## CHAPTER 1

# INTRODUCTION TO COASTAL NAVIGATION

> "And after this sort he proceedeth from place to place
> until he arrive unto his desired porte, which is a conclusion
> infallible if there be no other impediments (whereof there hath been
> good consideration had) which may breed errour,
> for from such negligence may arise many inconveniences."
>
> –*The Seaman's Secrets* by John Davis, 1607,
> as quoted in Schofield, *The Story of HMS Dryad*

What is coastal navigation? In simple terms, marine navigation is "getting your vessel from where you are to where you want to go, safely and efficiently." More formally, it is the "process of directing the movement of a vessel from one point to another." It is derived from the two Latin words, navis (ship), and agere (to move). *Coastal navigation* refers to navigation in coastal (sometimes termed pilot) waters, where the opportunity exists to determine or check the vessel's position by reference to navigational aids and observations (by either visual or electronic means) of the coast and its features. Coastal navigation is distinguished from "blue water" or ocean navigation, terms used to describe navigation out of sight of land and/or coastal *Aids to Navigation* (ATONs). Although blue-water navigation may appear to require more sophisticated techniques and equipment, such as the employment of methods to fix the vessel's position from observation of the sun, moon, or stars, coastal navigation often demands a greater degree of accuracy and attention to detail. On a long ocean passage, for example, it may suffice to determine the vessel's position only once or twice a day, and to within a margin of uncertainty of several square miles. A well-found oceangoing vessel may afford the navigator a dry workstation, and numerous electronic aids, such as the *Global Positioning System* (GPS) receiver and radar. A passing vessel would be a curiosity in seldom traveled waters, rather than an object for collision-avoidance maneuvers. In coastal waters, particularly in narrow channels, position fixes might be required every 5 to 15 minutes, and required accuracy limits could well be measured in yards. The navigator's workspace could be cramped, and the vessel's navigational gear limited to a hand-bearing compass. All this is to be done while dodging "heavy iron" (large vessels) in busy shipping channels.

**WHAT YOU WILL LEARN IN THIS CHAPTER**

- ❑ ***How the course is organized***
- ❑ ***Principles of voyage planning and underway navigation***
- ❑ ***Coordinate systems (latitude and longitude)***
- ❑ ***Measurement of direction***

## AN OVERVIEW OF THE COURSE

This section provides an overview of the *Advanced Coastal Navigation* (ACN) course in the context of the navigator's tasks on a typical voyage in coastal waters. To make the discussion concrete, suppose that you are the navigator for the 42-ft. trawler, *Verloren*, on a voyage from Tiverton, on the Sakonnet River in the state of Rhode Island, to Woods Hole, Massachusetts, approximately 40 miles distant. This area is covered by the 1210-Tr chart, which is distributed with the course materials. Reach for this chart now (the first of many times that you will be called to do this in the chapters ahead) and locate the place of departure on the voyage, Tiverton (roughly in the middle of the chart, near the top), Rhode Island, and the destination, Woods Hole, Massachusetts, on Vineyard Sound (at the far right of the chart).

It is convenient to subdivide navigation into two distinct, but related phases: *voyage planning* and *underway navigation*. The planning phase covers the initial shoreside paper-and-pencil or (increasingly) computer chores, and ends when the vessel's anchor is weighed or the mooring lines are slipped. Underway navigation covers navigation and decision making on the water. The overall steps in each phase are discussed below.

## STEPS IN VOYAGE PLANNING

Figure 1-1 highlights the principal steps in voyage planning. It starts with the *assembly of required reference materials and trip and vessel data*. Such materials include:

- ❑ Up-to-date (and corrected) nautical charts at the right scale (discussed in Chapter 3),
- ❑ *Tide and Tidal Current Tables* and related materials (discussed in Chapter 8),
- ❑ Navigation reference materials, such as the *Light List* (LL), U. S. *Coast Pilot* (USCP), and
- ❑ Cruising guides to the area (discussed in Chapter 10).

The nautical charts are used to lay out the voyage, measure distances and courses, identify landmarks or ATONs that will be used to fix the vessel's position, ensure that the course avoids hazards to navigation, and for many other purposes.

The *Light List* is consulted to determine the characteristics of the relevant ATONs (such as color or light characteristics and horn sequences that are important for recognition and identification purposes), while the USCP provides useful "local knowledge" in narrative form. For example, following a route from Tiverton through Buzzards Bay would require a transit of the channel between Buzzards Bay and Vineyard Sound. The USCP offers the following comments about this area:

> "The passage through Woods Hole, between numerous ledges and shoals, is marked by navigational aids. However, tidal currents are so strong that the passage is difficult and dangerous without some local knowledge. Buoys in the narrowest part of the channel sometimes are towed under, and a stranger should attempt passage only at slack water."

Such information is obviously invaluable for planning purposes.

*Tide Tables* are used to estimate the height of the tides that would be encountered on the voyage to ensure that a safe route is chosen. *Tidal Current Tables* provide information on the strength and direction of the currents, information used to estimate the vessel's ground speed and the selection of the correct course to compensate for these currents.

Other information requirements include operating data for the vessel, such as the relation between engine *revolutions per minute* (RPM) and the speed through the water (discussed in Chapter 5), and fuel capacity and consumption data (presented in Chapter 11). For example, at 2250 RPM, *Verloren* might make *8 knots* (nautical miles

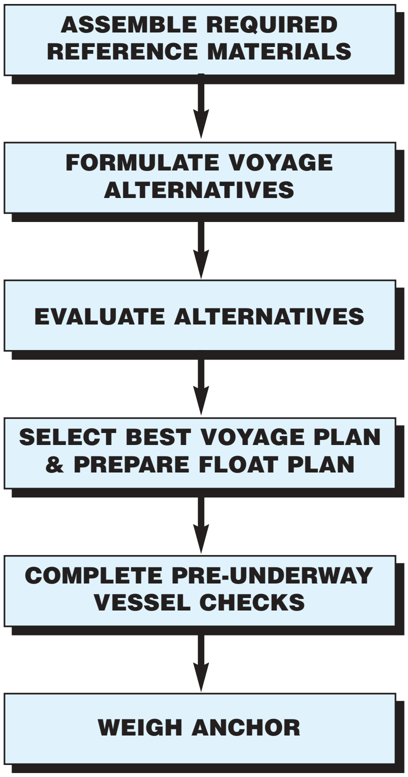


**FIG. 1-1**–Steps in Voyage Planning

per hour), and burn *7 gallons per hour* (GPH) of fuel from tanks that can hold 400 gallons when topped off (filled).

The second step in voyage planning is to consult the materials assembled and *formulate voyage options for later evaluation.* Voyage options relevant for this trip would include the overall route to follow (east through Buzzards Bay, or south, then east through Vineyard Sound are obvious alternatives), departure time (which affects the water currents and tide heights that will be encountered and also how much of the voyage will be conducted during daylight hours), the speed to be run (which affects the estimated en route time, fuel consumption, and arrival time), and planned stopovers for amenities, recreation, or fuel. Even for this "simple" trip, there are several alternatives that might be considered. Time spent developing thoughtful voyage options is time well spent. *A good navigator thinks and plans ahead, so that he/she doesn't have to exercise extraordinary seamanship!* If, for example, the more northerly route through Buzzards Bay is chosen, the trip schedule has to be worked out to minimize the hazards of transiting the channel between Buzzards Bay and Vineyard Sound. To someone unfamiliar with these waters, the USCP indicates that it would be prudent to make this transit during daylight hours at or near slack current. This can and should be figured out in advance, rather than "come upon" in failing light.

