sounder that displays a profile of the bottom on a rectangular TV-like picture tube. The profile moves across the screen as the vessel travels forward; no permanent record is made. Multiple colors may be used on some models to indicate different intensities of echos, and thus give an indication of the object—bottom or fish—that is returning the echo.

Electronic depth sounders used on small craft may use any of the displays discussed above. Because of the greater interest in shallower waters, maximum ranges will be less, and transmitters will operate at higher frequencies with less power; digital displays commonly show depths in tenths of a foot up to 10 feet, and in whole feet beyond that. Alarm buzzers are included in many units that will sound when depths decrease below a preset figure; on some models, an anchor alarm will sound when the depth either decreases or increases.

A U.S. Navy precision echo sounder of recent design, the AN/UQN-4, is described in article 3603.

PLOTTING EQUIPMENT

717 Most lines on a chart are made by means of a straightedge. Because of the width of the pencil lead and the conical shape of the sharpened end, the line ruled on the chart is a slight distance from the straightedge. Allowance for this distance must be made when placing the straightedge in position. The actual amount is easily determined by trial and error. The important point to remember is that the pencil must make the same angle with respect to the straightedge throughout the length of the line.

Use No. 2 pencils for plotting, and keep a number of them handy and well sharpened. Hexagonal pen-

cils are less likely to roll off a chart table than are round pencils.

Draw only light lines on the chart, so that they can be easily erased. Avoid drawing lines longer than necessary, and erase extra lengths. Label all lines and points as soon as drawn. An unlabeled line on a chart is a possible source of error. Avoid drawing lines through symbols for navigational aids, so that the symbols will not be made less distinct when the line is later erased.

A soft eraser, such as the "Pink Pearl" type, should be used for making small erasures. An "art gum" eraser is best for a more general cleaning of a chart.

Dividers

718 Dividers are frequently used by the navigator. He keeps them handy for immediate use, primarily for measuring distance on the chart, but they have many other uses, also.

Learn to use the dividers with one hand, keeping the other hand free for other purposes. With a little practice this can be done easily and it will speed up plotting considerably. The dividers should be tight enough to remain as set, but not so tight that setting is difficult. If there is any choice, pick a pair of dividers with long legs, so that considerable distances can be measured with one setting. Some navigators prefer to use traditional "one-hand" dividers that are shaped so that a squeeze in one position closes the distance between the points, while a squeeze in another position opens the gap. See figure 718a.

It is frequently desirable to have a second pair of dividers of the "bow" style in which the distance between the points is set, and maintained, by a cross arm with a setting screw; see figure 718b. These can be set to a specific distance and left with assurance that they will not be changed accidentally.

Compasses

719 Drafting compasses (not to be confused with magnetic compasses) are convenient for drawing circles and arcs. They are used most frequently for drawing in computed visibility circles of lights, but they are also useful in drawing circles of position when the range of an object is known, for drawing circles of position for high-altitude celestial observations, and other purposes.

The statement regarding the use, adjustment, and selection of dividers applies also to compasses. The pencil point must be kept well sharpened for neat and accurate work.

Figure 718a. Dividers are a basic piloting tool for measuring distances and plotting positions.

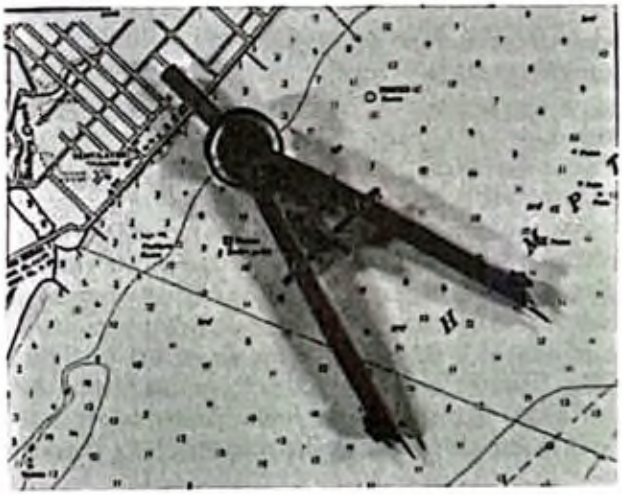

Figure 718b. "Bow" dividers are particularly useful as their setting cannot be accidentally changed.

Parallel Rulers

720 Although various types of plotters have appeared, and some are widely used, parallel rulers are still used by some navigators for measuring direction on a chart. Several types of parallel rulers are available. The best known consists of two bars—the "rulers"—of the same length connected by a mechanical linkage in such a manner that when one ruler is held in place on the chart and the other moved, the orientation of the ruler that is moved will remain parallel to the stationary ruler, and thus a line drawn using it is parallel to the original direction.

Parallel rulers are used for drawing straight lines, moving lines parallel to themselves (as in advancing lines of position), and for measuring direction. When the direction of a line is to be measured, one of the rulers is placed on the line and held firmly in place; the other ruler is opened away from the fixed ruler in the direction of the nearest *compass rose*. This ruler is then aligned with the center of the compass rose and the direction is read from its graduations. It may be necessary to "walk" the ruler through several steps to reach the compass rose, alternating the two rulers as stationary and moving. The key to successful operation is to press the stationary ruler *firmly* against the chart while the other ruler is being moved—slippage at this time will destroy the accuracy of the measurement. To plot a desired direction from a point on the chart, the direction is transferred by the parallel rulers from the compass rose to the given point.

Plotters

721 Parallel rulers are somewhat slow, and it is sometimes difficult to keep them from slipping when a direction is to be moved a considerable distance across the chart. Moreover, they are of little value for measuring direction when no compass rose is shown on the chart, as on those of polyconic or Lambert conformal projection.

For these reasons and as a matter of personal preference, many navigators use one of the various plotters that are available. Most of these consist of some form of protractor and a straightedge.

A typical plotter-protractor is shown in figure 721a. The rectangular piece of plastic has a 180° scale for measuring directions relative to any meridian; an auxiliary scale, rotated 90°, permits measuring relative to any parallel of latitude (as shown, it is measuring 186° from A to B). Some such plotters have distance markings on the longer edges at typical chart scales.

The Parallel Plotter, figure 721b, is a device that can be used as either a plotter or a roller-type parallel ruler. It is convenient for use on small craft and has been adopted by many ship navigators.

A pair of ordinary draftsman's triangles is also useful in plotting; they need not be of the same type or size. The two hypotenuse (longest) sides are placed together, and the pair is aligned so that the chart line or desired direction is along one of the other four sides; see figure 721c. By holding one triangle firmly in place and sliding the other with respect to it, alternating between them if the distance is great, the original direction, or one at right angles to it, can be transferred across the chart. The use of two triangles provides an easy and accurate means of drawing both a line and another line at right angles to the first one as is needed when plotting celestial sight reductions.