The third step in voyage planning is to *evaluate systematically the alternatives identified* in step two. Obviously, two important factors relevant to the voyage are *Verloren's* speed and the distance to be covered along each of the alternative routes. This distance is determined from a rough plot of the alternate routes on the nautical chart by techniques revealed in Chapter 3. In this case, the route through Buzzards Bay (approximately 37.5 miles for one possible route layout) is slightly shorter than that through Vineyard Sound (approximately 40 miles). Speed and distance determine the en route time required for the voyage (5 hours *estimated time en route* (ETE) to cover 40 miles at 8 knots assuming no current), and the fuel consumption (35 gallons required, assuming 5 hours en route at 7 gallons per hour). Simple *time-speed-distance* (TSD) calculations are reviewed in Chapter 5, fuel consumption calculations in Chapter ll, and the somewhat more complex task of allowing, and compensating, for currents in Chapter 7. Estimation of the probable currents is discussed at length in Chapter 8, As it happens, the currents in Buzzards Bay and Vineyard Sound are often moving in opposite directions, at speeds ranging from less than one knot to 2 knots or more. So, depending upon the current patterns prevailing on the day and time of the voyage, the two routes identified above could have significantly different ETEs.

Moreover, as illustrated in Chapter 8, it is entirely possible that the longer distance route would also be the shorter time route. As noted, the length of the Buzzards Bay route is approximately 37.5 miles, compared to 40 miles for the Vineyard Sound route. But if the average current along Vineyard Sound were, say, 2 knots in the direction of intended travel (a so-called *fair current*), and that in Buzzards Bay were 0.6 knots against the direction of travel (a so-called *foul current*), the time required for the trip through Vineyard Sound would be approximately 4 hours, compared to nearly 5 hours on the "shorter" route. (This calculation must be refined to take account of the fact that the first leg is common to both routes. Even a more exact calculation, however, shows that the longer distance route is the shorter time route.) This example is not hypothetical—the assumed currents are, in fact, the estimated currents at one point in the tidal current cycle. Additionally, the Vineyard Sound route avoids the trip through the channel next to Woods Hole. This benefit may not be important to someone with local knowledge, but might be a decisive factor otherwise.

For this voyage in *Verloren*, fuel certainly won't be a problem, assuming that the tanks are even near to being full prior to departure. But for longer trips, or in vessels with higher fuel consumption or lower fuel capacity, fuel planning is often a singularly important activity. For vessels with what are termed "short legs" (limited fuel capacity), fuel stopovers would need to be considered, and/or the engine throttle setting altered to stretch fuel reserves.


PHOTO COURTESY OF MAINSHIP

▲ A trawler moving serenely through the water. The material in this course will enable you to navigate such vessels with confidence.

Option evaluation is not limited to questions of time, speed, or fuel consumption. Many other factors need to be considered. For example, the difficulty of transiting channels or inlets, availability of *"bolt holes"* (safe places to anchor or moor in the event of mechanical problems or adverse weather), and the availability of suitable landmarks or ATONs to fix the vessel's position or to mark channels all need to be considered. Discussion of these important matters can be found scattered throughout this text in the examples used to illustrate key points.

The fourth step in voyage planning is to *select a plan* that is "best" in some sense, considering the vessel, navigational equipment aboard, skill and local knowledge of the navigator and crew, and other relevant factors. Included here is the important task of making a *"float plan"* that describes the route and estimated time(s) of arrival so that the *Search and Rescue* (SAR) personnel can be promptly alerted if you become overdue. (The float plan should also include a description of the vessel, number of persons on board, available safety and radio equipment, and other relevant information.) The float plan is left in the care of a responsible person, with instructions to notify the Coast Guard in the event that the vessel becomes overdue. The navigator often prepares a more detailed voyage plan in this step, identifying checkpoints and turnpoints for each leg of the trip, courses to steer, time estimates, and fuel consumption estimates.

In this fourth step, the navigator also plots the first "legs" (route segments) of the voyage on *a tactical (underway) dead reckoning plot* (DR plot). *Dead reckoning* (DR), explained in Chapter 5, is the name given to the process of predicting the future position of a vessel from knowledge of its present (or starting) position, the course steered, and the speed maintained. A tactical DR plot shows course legs (including direction, speed, and, occasionally, distance) and future positions (termed dead reckoning positions) at various times in a stylized format. The DR plot is maintained and updated throughout the underway portion of the voyage.

The fifth step in voyage planning is to complete *prevoyage checks* on the vessel and its equipment—much as aircraft pilots do in the preflight inspection. For example, the navigator would verify that all communications and navigation equipment were functioning properly and that the correct charts and other reference materials were aboard. Weather information should be gathered and used as part of the "go-no-go" decision. If all goes well in this step, it is time to start engines, slip *Verloren's* dock lines, note the departure time in the navigator's or ship's log, and get underway.

## STEPS WHILE UNDERWAY

Figure 1-2 shows a simplified summary of the key underway activities. As noted above, the navigator estimates the future position of the vessel at various times using DR (see Chapter 5). But, these estimates are not error free. Neither wind nor current, for example, is considered in the determination of DR positions—for reasons that are apparent on reading Chapter 5. Therefore, it is very important to check and update the actual progress of the voyage at frequent intervals in coastal waters. This is done with a series of "fixes," points in time at which the vessel's position is accurately determined.

The vessel's position can be fixed by three principal methods.

- First, visual observation of the range or bearing of landmarks or ATONs can determine its position. For example, the navigator could determine the magnetic bearing of the abandoned lighthouse on Sakonnet Point, and that of the tower on Gooseberry Neck, which could fix *Verloren's* position by triangulation if the Buzzards Bay route were taken. This method for position fixing is termed *piloting*, and is discussed in Chapter 6.
- Second, the vessel's position can be fixed by use of *electronic navigational systems*, such as GPS, loran, or radar. For example, GPS could be used to read the vessel's latitude and longitude directly. Alternatively, radar could be used to measure the range and bearing to a recognizable landmark. This is termed *electronic navigation*, and is discussed in Chapters 6 and 9.
- Third, the position of the ship can be fixed by *observation of the angle (elevation) of heavenly bodies* (here meant to mean the sun, moon, or stars). This process is termed *celestial navigation*. For various reasons, including the limited opportunities for fixes, and the possible error of celestial fixes, celestial navigation is not extensively used in coastal waters and is not presented in this text.

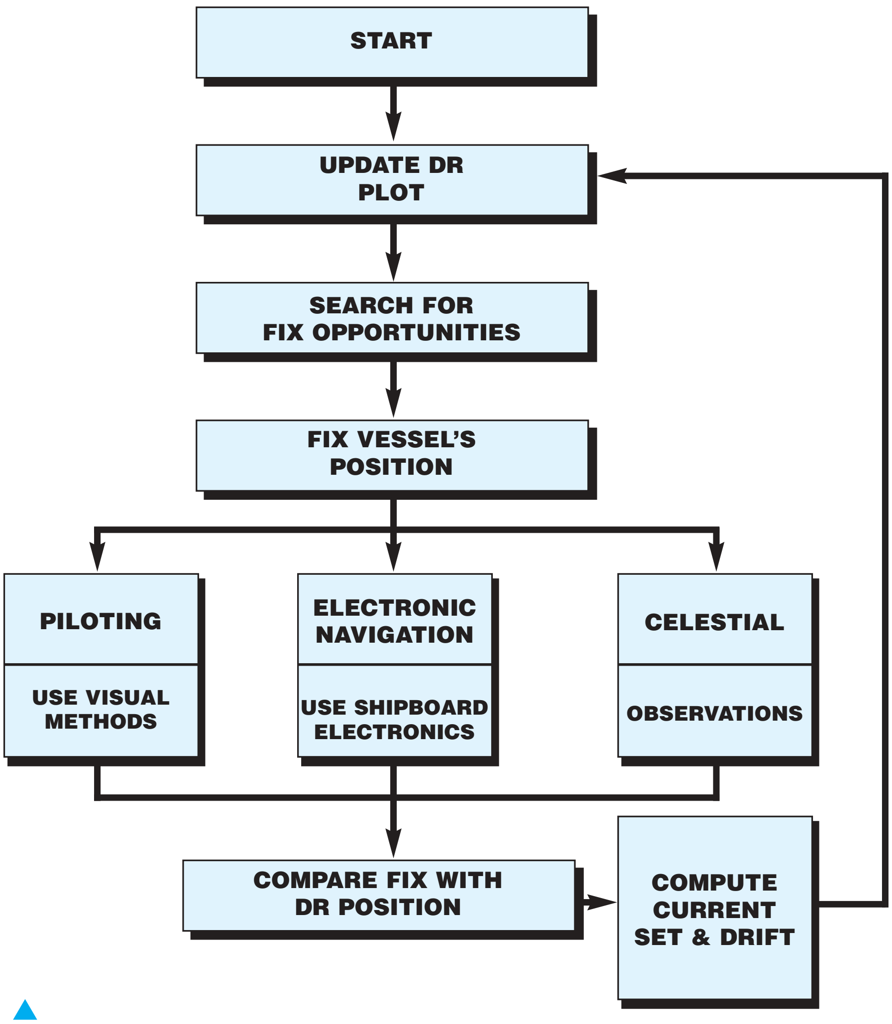


**FIG. 1-2**–Steps in Underway Navigation

Once a fix is determined, this is plotted on the tactical DR plot (see Chapter 5) and the plot is updated with this fix. (The data for this fix are also entered into the navigator's or ship's log.) A comparison of the fix with the vessel's DR position can be used as a "plausibility" or "reality" check on the fix and the DR position. Absent blunders, any discrepancy between the fix and the DR position is due to current, so a comparison of these two positions can be used to estimate the actual currents (the term *set* refers to the direction toward which the current is flowing, and *drift* refers to the speed of the current) encountered (the method for estimating set and drift is discussed in Chapter 7).

For introductory purposes, Figure 1-2 has been simplified considerably. In practice, the navigator's underway tasks are often more complex and varied. For example, instead of merely estimating the set and drift of the current, the navigator would usually estimate a course (by the methods discussed in Chapter 7) to compensate for these effects and ensure that the vessel stays in safe water. On such a short voyage, as is illustrated here, en route decision making may be relatively simple. But on other trips, the navigator would be continually revising fuel consumption estimates and the *estimated time of arrival*

PHOTO COURTESY OF UNITED STATES COAST GUARD

Navigation of faster boats and/or navigation in rough waters requires greater preplanning. Here is a United States Coast Guard 44-ft patrol boat crashes through a wave. There is little time or space to plot positions exactly.

(ETA). These revised estimates could signal the need to change the voyage plan. For example, the discovery that fuel consumption was significantly higher than planned could mean that the vessel would have to be diverted to an alternate destination.

The navigator should also check the accuracy of the navigation equipment in use by comparing, whenever possible, fixes determined by various methods. For example, a comparison between an accurate visual fix and one determined by GPS or Loran-C could be used to verify that these systems were functioning properly. Likewise, a prudent navigator would make periodic checks on the accuracy of the vessel's compass, perhaps by spot checks of the compass' *deviation table*, as explained in Chapter 2.

There you have it—a brief illustration of the various navigator's tasks and where these are addressed in this text. Of course, not all voyages are sufficiently long or complex to require the *formal* use of all the techniques discussed above. For short voyages in familiar and well-marked waters, and when weather conditions are close to ideal (e.g., moderate seas, calm winds, and good visibility), various short cuts can be taken to simplify the navigator's duties. This is termed navigation by *seaman's eye* and is addressed in Chapter 11. Navigation of high-speed vessels is both simpler and more difficult. Currents are less of a factor for high-speed vessels and these computations are usually omitted. However, there is less time to use traditional methods and more preplanning is required. Navigation of high-speed vessels is covered briefly in this text.

In the above discussion, the contents of two chapters were omitted. Chapter 2 covers the marine magnetic compass, and Chapter 4 provides a summary discussion of the navigator's tools (other than the vessel's compass).

Before moving on to some of the interesting material in the chapters ahead, it is necessary to address two important introductory topics: the earth's coordinate system and measurement of direction.

## BACK TO BASICS: THE PLANET EARTH

The earth is approximately spherical, as illustrated in Figure 1-3. Technically, the earth is termed an *oblate spheroid* (a sphere flattened at the poles and bulges in the middle, as opposed to a *prolate spheroid* which resembles a football; but don't go calling it prolate spheroid ball, or you will wind up being called an oddball!), but the difference between the earth's actual shape and that of a perfect sphere is not important for this course. The average diameter of the earth is approximately 6,880 nautical miles, and its circumference is approximately 21,614 nautical miles. Since there are 360 degrees (denoted with the degree symbol °) of angular measure in a circle, 1 degree of angular measure along the earth's surface is approximately 60 nautical miles. Degrees are further subdivided into minutes (denoted with an apostrophe, e.g., 30 minutes is written 30'), and seconds (denoted with two apostrophes, e.g., 40 seconds is written 40"). There are 60 minutes in a degree (and 60 seconds

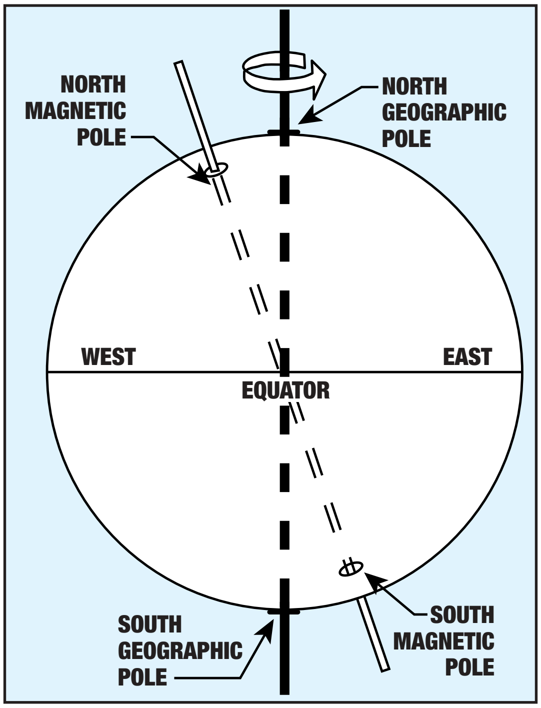


**FIG. 1-3**–The Earth and Its Poles

in a minute), so 1 minute of angular measure is approximately equal to 1 nautical mile.