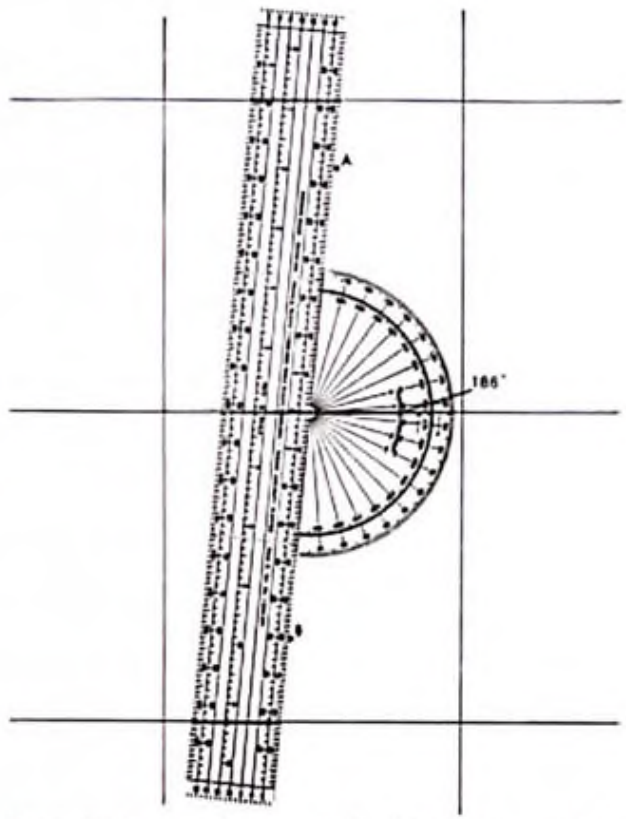

Figure 721a. Aircraft-type "AN" plotter, often used in marine navigation.

Protractors

722 While not essential, a common protractor is sometimes useful for measuring angles. Any type will do, but a fairly large one made of transparent plastic is most desirable. One model has several small cutouts in its face so that it can be used for drawing standard plotting symbols.

A special type of protractor with three arms is useful for plotting the position of a vessel. The middle arm is fixed and the others movable so that they can be set at essentially any angle to the fixed arm. A complete description of this instrument and the method of using it is given in article 1110; the instrument is illustrated in figure 1110a.

Drafting Machines

723 Chart plotting on most large ships is done with a *drafting machine*, also called a parallel motion protractor. Figure 723 shows such a device; smaller and simplified models are sometimes used

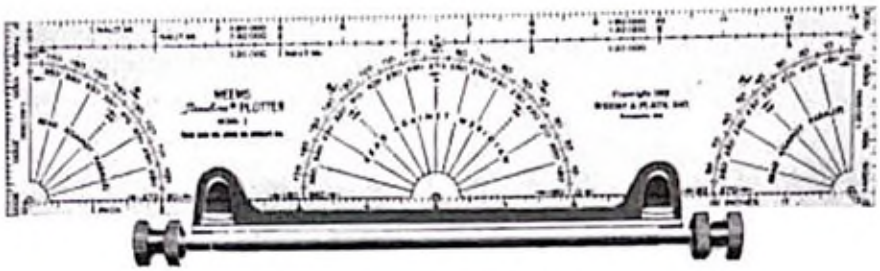

Figure 721b. Parallel plotter.

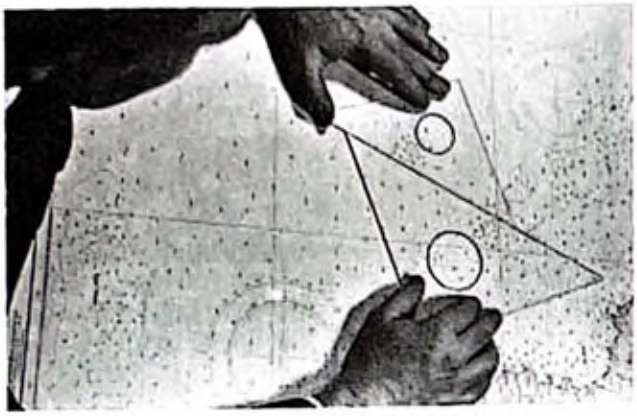

Figure 721c. Two drafting triangles can be used to transfer a direction across a chart.

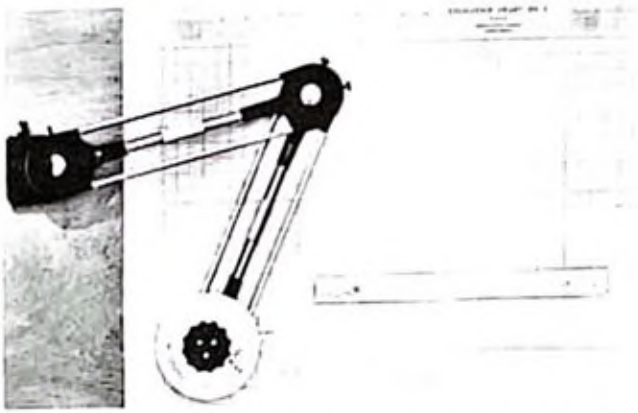

Figure 723. A universal drafting machine is excellent for plotting.

on recreational and commercial boats. A typical unit consists of a protractor carried on a parallel-motion linkage system fastened to the upper left-hand corner of the chart table. The linkage permits the movement of the protractor to any part of the chart without change of orientation. Several graduated rulers of different length are provided. On some models any two of these can be mounted, one as shown and the other at right angles to the first, to facilitate plotting of lines of position from celestial observations. However, most navigators prefer to use a right triangle to obtain the perpendicular. The graduated protractor rim, or compass rose, can be rotated and clamped in any position desired. Hence, it can be oriented to directions on the chart.

Dead Reckoning Equipment

724 Many large vessels are equipped with a dead reckoning electro-mechanical computer. The basic part of this device is its *analyzer* (DRA); heading information is fed into the DRA from the ship's gyrocompass, and speed information is supplied by the log. The speed input is integrated with time to read distance. The DRA has three readouts: miles steamed north or south, miles steamed east or west, and total number of miles steamed.

Some DRAs also give latitude and longitude readouts, in which case they are usually called Dead Reckoning Analyzer-Indicators (DRAI). A Mark 9 Mod 4 DRAI is shown in figure 724a. There is also a DRAI Mark 10.