The earth rotates about a straight line called the *axis of rotation*, or *polar axis*. The earth completes one rotation every 24 hours (*the solar day*). The axis of rotation passes through the center of the earth, intersecting the surface at two points, termed the *north and south geographic poles* (denoted Pn and Ps, respectively). The earth rotates from west to east, i.e., counterclockwise when viewed from a point in space atop the North Pole. The west-to-east rotation makes the sun appear to rise in the east and set in the west. The earth is also a magnet—discussed below—and has *North and South Magnetic Poles.* These poles (shown also in Figure 1-3) *are not coincident* with the geographic poles, an important point explored below.

## GREAT AND SMALL CIRCLES

A plane passed through the center of the earth separates the earth into two *hemispheres*, and intersects the surface of the earth to produce a geometric figure termed a *great circle*. On the surface of a sphere, the shortest distance between any two points lies along the great circle that connects these two points. (On the slightly flattened surface of the earth, the shortest distance between two points is technically termed a geodesic, but for the purposes of this course a great circle and a *geodesic* are one and the same.)

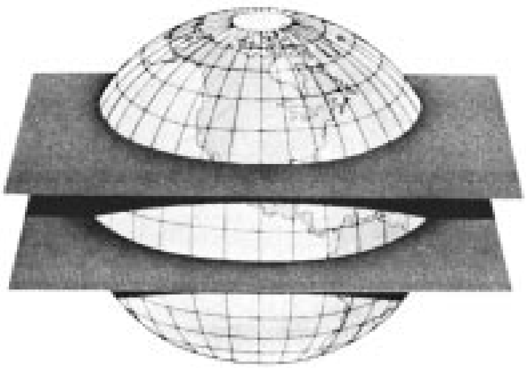


**FIG. 1-5**–A Parallel of Latitude

If the plane is passed so that it is perpendicular to the earth's axis of rotation (i.e., equidistant from the geographic poles), the resulting great circle is termed the *equator*, as shown in Figure 1-4, and the two hemispheres formed are named the *northern and southern hemispheres.*

A *small circle* results if a plane is passed through the earth that does not touch the earth's center. Small circles parallel to the equator *(termed parallels)* are one of the two reference coordinates used to

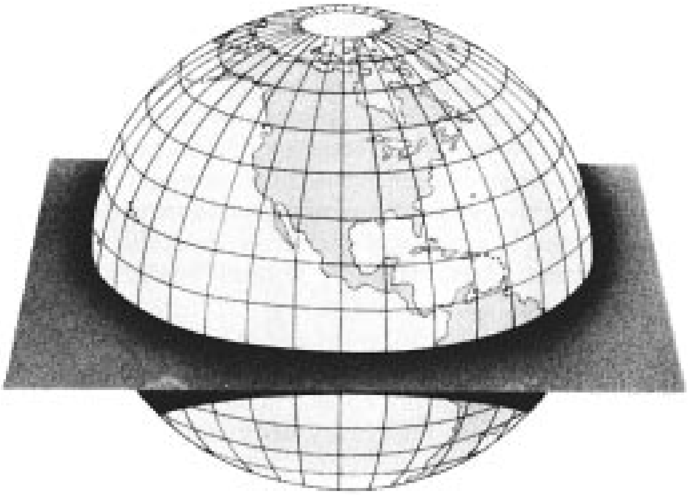


**FIG. 1-4**–The Equator

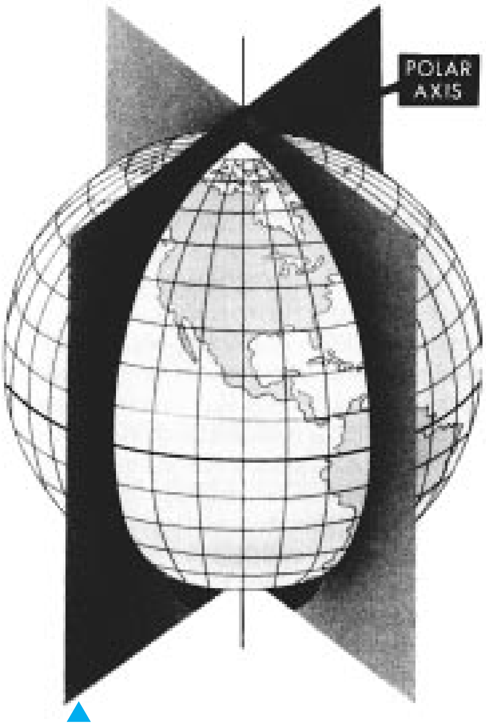


**FIG. 1-6**–The Planes of the Meridians (Longitude) Meet at the Polar Axis

define position on the earth’s surface. Figure 1-5 shows the equator and another parallel of latitude. Latitude is the angular measure of the distance north or south of the equator and is measured in degrees (0 to 90 degrees).

A great circle that passes through the polar axis or axis of rotation is termed a meridian. It has two parts—that on the observer’s side of the earth, which is called the upper branch, and one on the other side of the earth, which is called the lower branch of the meridian. The planes of the meridians meet at the polar axis, as shown in Figure 1-6. Meridians are used to define the other major coordinate for specifying position on the earth’s surface–longitude.

## LONGITUDE AND LATITUDE

The prime meridian (more specifically, its upper branch) passes through the original site of the Royal Observatory in Greenwich, England. Also called the *Greenwich Meridian*, it is used as the origin of measurement of longitude (see sidebar). More precisely, longitude (abbreviated Lo, or sometimes written λ, the Greek letter lambda) is the angular distance (in degrees, minutes, and seconds, or degrees and decimal minutes) between a position on the earth and the prime meridian measured eastward or westward through 180 degrees along the arc of the equator to the meridian of the position. Because longitude is measured only through 180 degrees, rather than 360 degrees, from the prime meridian, it is necessary to include the word east (E) or west (W) to define the longitude uniquely. For example, the meridian passing through the Naval Observatory in Washington, DC, would be identified as Lo = 77° 03.9’ W (77 degrees, 3.9 minutes, west of the prime meridian) or, equivalently as 77 03’ 54” (77 degrees, 3 minutes, 54 seconds west of the prime meridian). The degree sign is sometimes omitted. In some writings, E or W is omitted when it is clear that the longitude is east or west, but this practice should be discouraged.

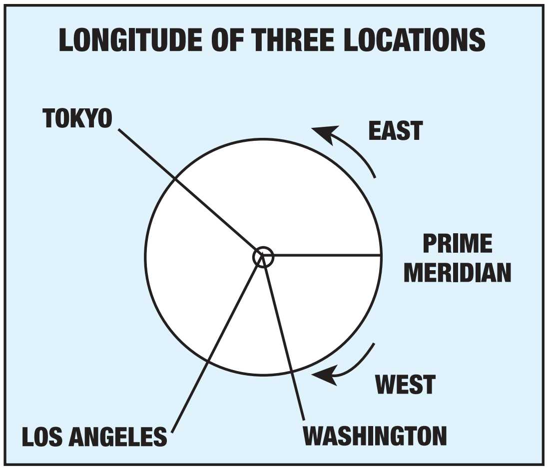


**FIG. 1-7**–Longitude for Three Locations on the Earth’s Surface

As other examples, the longitude of the Griffin Observatory in Los Angeles, CA, is Lo = 118 18.1’ W, and that of the Tokyo Astronomical Observatory at Mitka, Japan, is Lo = 139 32.5’ E. Remember, longitude is always specified as east or west of the prime meridian. Figure 1-7 shows the longitudes of these three locations on the earth’s surface as viewed from atop Pn.

It is not sufficient to identify a position on the earth’s surface by its longitude alone, because there are an infinite number of points that lie on any meridian. Another coordinate is necessary to specify position uniquely.

As noted, this second coordinate is termed *latitude*. More formally, latitude (abbreviated L or Lat.) is the angular distance between a position on the earth’s surface and the equator, measured northward or southward from the equator along a meridian and labeled with an “N” or an “S” to denote whether the point is located in the northern or southern hemispheres, respectively. (Sometimes, when the hemisphere

## HISTORICAL FOOTNOTE:

### Where is the Reference Meridian?

***As noted in the text, the prime meridian passes through Greenwich, England. However, unlike the equator, its location is entirely arbitrary. Ptolemy, for example, chose to place the prime meridian through the Canary & Madeira Islands. Later it was moved to the Azores and the Cape Verde Islands. Various governments have placed it in Copenhagen, Jerusalem, London, Paris, Philadelphia, Pisa, Rome, and St. Petersburg. At the Third International Geophysical Congress meeting in Venice in 1881, several other proposals were floated, including use of the Great Pyramid of Egypt as the prime meridian. In 1884, representatives from 26 countries to the International Meridian Conference in Washington, DC, voted to select Greenwich as the official prime meridian. The French continued to recognize the Paris Observatory as the “correct” location of the prime meridian until 1911. These and other stories are related in Sobel (1995) and O’Malley (1990).***

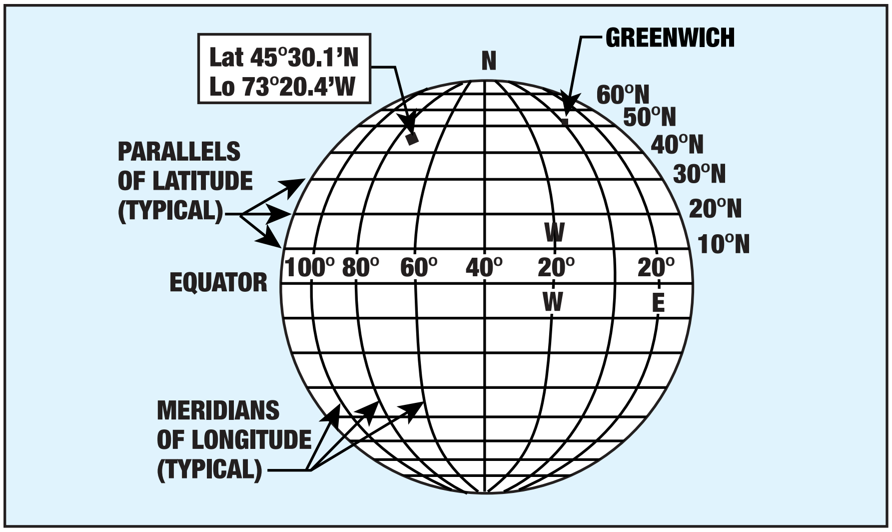


**FIG. 1-8**–Grid System of Latitude and Longitude

is clearly implicit, the N or S will be omitted, but this practice is to be discouraged.) Latitude ranges from 0 degrees (for a point located at the equator) to 90 degrees N or S (for a point at the north or south geographic pole). Lines of constant latitude are called parallels of latitude, or simply, parallels.

Continuing the earlier examples, the latitude of the Naval Observatory in Washington, DC, is L (or Lat.) = 38 55.2' N, that of the observatory in Tokyo, Japan, L = 35 40.4' N, and that of the Griffith Observatory, L = 34 06.8' N. These two coordinates, latitude and longitude, are used to define locations on the earth's surface, as shown in Figure 1-8. By convention, a point's latitude is written first and its longitude second, so if there are no labels, the first number written is latitude, the second longitude (the notation E or W, versus N or S also define the coordinate).

One important attribute of latitude (noted implicitly above) is the fact that 1 degree of latitude, measured up or down (north or south) along any meridian, is equal to 60 nautical miles, and 1 minute is equal to 1 mile. *Note, however, that this does not hold for longitude. Although 1 minute of longitude is approximately equal to 1 nautical mile at the equator,* as the latitude increases, the distance along any parallel, between two meridians, becomes smaller, reaching 0 miles at either pole. (The length of 1 degree of longitude is approximately equal to 60 times the cosine of the latitude. For example, at latitude of 41 30' north, approximately the midpoint of the latitudes given on the 1210-Tr chart, the length of 1 degree of longitude is approximately 45 nautical miles rather than 60 nautical miles on the equator.) Remember that latitude is measured along a meridian (running north or south), while longitude is measured along a parallel (running east or west) from the prime meridian.

## DIRECTION

Latitude and longitude are all that are required to specify *location* on the earth's surface. But, it is also necessary to have some means for specifying *direction* on the earth's surface.

Direction is not absolute but must be keyed to some reference point. Three common reference points are *true north, magnetic north* (discussed below), and the *ship's heading* (relative bearings are discussed below).

If direction is referenced to true north (geographic north or the North Pole), it is defined relative to the local meridian passing through the point of interest (also called the local geographic meridian). The local geographic meridian passes through the north geographic pole, so this direction is relative to the north geographic pole or to north. The direction of true north, or northward along the upper branch of the local geographic meridian, is defined as zero degrees and becomes the reference direction. By convention, the precision of angular measurement for courses or bearings is to the nearest degree. Degrees are reported to three digits; so, for example, north has the direction 000 degrees. Direction is specified clockwise from true north. Thus, east is 090 degrees, south is 180 degrees, west 270 degrees, etc. The direction 360 degrees and 000 degrees are one and the same and, by convention, this direction is usually written 000 degrees. Therefore, it is said that direction is measured clockwise from north, and ranges from 000 degrees to 359 degrees.

With a suitable device for measuring angles (see Chapter 4), directions can be read from a chart off the local meridian. However, for reasons that are apparent in later chapters, it is useful to have additional sources of directional infor-