The *Dead Reckoning Tracer* (DRT) receives its heading and speed inputs from the DRA, and provides a graphic trace of the ship's travel through the water. Some new models also trace the paths of two or more targets, permitting a constant readout of target range and bearing; target data are supplied from radar or sonar inputs. The DRT permits the choice of one of a number of scales, depending on the tactical situation, and the trace may be on a Mercator chart or a polar coordinate chart. The "own ship" trace may be made by a pencil moved across the chart; alternately, the ship's position as well as that of the targets may be indicated by spots of light focused on the chart from underneath. Such a DRT is shown in figure 724b; it is the PT-512 plotting table, designed primarily for use aboard ASW vessels. This plotting table permits a

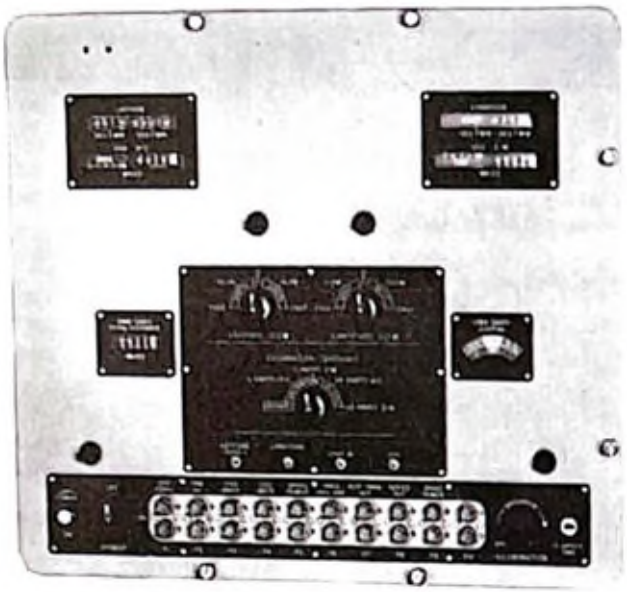

Figure 724a. Dead Reckoning Analyzer-Indicator, Mark 9, Mod 4.

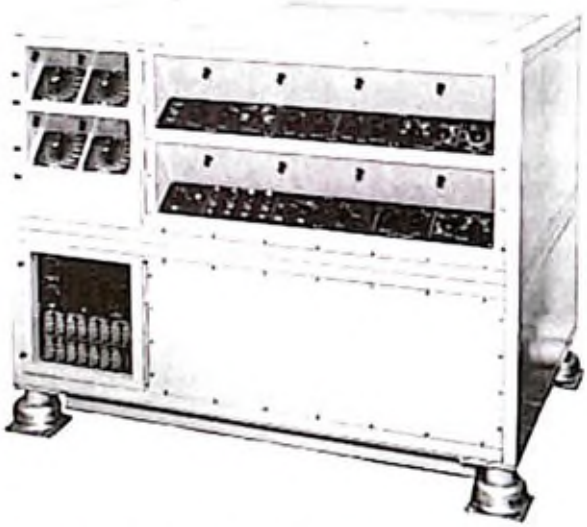

Figure 724b. Plotting Table, PT-512.

choice of eight scales, ranging from 200 yards per inch to 5 miles per inch, and gives a plotting area of 30 by 30 inches (76 by 76 cm). There is also a DRT Mark 6 Mod 4.

Nautical Slide Rule

725 Circular plastic slide rules (figure 725 is typical) are widely used for the rapid solution of problems involving time, distance, and speed. Given any two of these factors, the third may be obtained. The time scale gives hours in red figures and minutes and seconds in black figures. Seconds are shown separately to 120; this scale may be used only for times of 120 seconds or less. Hours and minutes are both stated in units and decimals. If the hour scale is set to 2.5, the minute scale will read 150. Similarly, if the minute scale is set to 1.5, 90 seconds may also be read.

In the model shown, the distance scale is in miles in red figures and in yards in black figures. The yards scale is based on the assumption that 1 nautical mile equals 2,000 yards; this is an assumption frequently used in marine surface navigation—the slight error, 1¼ percent, is ignored for the convenience gained. Therefore, if the distance scale is set at 3 miles, it will also read 6,000 yards. The figures on the distance scale may also be used in solving problems involving statute miles; however, in this case, the yard scale must *not* be used.

In using the slide rule, when the distance is one of the known factors, the distance setting should be made *first*. When speed is a known factor, it should always be set last, as the speed scale is read through both dials.

Electronic Calculators and Computers

726 The rapid development of small hand-held electronic calculators has brought them onto the bridge of both large and small vessels for the solution of many navigational problems. These have essentially replaced conventional slide rules; they permit quick, easy, and accurate solutions of problems of speed-time-distance, dead reckoning, current sailing, metric conversions, and many others related to navigation or general "ship's business." The more sophisticated personal calculators can be programmed and approach the capabilities of microcomputers. See appendix F for more on these mathematical instruments.

Many modern naval vessels are equipped with a number of computers, usually specialized ones "dedicated" to some specific function such as weapons control. Minicomputers and microcomputers of a more general type are being increasingly found on merchant ships and yachts. Consideration of the use of computers in navigation will be found in chapter 38 and appendix F.

TIME MEASUREMENTS

727 Knowledge of the time of day and of elapsed time is essential in many phases of piloting. An accurate, easily read clock, indicating seconds, should be mounted near the navigator's station. This may be a conventional analog clock with

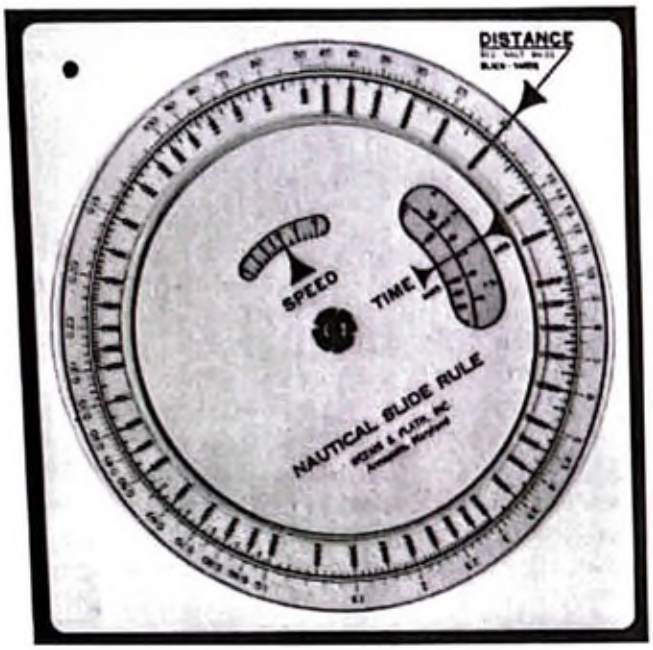

Figure 725. Nautical slide rule.

sweep-second hand, but digital models showing time directly in the 24-hour system are becoming more widely used.