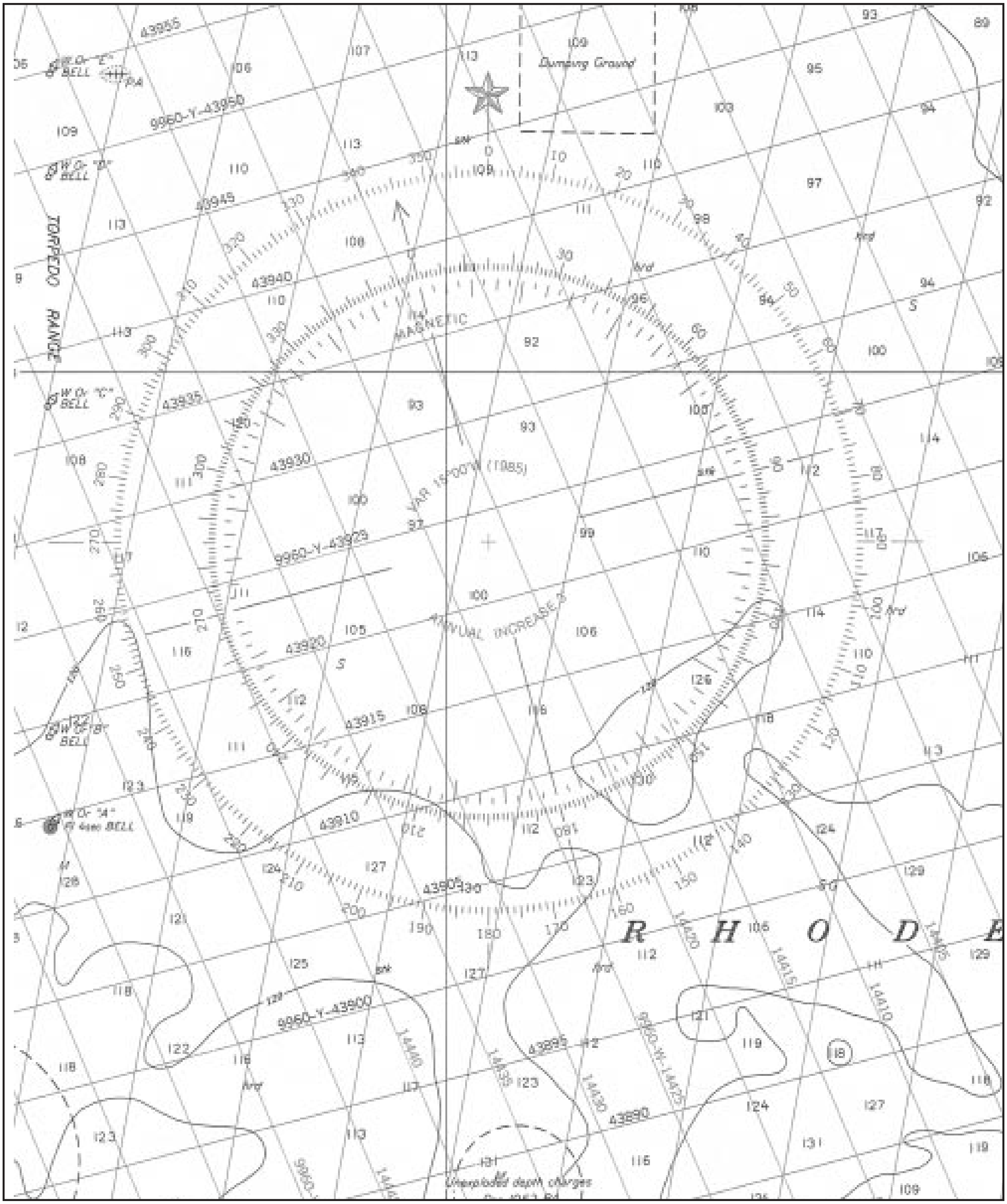


**FIG. 1-9**–True and Compass Rose as Presented on the 1210-Tr Chart

## FACTOID

***According to records dating back to the 1700s, the apparent position of the north magnetic pole has shifted from a position north of Scandinavia across Greenland to its present position in the Parry Islands in northern Canada. Over geologic time, the shifts have been even more dramatic; it is believed that 200 million years ago the magnetic poles were near the equator!***

mation provided on the nautical chart. One common directional reference is termed a *compass rose,* which provides directional information relative to both true and to magnetic north (discussed below). Figure 1-9 shows a dual compass rose taken from the 1210-Tr chart. Directions relative to true north are given on the *outer circle* of the rose. True north is generally indicated with a *star symbol* (presumably a reference to Polaris, the star that is, to within a degree or so, aligned with true north). The principal advantage of printing compass roses on nautical charts is that it is relatively easy to *transfer* (i.e., measure) these directions with parallel rulers or a paraline plotter (see Chapter 4).

When a direction other than exactly north, south, east, or west is specified on the earth, and followed for any distance, such that each subsequent meridian is passed at the same angle relative to the direction of the geographic pole, a line is formed that "spirals" around the globe, continually edging either northward (for directions between 271 degrees and 359 degrees or 000 degrees and 089 degrees) or southward (for directions between 091 degrees and 269 degrees). This line, termed a *rhumb line* or *loxodrome,* approaches either pole, as shown in Figure 1-10. This line drawn on the surface of a sphere, such as the earth, is actually *curved,* not straight. (However, as noted in Chapter 3, it will plot as a straight line on the Mercator chart typically used for coastal navigation.)

The earth has a weak magnetic field, thought to be generated by the flow of the liquid iron alloy core of the planet. This field, termed a *dipole field,* is similar to the magnetic field that would be generated by a large bar magnet located near the center of the earth. The magnetic flux lines diagramed in the stylized and simplified representation of Figure 1-11 flow out from the core through the auroral zone of the South Pole, around the earth, and return through the auroral zone of the North Pole. *More important to the mariner, the magnetic poles on the earth differ from the geographic poles.* In 1984, the North Magnetic Pole, for example, was located in Canada's Northwest Territories, at approximately a latitude of 78.9 degrees north and longitude 103.8 degrees west, several hundred miles removed from the geographic North Pole.

At the surface of the earth, lines of magnetic force are *termed magnetic meridians,* analogous to geographic meridians. However, unlike geographic meridians, which have a simple geometrical interpretation, the *magnetic meridians* are irregular, a phenomenon caused by the nonuniform distribution of magnetic material throughout the earth.

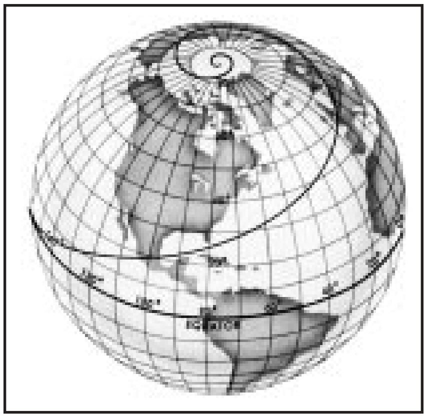


**FIG. 1-10**–A Rhumb Line or Loxodrome as Given in Bowditch

The angular difference between the geographic and magnetic meridians at any point on the earth is called the *magnetic variation,* or simply variation. (The term *magnetic declination* is also used.) Variation is said to be east if the magnetic meridian points eastward of the north geographic pole, or west if (as shown in Figures l-12 or

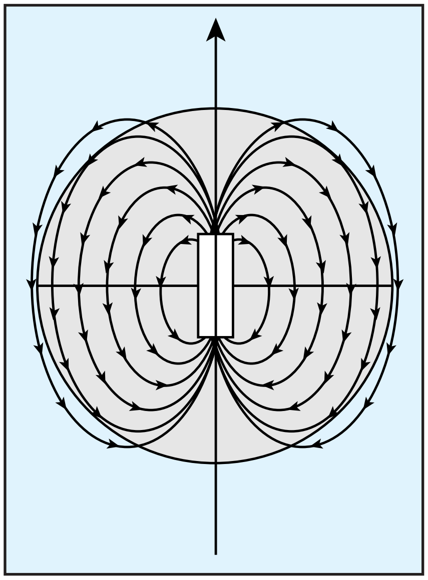


**FIG. 1-11**–The Earth is a Magnet

1-13) the north magnetic pole is westward (to the left) of the north geographic pole as seen by the observer.

Incidentally, diagrams such as Figures 1-12 and 1-13, are very helpful in understanding the concept of variation but are not, strictly speaking, accurate. This is because they suggest that a compass (free of shipboard magnetic influences) would always point toward the North Magnetic Pole. In fact, a freely suspended magnetic compass needle acted upon by the earth's magnetic field alone will lie in a vertical plane known as the magnetic meridian. These magnetic meridians, however, do not necessarily point towards the magnetic poles, because the earth's magnetic field is irregular. This technicality aside, it still follows that variation is the angular difference between true north and the direction that the vessel's compass would point, absent shipboard magnetic influence. Lines of constant variation are termed *isogonic* lines, and the line where the variation is exactly zero degrees is called the *agonic* line. These isogonic lines arc charted and are published on Chart #42 by the National Imagery and Mapping Agency.

The relevance of all this to the mariner is that the magnets in the vessel's compass (discussed in Chapter 2) tend to align with the magnetic meridians, rather than the true or geographic meridians. (It is actually slightly more complicated than that, but Chapter 2 straightens out the details.) Therefore, it is necessary to know the variation to be able to convert from true to magnetic directions or the reverse.

Variation data can be found in several sources. Perhaps most convenient, variation data are printed on the compass rose found on nautical charts, such as is illustrated in Figure 1-9. There the *inner circle of the compass rose shows magnetic directions* while the outer circle shows true directions. In this illustration, the magnetic meridian points to the left of the local geographic meridian—and the variation is approximately 15 degrees *west*. (As noted above, the magnetic meridians shift around, and have daily *(diurnal)* and longer term *(secular)* changes, so, for this reason, the important shifts are identified on the chart. Reference to Figure 1-9, for example, shows that

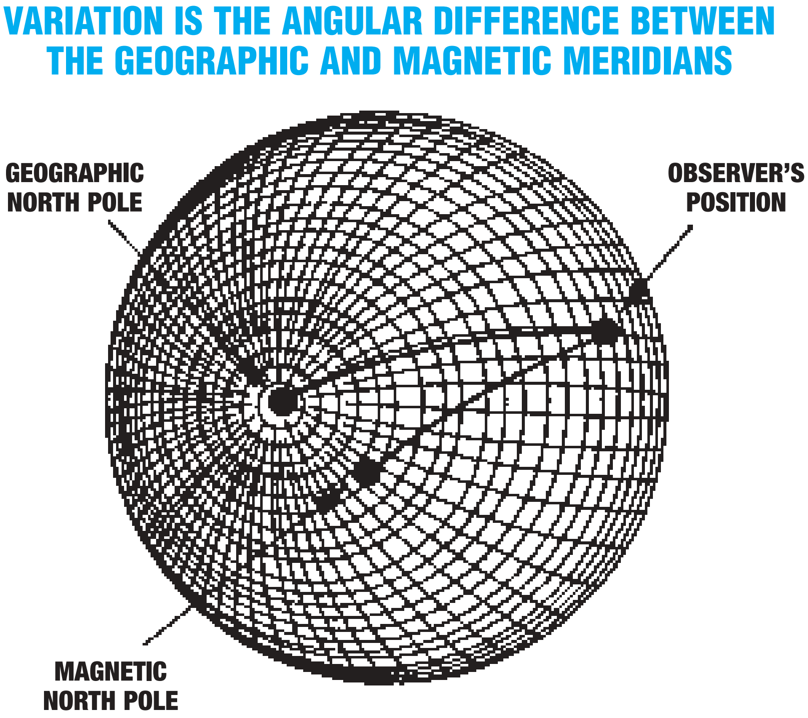


**FIG. 1-12**–Variation: The Approximate Difference Between the Directions to the North Geographic Pole and the Magnetic Meridian

the variation at this location was 15 degrees west in 1985, and that it is increasing at the rate of three minutes per year.)

Within the continental United States, variation ranges from about 20 W in northern Maine, through 0 in portions of Florida, to 21 E in northern Washington state. (On the northern border between Alaska and Canada, it is approximately 35 E as of this writing.)

## CONVERSION FROM TRUE TO MAGNETIC AND VICE VERSA

It is often necessary to convert from direction expressed relative to magnetic north to direction expressed relative to true north or vice versa. For example, a hand-bearing compass, discussed in Chapter 4, might be used to take a bearing on a shore-based object, and the navigator may wish to convert this to a true bearing for plotting on the nautical chart. Alternatively, a mariner may measure a true course on the chart (discussed in Chapter 3) and wish to convert this to a magnetic course.

Conversion from one reference point to another is relatively simple. Suppose, for example, that the variation is 15 degrees west, as is shown in Figure 1-9, as would apply to one portion of the area covered by the 1210-Tr chart. An object located in the direction of magnetic north from the perspective of the observer (said to have bearing 000 magnetic) would actually bear 345 degrees true. This is because, at this location, the variation is 15 degrees west, or to the left of true. A glance at the compass rose shows that all bearings have this fixed difference between magnetic and true. *Conversion from magnetic to true is, therefore, a simple matter of subtraction of a westerly variation, or addition of an easterly variation.* Thus, for example, an object bearing 090 magnetic, would bear 090 - 015 or 075 true. (Chapter 2 provides some handy memory aids to keep the addition and subtraction straight, but a simple one to remember is “magnetic or compass to true, add east.”) As discussed in other chapters, magnetic courses or bearings are identified as such by the use of