A stopwatch or a navigational timer, which can be started and stopped at will, is of particular value in timing the period of a navigational light to determine its characteristic for purposes of identification. When equipped with a luminous dial and sweep-second hand, the watch may be read without the use of artificial light, thereby maintaining night-adapted vision.

Split-second timers, sometimes referred to as split-action stopwatches, are now available. With this feature the watch continues to run and measure elapsed time while simultaneously timing events of short duration; there are, in effect, two second hands that run together. When the side push button on the stopwatch is depressed, one of these second hands is stopped so that the exact interval can be read from the face of the watch. A second depression of the side push button causes the second hands to run together. This feature is also available on chronographs that can be kept running on GMT, with the split-second feature being used to determine the exact time of an event, such as passing a buoy, without disturbing the time-keeping function of the watch.

Electronic watches and stopwatches are now available with direct digital readouts. These generally have several modes of split-second operation suitable for the timing of different types of events. Some models have alarms that can be set to a specific time, or to count down and sound at the end of a preset interval. Also available are electronic wristwatches that can show time in a second zone, such as GMT, by the press of a button.

WEATHER INSTRUMENTS

Barometer

728 A *barometer* is an instrument for determining the atmospheric pressure, a meteorological ele-

Figure 726. A personal electronic calculator. Courtesy Texas Instruments, Inc.

Figure 727. A stopwatch (left) and a chronograph with split-second capability.

ment of considerable interest to a mariner, as its fluctuations provide an index useful in predicting weather, an important factor in navigation and ship handling. Because bad weather is usually associated with regions of low atmospheric pressure and good weather with areas of high pressure, a rapidly falling barometer usually indicates the approach of a storm.

Two general types of barometers are used. The *mercurial* barometer consists essentially of a column of mercury in a tube, the upper end of which is closed and the lower end open to the atmosphere. The height of the column of mercury supported by the atmosphere is read by a suitable scale. Readings are in inches of mercury. The *standard* atmospheric pressure is 29.92 inches or 1013.2 millibars.

An *aneroid* barometer consists essentially of a short metal cylinder from which the air has been partly exhausted. The ends of the cylinder, being of thin metal, expand or contract as the external atmospheric pressure changes. This motion is transferred by a suitable mechanical linkage to a registering device that may be graduated in either inches of mercury or millibars, or both. A reading of one scale can be converted to one of the other by table or arithmetically if both scales are not shown.

A *barograph* is a recording instrument that provides a permanent record of atmospheric pressure over a period of time. It is a relatively sensitive instrument and must be protected from shock and vibration; it is not normally affected by motions of the vessel, including rough weather.

Thermometer

729 For measuring temperature on board vessels *thermometers* are usually graduated to the Fahrenheit scale (water freezes at 32° and boils at 212° at standard atmospheric pressure), but use of the metric scale of Celsius (formerly centigrade) degrees (0° is freezing, 100° is boiling) is increasing, particularly in international applications. The reading of one scale can be easily converted to that of the other by means of Table 15, *Bowditch*, or mathematically, since

$$°F = \tfrac{9}{5}C° + 32°$$
$$°C = \tfrac{5}{9}(F° - 32°)$$

in which °F = degrees Fahrenheit, and °C = degrees Celsius.

Two thermometers are often mounted together in an *instrument shelter*, a wooden box with louvered sides to protect the instruments from direct rays of the sun and other conditions that would render their readings inaccurate. The instrument shelter is installed at some exposed position aboard ship. One of the thermometers has its bulb covered with a wet fabric, and the other is exposed to the air. The rate of evaporation of the water is dependent upon the *relative humidity* of the air, or the relative amount of water vapor in the air. The evaporating water cools the bulb of the thermometer, resulting in a lower temperature. Knowing the air temperature (reading of the *dry bulb thermometer*) and the difference between this and the reading of the *wet bulb thermometer*, the relative humidity and *dew point* (the temperature to which the air must be cooled for condensation to take place) can be easily determined; Tables 16 and 17 of *Bowditch* are applicable. Calculations of relative humidity and dew point are of special interest to the mariner in connection with the formation of fog. A combination of wet and dry thermometers is known as a *psychrometer*.

Anemometer

730 An *anemometer* is an instrument for measuring wind force or speed, usually in knots. It must always be remembered that wind speed measured on a moving vessel is *apparent* wind, or wind relative to the moving ship or both. Apparent wind can be converted to true wind, or vice versa, by means of a simple graphic solution (see article 1417) or by the use of tables such as Table 10 in *Bowditch*.

MISCELLANEOUS EQUIPMENT

Binoculars

731 The term "pair of binoculars" is commonly used for a single unit, but this is not strictly correct; the proper term is "binocular"—as in "bicycle." However, since the plural form is usually used, that form will be used here. Good binoculars are useful for visually detecting aids to navigation, especially small ones such as buoys, and in reading their identifying markings. The navigator should have binoculars for his own exclusive use; they should be kept in a handy location, but sufficiently protected to prevent damage from dropping, being knocked off a table by the motion of the ship, or by weather. When they are being used, the strap should be placed around the user's neck. Like the other instruments used by the navigator, binoculars must receive proper care if they are to give reliable service.

The size of binoculars deemed most useful for marine work is 7 × 50; this describes glasses with a magnification of 7 powers and an objective lens

Figure 731. A good pair of binoculars is essential to the navigation of a vessel of any size.

50 mm in diameter. This ratio of magnification is a satisfying compromise between need for magnification and the reduction of field of view that results as the magnification is increased. Objective lenses of 50-mm diameter have excellent light-gathering characteristics, making them particularly suitable for night use.

Other models, such as 6 × 30, may be used, but these are generally somewhat less satisfactory. The style in which each eye is *individually focused* has been adopted by the U.S. Navy, but many civilian mariners and boatmen use the *center-focusing* style that focuses for both eyes simultaneously after an initial correction is made for any difference between the user's two eyes. Either style will serve the purpose; the choice can be made on personal preference.

Much higher powered binoculars may be found on pedestals on the wings of many ships' bridges; the mounting is necessary because of the much greater weight of these larger glasses.

Flashlight

732 At least one good flashlight should be kept handy for an accurate reading of watches and sextants during twilight observations if the latter are not equipped with their own light, and for timing light characteristics, etc., during the hours of darkness. To protect dark-adapted vision, this flashlight should be equipped with a red bulb, or a red lens. Lacking these, a red plastic or cellophane filter should be fitted.

If accurate twilight or night observations are to be made, the navigator must protect his eyes from any direct white light. If no red flashlight is available, the person who is acting as recorder should stand with his back to the observer, with his light shielded and close to the watch. After the altitude is obtained, if the sextant has no readout light the navigator should hand it to the recorder for reading.