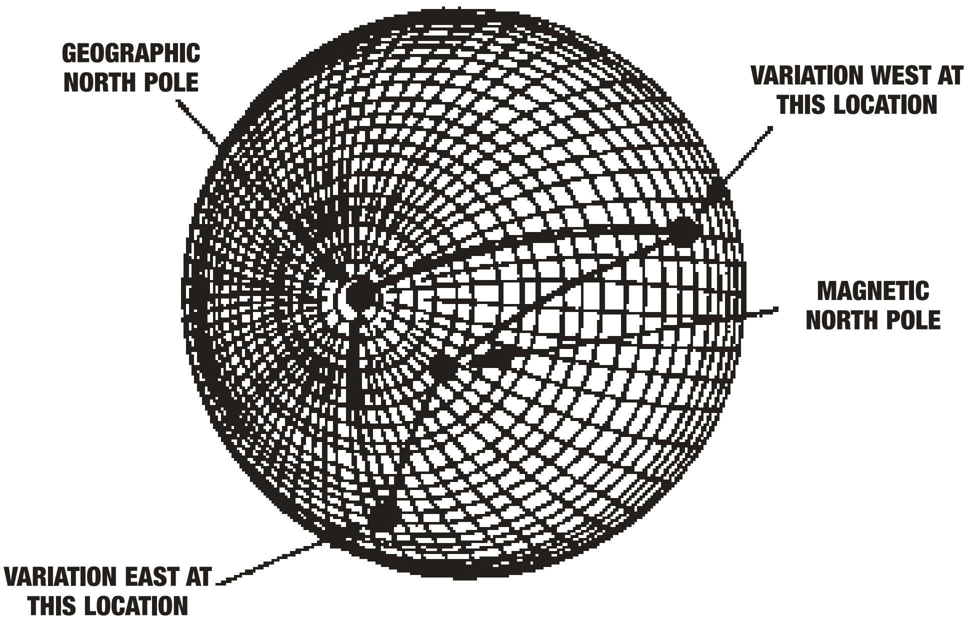
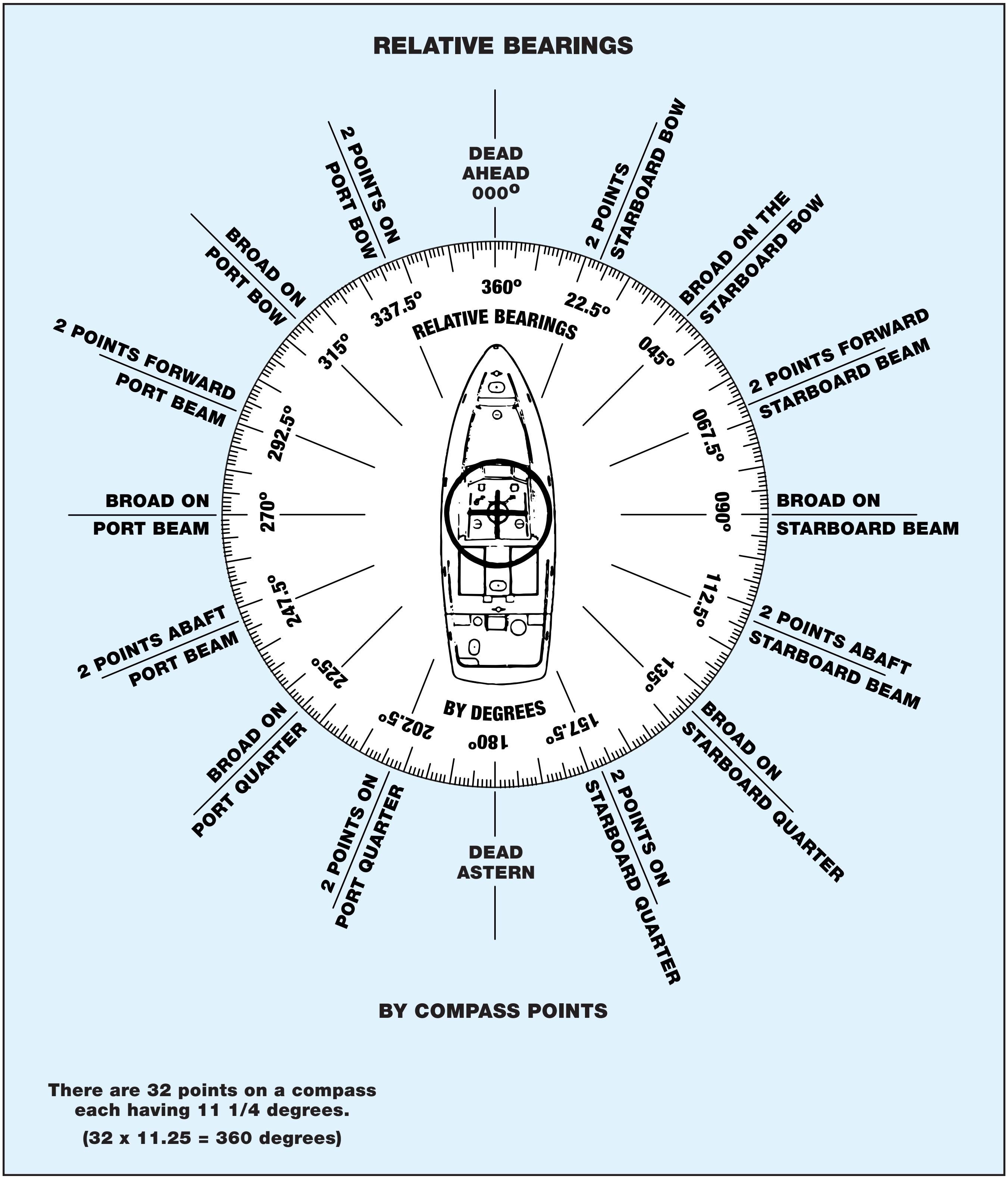


**FIG. 1-13**–Variation is the Angular Difference between the Geographic (True) Meridian and the Magnetic Meridian. Variation Changes with Locality.



RELATIVE BEARINGS

BY COMPASS POINTS

There are 32 points on a compass
each having 11 1/4 degrees.
(32 x 11.25 = 360 degrees)

**FIG. 1-14**–Relative Bearings by Degrees and Points the word “magnetic,” or the writing of an “M” after the number. If no such prefix or suffix is added, it is assumed that the course or bearing is “true.”

## RELATIVE DIRECTIONS (BEARINGS)

It is convenient, from time to time, for mariners to indicate directions referenced to objects other than the true and/or magnetic meridians. In fact, one of the most used direction systems is that referenced to the fore-and-aft line parallel to, or directly over, the keel of the observer’s vessel.

If a direction “rose” were superimposed over the vessel (plan view) with the 000 line directly forward, at the vessel’s bow, 090 on the vessel’s starboard beam, 180 directly aft, on the vessel’s stern, and 270 on the port beam, the *relative bearing* system is developed as illustrated in Figure 1-14. Objects relative to the instantaneous direction of the bow of the boat are indicated in degrees of angular measure, clockwise, just as directions are indicated for the true and magnetic direction systems. Shown also in Figure 1-14 are relative bearings in the older “point system,” in which the 360 degrees are subdivided into 32 points. (The older “*point system*” is included for historical interest only, and is not used in this text.)

An object 45° off the bow on the starboard side (broad on the starboard bow in the older system) would have a relative bearing of (or would bear) 045 R (here the “R” denotes “relative”). If the object were 45° off the bow on the port side, it would have a relative bearing of: 360 - 045 =315R. A vessel dead ahead, directly off the bow, would bear 000 R. Note that relative bearings relate to the fore-and-aft or bow direction of the boat and change direction as the boat changes direction (heading) or position. If the boat is underway, and the object observed is stationary, the relative bearing will change as the boat approaches, passes, and continues on. The relative bearing would also change if the boat were turned, increasing in a clockwise manner as the boat turned counterclockwise.

To convert from relative bearing to either a true or magnetic bearing, all that is necessary is to remember the equation: ship’s heading + relative bearing = bearing to object. Thus, for example, if the vessel were heading 070 true, and you observed an object bearing 135 R, the object would bear 070 + 135 = 205 true. Of course, because there are only 360 degrees of arc measure in a circle, it may be necessary to subtract 360 degrees from the calculated bearing of the object. For example, if the ship’s heading were 315 degrees true and the object’s relative bearing were 135 degrees, the true bearing would be 315 + 135 = 450; subtracting 360 gives the correct answer of 090 degrees.

The concept of relative bearings is fundamental in the practice of navigation. The concept should be thoroughly understood. The three direction systems will be linked together in the use of the magnetic compass and the practice of piloting.

## RECIPROCAL BEARINGS

Finally, we conclude with brief mention of *reciprocal bearings.* A reciprocal bearing is one that differs from the original by 180 degrees. For example, if a fixed navigational aid, such as a lighthouse, were to bear 000 degrees true from your vessel (i.e., be directly *north* of your vessel), it could equally be said that your vessel is directly *south* of the lighthouse. That is, your vessel would be on a reciprocal bearing from the lighthouse. To calculate a reciprocal bearing, all that is necessary is to add or subtract 180 from the given bearing. In this example, the reciprocal of 000 degrees is 180 degrees (obtained by adding 180). (Helpful hint: in calculating a reciprocal by addition or subtraction, it may also be necessary to add or subtract 360 degrees to the result to ensure that the answer lies between 000 and 360.) The reciprocal of 270 degrees is 090 degrees, the reciprocal of 315 degrees is 135 degrees, etc. (With a little practice you can do these in your head quickly by first adding 200 and taking away 20, or subtracting 200 and adding 20! Thus, for example, the reciprocal of 121 degrees is 301 degrees, obtained by quickly adding 200 to 121 to get 321, and then subtracting 20 to get 301).

If your compass is the top-reading type (see Chapter 2) you can read the reciprocal bearing directly. Reciprocals can also be read from a convenient compass rose.

Bearings, whether with respect to true north (true bearings) or magnetic north (magnetic bearings), are all bearings from the vessel to an object. Reciprocal bearings are *bearings from* an object to the vessel.

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