Chapter 8 Dead Reckoning

Introduction

801 Once primitive man took to the larger bodies of water and developed enough skills in piloting to venture long distances from home port, it became necessary for him to keep track of his vessel's movements and position. Thus was developed *dead reckoning* (DR), now one of the four principal divisions of navigation. The term is derived from *deduced*, or *ded*, reckoning, the process by which a vessel's position was *deduced* or computed trigonometrically in relation to a known point of departure. While modern charts permit solutions by graphic methods, rather than by laborious mathematics, the term *dead reckoning* continues in use. Although treated as a separate division of navigation in this text, DR is actually basic to all phases of navigation.

DR Defined

802 Dead reckoning is the process of determining a ship's approximate position by applying from its last known position a vector or a series of consecutive vectors representing the run that has since been made, using only the courses steered, and the distance run as determined by log, engine revolutions, or calculations from speed measurements, *without considering current*. By projecting these course and speed vectors ahead of the present position, the ship's predicted DR position for any desired time can be determined. Dead reckoning is normally a process carried out as a vessel proceeds along its passage. It can, however, be done in advance to plot an intended track.

The key elements of dead reckoning may be summarized as follows:

Only the courses steered are used to determine a DR position.

The distance used in determining a DR position is obtained by multiplying the ordered engine speed by the time involved in the run.

A DR plot is always started from an established position, that is, a fix or running fix. (See article 804.)

The effects of current are *not* considered in determining a DR position. If the effects of known or anticipated currents are included, the result is a plot of *estimated positions* (EPs). (See article 1205.)

The Importance of DR

803 The importance of maintaining an accurate dead reckoning plot cannot be overemphasized. Other means of fixing the ship's position are not always available, due to weather, equipment failure, etc. Under such conditions, a navigator must rely on his dead reckoning. It is obvious that a DR position must be used with extreme caution in the vicinity of shoal water or other dangers to navigation; if adequate information is available, an EP plot should be maintained in addition to, but *not* in lieu of, the DR plot.

If a ship made good the exact course and speed ordered, and there was no wind or current, dead reckoning would at all times provide an accurate indication of position. Such conditions rarely exist, however, and a DR position is only an approximation of the true position. A navigator must know his position, or approximate position, to determine when to make changes in course and/or speed, to predict the time of sighting lights or other aids to navigation, and to identify landmarks.

Although dead reckoning can be quickly and accurately done on a computer or calculator, it is almost always done graphically on a chart or plotting sheet appropriate to the area in which the vessel is operating. Graphic solutions are advantageous in that they enable the navigator to visualize his vessel's position relative to landmarks, aids to navigation, and hazards.

DR Terms Defined

804 A number of terms used in dead reckoning must be defined. Not all books on navigation use exactly the same terms and definitions; the terms used in this book are defined below.

Heading (Hdg. or SH). The direction in which a ship points or heads *at any instant*, expressed in angular units, clockwise from 000° through 360°, from a reference direction—true, magnetic, or compass—(figure 804). The heading of a ship is also called *ship's head*. Heading is a constantly changing value as a ship oscillates or yaws across the course due to the effects of the sea and of steering error.

Course (C). As applied to marine navigation, the direction in which a vessel is to be steered, or is being steered; the direction of travel through the water. The course is measured from 000° clockwise from the reference direction to 360°. Course may be designated as *true, magnetic, compass,* or *grid* as determined by the reference direction.

Course line. The graphic representation of a vessel's course, normally used in the construction of a dead reckoning plot.

Speed (S). The ordered rate of travel of a vessel through the water; normally expressed in knots. (In some areas, where distances are stated in statute miles, such as on the Great Lakes and other inland waters, speed units will be "miles per hour.") It is used in conjunction with time to establish a distance run on each of the consecutive segments of a DR plot.

DR position. A position determined by plotting a vector or series of consecutive vectors using only the course, and distance determined by speed through the water, without considering current.

DR plot. The graphical representation on the nautical chart of the line or series of lines that are the vectors of the ordered true courses, and distance run on these courses at the ordered speeds, while proceeding from a fixed point. The DR plot originates at a fix or running fix; it is suitably labeled as to courses, speeds, and times of various dead reckoning positions, usually at hourly intervals or at times of change of course or speed. A DR plot properly represents courses and speeds that have been used; a similar plot may be made in advance for courses and speeds that are expected to be used.

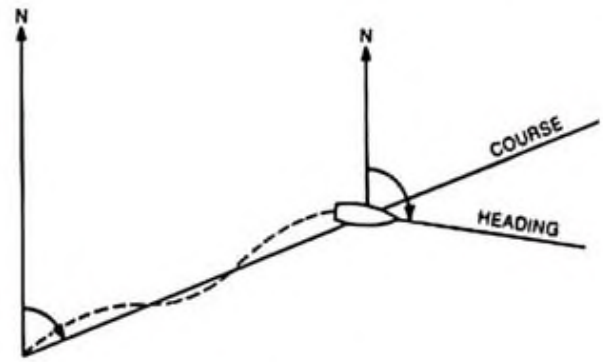

Figure 804. Heading and course.

Estimated position (EP). The more probable position of a vessel determined from incomplete data or data of questionable accuracy. In practical usage it is often the DR position modified by the best additional information available.

Fix. A position established at a specific time to a high degree of accuracy; it may be determined by any of a number of methods discussed in chapter 11. A *running fix* is a position of lesser accuracy based in part on present information and in part on information transferred from a prior time.

Estimated time of departure (ETD). The estimate of the time of departure from a specified location in accordance with planned courses and speeds and anticipated currents.

Course, speed, time, distance, and position will be stated to an order of precision suitable to the vessel concerned and prevailing conditions; see appendix C.

A planned or intended path *with respect to the earth* rather than the water is labeled *Track* and *Speed of Advance;* see chapter 12.

Labeling a DR or EP Plot

805 It is of the utmost importance that all points and lines plotted on a chart be properly labeled. The use of standardized methods will ensure that the plot will mean the same thing to others as it did to the navigator who made it; this is essential to the safety of the vessel.

The principal rules for labeling DR plots are:

Immediately after drawing any line or plotting any point, it should be labeled.

Labels indicating direction and speed along a course line should be written *along* that line.

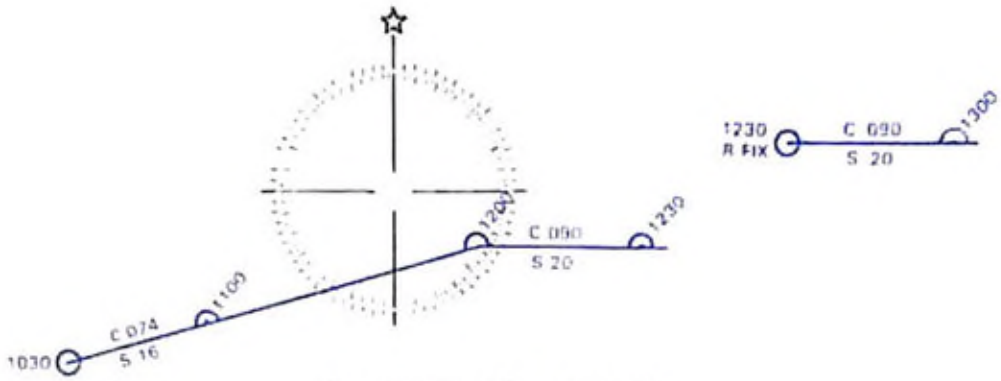

Figure 805. Labeling a DR plot.

The label for direction should be the letter *C* followed by three digits indicating the *true* course in degrees (the degree symbol is not used); this is placed *above* the course line. (Should course be stated with reference to another base direction, an appropriate letter is added following the digits, such as *M* for magnetic.)

The label indicating the rate of movement along the course line is the letter *S* followed by digits indicating the speed; the name of the units being used is normally omitted. This is placed *below* the course line, usually directly beneath the direction label.

The label for any point on a line should *not* be placed close alongside that line. Labels for fixes, running fixes, and estimated positions should be written horizontally as the chart is normally viewed; labels for time of DR positions should be placed at an angle to the horizontal.

The symbol for a DR position is a small semicircle around a small dot on a straight segment of a course line; it will be more or less than a semicircle when plotted at a change in direction. The letters "DR" are *not* used. Time, to the nearest minute—stated in the 24-hour system as a four-digit number without a colon or a dash (see article 210)—is written nearby *at an angle to the horizontal and to the course line.*

The symbol for an estimated position is a small square. Time is written *horizontally* close nearby.

The symbol for a fix is a small circle (with a dot if needed); the word "FIX" is *not* used. Time is written nearby *horizontally*. The symbol for a running fix is the same as for a fix, but the letters "R FIX" are added following the time.

If a DR plot is drawn in advance of actual vessel movement, distances are known; speeds may or may not be known prior to departure. If it is desired to label a DR plot with distance, this is done with the letter *D* followed by the distance in nautical miles (statute miles in some areas), usually to the nearest tenth of a mile; this is placed below the course line. (Some navigators will label a destination, usually in pilot waters, with its ETA and then intermediate points, marked by a heavy dot, with the ETA there plus the distance measured back from the final destination along the intended track.)

All labels should be printed clearly and neatly.

The dot in a fix, estimated position, or DR position symbol is used to emphasize the point of the position; it should be small and neat, and is not needed if the position is at the intersection of two lines. Course lines, properly labeled, are shown in figure 805.

When DR Positions Are to Be Plotted

806 In addition to the rules for symbols and labels, there are also standard rules that will guide a navigator as to *when* DR positions and course lines are required to be plotted:

A DR position shall be plotted every hour on the hour.

A DR position shall be plotted at the time of every course change.

A DR position shall be plotted at the time of every speed change.

A DR position shall be plotted at the time of obtaining a fix or a running fix.

A DR position shall be plotted at the time of obtaining a single line of position.

A new course line shall be plotted from each fix or running fix as soon as the fix or running fix has been determined and plotted on the chart.

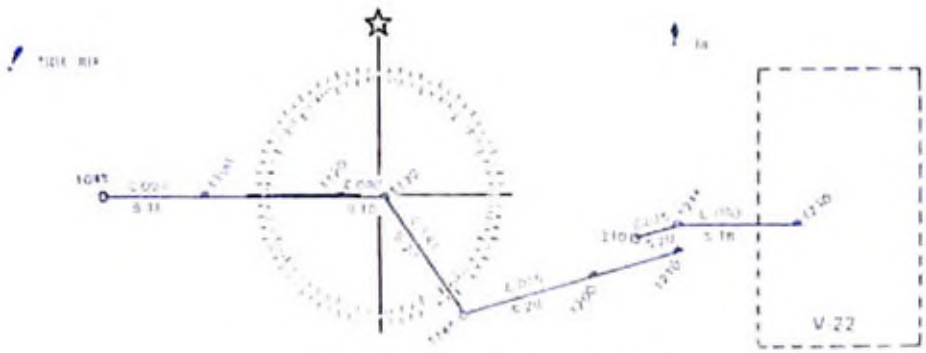

Figure 807. A typical navigator's DR plot.

These rules of dead reckoning are considered adequate to meet the needs and requirements of navigation in the open waters of the sea. There are occasions, however, when a *more frequent* plot of the vessel's dead reckoning position is essential to safe navigation, as when in the confined waters of channels, bays, straits, and harbors. Knowledge of when to plot frequent fixes and even more frequent dead reckoning positions when in such waters will come with experience and judgment. This subject will be discussed more fully in chapter 15.

Example of a DR Plot

807 The following example illustrates a typical dead reckoning plot; see figure 807.

A partial extract from a ship's deck log reads as follows:

1045. With Tide Rip Light bearing 315°, distant 6 miles, took departure for operating area V-22 on course 090°, speed 15 knots.
1120. Changed speed to 10 knots.
1130. Changed course to 145° and increased speed to 20 knots.
1145. Changed course to 075°.
1210. Made radar contact on Buoy 1A bearing 010°, distant 8 miles.
1215. Changed course to 090° and changed speed to 18 knots to arrive at the rendezvous point at 1230.

Note the applicability of the rules for dead reckoning as they pertain to this example. Commencing at the initial known position, the 1045 fix, the navigator plotted the course line in a direction of 090°, the ordered course. The rate of travel, speed 15 knots, for an elapsed time of 15 minutes and then 20 minutes enabled the navigator to make a scaled plot of the 1100 DR and 1120 DR positions on his chart. Labeling the fix, the 1100 DR, the 1120 DR, and the course line itself completes the graphic description of the ship's travel until 1120. At 1120, only the speed was changed. At 1130, both the course and speed were changed, while at 1145, only the course was changed. Each of these occurrences requires a separate DR position on the plot, while segments of the course lines are labeled to indicate what the course and speed were at that time. The 1200 DR was plotted on the whole hour as prescribed. At 1210, since the navigator fixed his position by radar, he must then plot both the 1210 DR on the former course line and the 1210 radar fix from which he commences a new course line. The navigator plots the ship from the fix on a course of 075° at a speed of 20 knots to 1215, at which time the course is changed to 090° and the speed is reduced to 18 knots in order to arrive at the operating area at 1230 as scheduled. (Note that while a new course line is drawn from the fix, the ship continues on briefly on the old course and speed while a revised course and speed are being determined—in this example, for five minutes. See article 809.) The DR plot reflects the new course and speed and includes the 1230 DR as shown.

Planned Track

808 In actual practice, a preplanned track line is often plotted on a tentative basis before a ship ever gets underway. Called "navigational planning," it is a fundamental principle of safe navigation. Every passage, every departure from and entry into port, must be planned in advance, based on all information available to the navigator. The material studied in the course of this planning includes the charts of the areas to be traversed, the navigational aids expected to be sighted, the availability of radionavigation systems, estimates of currents and weather to be encountered, the contour of the bottom, and other factors that will be discussed in this book. The preplanning phase also includes the plotting of danger bearings, ranges,

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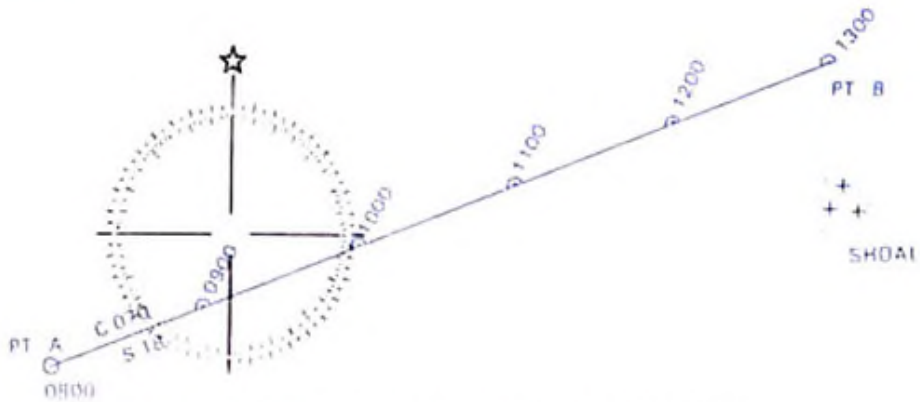


Figure 808a. Intended DR, plotted and labeled in advance.

etc. The following description of a short voyage will serve to illustrate many of the principles and concepts enumerated so far in this chapter.

Referring to figure 808a, assume that a ship is located at point A, and receives orders to depart at 0800 for point B, 90 miles distant, arriving at 1300. Immediately upon receipt of this information, the navigator locates points A and B on the appropriate small-scale chart of the area. By measuring the direction of B from A, the course of 070° is determined and noted on the DR plot as "C 070." Dividing the rhumb-line distance between A and B by five hours, the required speed is computed to be 18 knots and labeled accordingly. Next, starting at the known position, or fix, at 0800, the navigator steps off and marks the successive hourly positions that the ship is expected to occupy. The plot is now complete and barring any unforeseen circumstances, represents the track that the ship will follow from the point of departure to her destination. Note that in this case the vessel was able to order the planned course and speed and arrive at the destination as planned; this very seldom happens in actual practice. The technique of handling deviations from the plan is the subject of the next article.

An alternative procedure of labeling is shown in figure 808b. Here *distances to go* are given at each change of course, and the line is labeled for track (TR) and speed of advance (SOA). Actual courses and speeds ordered will differ as allowance is made for the river's current.

Departures from Plan

809 The ship gets underway as scheduled in figure 808a and sets course 070° true and speed 18 knots to arrive at B at 1300. If the calculations are correct and there is no current or change of course to avoid shipping, the ship should arrive at B as planned. The navigator's work now consists of trying to establish his actual position from time to time, in order to be sure that the ship is following the intended track, or if it is not following it, to recommend changes in course or speed, or both, that will bring the ship safely back to the intended track at any selected point on it.

The navigator had poor weather and was unable to establish his position until about noon, at which time he obtained a 1200 fix. When the fix was plotted, he found that the ship was actually about 10 miles south and a bit east of his 1200 DR position; see figure 809. He further noted that if his ship maintained the same course from the 1200 fix as it had from point A, she would be in danger of grounding on the indicated shoal.

Since the ship will not reach the desired destination on a course of 070° and a speed of 18 knots, the navigator must determine a new course and speed to arrive at point B by 1300, based upon the relationship between point B and the latest fix at 1200.

Since time was required to record the fix, evaluate it, and decide upon a new course and speed, this change cannot be effected from the 1200 fix, but rather from a DR position some time later. Making a rough estimate of how long it will take him to determine a new course and speed, and get approval, the navigator plots a 1215 DR position based on the old, and still maintained, course and speed. From here he calculates a new course and a new speed (or new ETA if the ship is not capable of the greater speed needed to reach point B by 1300). It is very important to remember that *the course line will continue in the direction and at the speed originally ordered during the time required to obtain and plot the fix and decide upon a new course of action.* Upon the advice of the navigator in this instance, the captain ordered a course of 028° and a

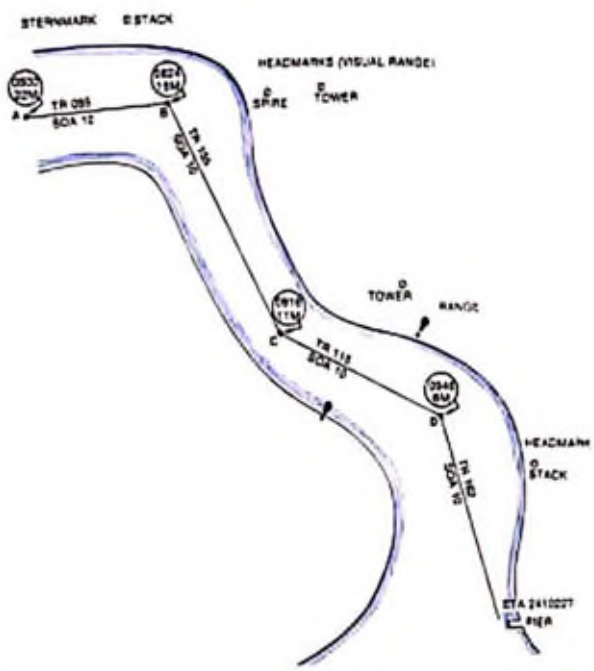


Figure 808b. Alternative labeling of a proposed track.

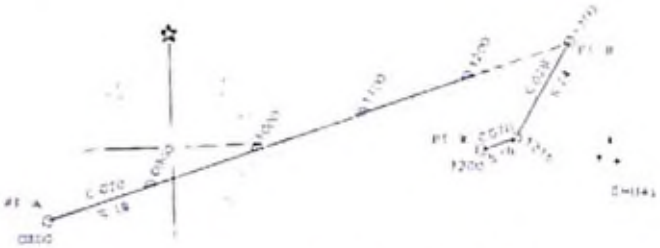


Figure 809. The practice of dead reckoning.

speed of 24 knots at 1215 so that the ship would arrive at point B at 1300. Although it is apparent that a current existed, it is not considered in this simplified example. The technique and procedures of computing and allowing for current are explained later in chapter 12; they would have been used by the navigator in the computation of the new course and speed through the water.

The navigator believed that the ship was following the intended track until he obtained and plotted his 1200 fix. This illustrates the fundamental weakness of relying solely on dead reckoning, for dead reckoning is dependent upon the assumption that the ship makes good over the ground the same direction that it is traveling through the water, and that the ship makes good over the ground the same speed that it is traveling through the water. Therefore, the dead reckoning position should not be relied upon if it is possible to obtain information to determine the position by other means. The many volumes of records on maritime disasters are filled with reports of vessels having been put aground and lost because of a navigator's adherence to a course that was laid in safe waters, while the actual movement was an unknown path leading to danger.

Plotting Techniques

810 As stated above, neatness and accuracy in plotting are essential for safe navigation. Skill will come with experience and practice, but a few hints and suggestions may be of assistance toward both accuracy and speed in plotting.

A drafting machine should be used whenever available to determine the direction of a line, as it is both more rapid and accurate than other methods. When a drafting machine is not available, a course plotter (or protractor or parallel rulers) is used. Various types are shown in chapter 7.

Tape the chart to the table or desk used. This will maintain proper orientation of the chart. Tape is preferable to thumbtacks for this purpose, and masking tape should be used, as it will not harm the surface of the chart when removed provided it has not been left in place for an extended time and allowed to harden.

If the chart is too large to fit on the table used, determine the extent of the chart that must be used, then fold under the portions of the chart that will not be required. Be sure to leave one latitude scale and one longitude scale available for measurement.

Use a *sharp* No. 2 pencil. A harder pencil will not erase well, and a softer pencil will smear.

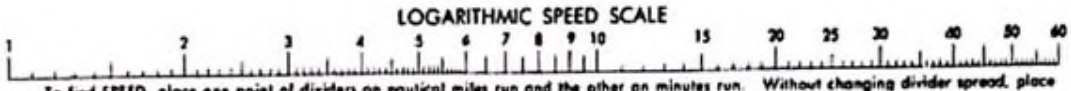
Draw lines heavy enough to be seen readily, but light enough so that they do not indent the chart paper.

Avoid drawing unnecessary lines, and erase any lines used only for the purpose of measurement. Do not extend course lines excessively beyond the point at which their direction is to be changed or bearing lines much beyond the anticipated fix.

Hold the pencil against the straightedge in a vertical position throughout the entire length of a line when drawing it.

Measure all directions and distances carefully. Accuracy is the mark of good navigation. On Mercator charts, measure distance on the graphic bar scale or on the *latitude* scale using the portion of the scale that is opposite the line that is being measured. Be neat and exact in plotting work. Use standard symbols and labels and print neatly.

Lay down a new DR (or EP) track from each new fix or running fix. Plot a DR position at every change of course, at every change of speed, at the



To find SPEED, place one point of dividers on nautical miles run and the other on minutes run. Without changing divider spread, place right point on 60 and left point will then indicate speed in knots. Example: with 4.0 miles run in 15 minutes, the speed is 16.0 knots.

Figure 811. Logarithmic scales for determining speed or distance.

time of obtaining a fix, a running fix, or a single line of position, and on the whole hour.

Time-speed-distance Calculations

811 The navigator may find it convenient to use a *nautical slide rule* (figure 725) for the solution of time, speed, and distance problems. Small hand-held electronic calculators (appendix F) are also useful for the easy, quick, and very accurate solution of these problems. Alternatively, he may use precomputed tables, such as those in *Bowditch*, Volume II, for such solutions. He must, however, always be able to solve these problems quickly and accurately without the use of any equipment beyond pencil and paper.

Regardless of the tools used, however, *it must always be remembered in adding or subtracting values of time, there are 60 minutes in an hour, and 60 seconds in each minute;* don't forget and work in decimal terms of 100 units.

Time, distance, and speed calculations—finding the third quantity if the other two are known—can also be worked graphically using the logarithmic scale printed on larger-scale NOS and DMAHTC charts, on some plotting sheets, and as the top line of the nomogram printed near the bottom of Maneuvering Board sheets, DMAHTC Pub. No. 5090 and 5091; see figure 811. The scale, together with a pair of dividers, is used as a slide rule. Let the right leg of a pair of dividers represent time in minutes and the left leg, distance. Consider speed as distance in 60 minutes. Then, to obtain time, place the left leg of the dividers on the speed and the right leg on 60. Without changing the spread of the dividers, place the left leg on the required distance and read off the time at the right leg. If distance in a given time is desired, place the right leg on the given time and read off the distance at the left leg. If speed is required, set the left leg of the dividers at distance and the right leg at time, and then, without changing the spread, place the right leg on 60 and read the speed at the left leg.

If the problem runs off the scale, the solution can be found by using a fraction of the speed, or distance (only one), and multiplying the answer by the inverse of that fraction.

If in doubt as to the accuracy of a solution, check it mentally or by simple arithmetic using the formula $D = S \times T$, where D is distance in miles, S is speed in knots, and T is time in hours (or 60D if T is in minutes).

The Maneuvering Board sheets also have a three-scale nomogram that can be used as described in article 1404.

A useful rule to use in plotting in confined waters where frequent fixes and DR positions are required is the so-called *three-minute rule*, applied as follows: the travel of a ship *in yards* in three minutes is equal to the speed of the ship in knots multiplied by 100. (This uses the assumption that one nautical mile is equal to 2,000 yards—not exact, but close enough for practical use.) Where a *six-minute* DR would be more appropriate than a three-minute plot, the travel of a ship *in miles* in six minutes is equal to the speed of the vessel divided by 10, a shift of the decimal point one place to the left.

Example 1: A navigator desires to plot a three-minute DR from his last fix in Brewerton Channel. The ship is making a speed of 12 knots. To compute the travel of the ship in yards in three minutes, he multiplies the speed in knots, 12, by the factor 100 and determines the DR advance to be 1,200 yards.

Answer: Distance 1,200 yards.

Example 2: A navigator desires to plot a six-minute DR from his last fix in Chesapeake Bay. The ship is making a speed of 15 knots. To compute the travel of the ship in miles, he divides the speed in knots, 15, by the factor 10 and determines the DR advance to be 1.5 miles.

Answer: Distance 1.5 miles.